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A New Conceptual Framework for Water Conservation Based on Addressing Water Balance, Crop Rotation and Economics

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Abstract: This paper presents a conceptual framework for water conservation where, new concepts are introduced and new indicators for describing the status of irrigation management defined. The new performance indicators are systematically tied to the very important and related issues of crop rotations, water balance and economics. The concepts and indicators in this paper are expected to be instrumental among other things in: 1) The identification of opportunities for water savings and increasing water productivity; 2) Developing a better understanding of present patterns of water use and impacts of interventions. The framework can be adapted to specific farm conditions. Using a case study of two successive rotations since 2012, in Kafr El-Sheikh- Egypt, we demonstrate how the new performance indicators can be used to develop better understanding of the reality governing current irrigation water taking into account the difference in the yield and value of different crops. Analysis results show that net inflow and depletion in the Rice-Sugar beet-Cotton-Wheat (RSCW) rotation system are 3883 mm and 2511 mm respectively, which are higher than that of the corresponding figures (3765 mm and 2291 mm respectively) in Cotton-Wheat –Rice-Wheat (CWRW) rotation system. The gross and net depletion fractions (DF) are 6.1 and 6.2% less in the CWRW compared with RSCW. Net inflow of rice was 1520 mm greater following cotton and sugar beet than wheat in RSCW and wheat in CWRW. Total outflow was higher in RSCW than CWRW (1323vs. 1212 mm). The RSCW rotation has the highest net returns, about US\$2286 ha^{-1} compared with US\$2003 ha^{-1} for a CWRW rotation. Therefore, when water is becoming a limiting factor for agriculture, a systems performance indicator rather than a crop performance indicator is needed to determine the optimum crop rotation, water allocation among those crops and ultimate net return of the cropping system should be.

Key words: Irrigation water · Performance indicators · Depletion fraction · Crop rotation and economics

INTRODUCTION

The study aimed to raise awareness of the seriousness of the water scarcity issues in the region and about the urgent needs and commitments for regular assessment and monitoring of the current status of water-use efficiency in order to identify practical ways of improving water-use efficiency at the farm levels, as well as in the agriculture sector at large, with a focus at participatory approaches. The study tackled issues such as the challenges of water scarcity in agriculture; conceptual issues in water productivity and water-use efficiency and country-specific experiences with a focus on policies enacted, innovations introduced, good practices and improving on-farm water use efficiency with the active participation of stakeholders. The study concluded with the expectation that water accounting and provides generic terminologies and procedures approaches in the field in order to improve on-farm water-use efficiency and ensure a positive impact in their respective countries.

Due to vastly different types and scales of use, communicating about water between professionals and non-water professionals is quite difficult. Policy decisions are often taken without a clear understanding of consequences on all water users. As competition for a limited supply of water increases, it becomes increasingly important to clearly communicate about how water is being used and how water resource developments will affect present use patterns. As irrigation is a large consumer of water, developments in irrigation have profound impacts on farm-wide water use and availability. Yet, planning and execution of on-farm irrigation interventions often take place without consideration of

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other uses. One of the main reasons for this restricted view of irrigation workers is inadequate means to describe how irrigation water is being used. On-farm irrigation efficiency is the most commonly used term to describe how well water is being used. But increases in irrigation efficiency do not always coincide with increases in overall basin productivity of water.

One of the most extensively used terms to evaluate the performance of an irrigation system is “water efficiency”. In general terms, water efficiency is defined as the ratio between the amount of water that is used for an intended purpose and the total amount of water input within a spatial domain of interest.

In this context, the amount of water applied to a field of interest but not used for the intended purpose is a “loss” from that field. Clearly, to increase the efficiency of a field of interest, it is important to identify losses and minimize them. Depending on the intended purpose and the field of interest, many “efficiency” concepts are involved, such as crop water use efficiency, water-application efficiency and others [1].

During the crop growth period, the amount of water usually applied to the field is much more than the actual field requirement. This leads to a high amount of surface runoff and seepage and percolation. Seepage and percolation account for about 23-40% of the total water input to the field [2, 3].

On-farm productivity of irrigation water can be increased by doing one of the following: (1) increasing yield per unit evapotranspiration during crop growth; (2) reducing evaporation especially during land preparation; (3) reducing seepage and percolation during land preparation and crop growth periods; and (4) reducing surface runoff.

Define water productivity (WP), using the first of the above definitions, as the ratio of the physical yield of a 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 (m^3) [4].

Water is likely to be the single most important regional and global resource issue in the coming years. Its “wise” use is becoming an immediate necessity. A criterion that perhaps is generally accepted to evaluate a wise use of water is what is referred to as Water Use Efficiency (WUE). The term indicates how much food and/or fiber a cubic meter of water may produce. Comparing WUE of Supplemental Irrigation (SI) of wheat with that of Full Irrigation (FI), a real opportunity for water use improvement was found.

According to ICARDA trials and farmers demonstration fields in Syria, a cubic meter of water used in SI produced, on average, an extra 3 kg of wheat over rainfed yield (WUE = 3 kg m^{-3}), whereas a cubic meter used in FI produces about 0.5 kg, i.e., WUE = 0.5 kg m^{-3}. This large difference in the WUE is attributed to the conjunctive use of rainfall and SI water. In Jordan rainfall WUE in rainfed wheat in Mushagar (300 mm annual rainfall) is 0.33 kg m^{-3}, when the cubic meter of rainfall is combined with ½ m^3 supplemental irrigation, the overall WUE was increased to 3.5 kg m^{-3}. With such obvious advantages decision makers at the national level may need to consider the feasibility of diverting some irrigation water from FI to SI, or a combined use of both for optimal crop-water allocation [5].

Average WUE of rain in producing wheat in the dry areas of West Asia and North Africa (WANA) is about 0.35 kg grain m^{-3}, although with good management and favorable rainfall (amount and distribution), this can be increased to 1 kg grain m^{-3}. However, water used in SI can be much more efficient. Research at ICARDA showed that a cubic meter of water applied at the right time (when the crop is suffering from moisture stress), combined with good management, could produce more than 2.5 kg of grain over the rain-fed production. This extremely high WUE is mainly attributed to the effectiveness of a small amount of water in alleviating severe moisture stress during the most sensitive stage of crop growth and seed-filling. When SI water is applied before such conditions occur, the plant may reach its high yield potential [6]. In comparison to the productivity of water in fully irrigated areas (when rainfall effect is negligible), the productivity is higher with SI. In fully irrigated areas with good management, wheat grain yield is about 6t/ha using 800 mm of water. Thus, the WUE is about 0.75 kg m^{-3}, one-third of that is under SI with similar management. This suggests that water resources may be better allocated to SI when other physical and economic conditions are favorable.

In the Beni-Sweif area of Egypt, Surface water is the main source of irrigation for all farmers in the survey. Main produced crops are wheat and berseem for winter cropping, whereas, summer cropping includes cotton, sunflower, tomatoes and corn. On-farm WUE is the highest for cotton (0.75), berseem and corn (0.72, each), indicating that actual water use exceeds water requirements by about 25 to 28%. The lowest WUE of 0.56 for tomatoes suggests that producers over-irrigate this crop by 44% compared to its requirements. Therefore, any improvement in the water-use efficiency of this crop will save a large amount of scarce water that can be used to expand the farm's irrigated area or for other crops. Likewise, farmers of wheat and sunflower exceed crops' water requirements by 35%. Either below-average yields or inefficient use of irrigation water can explain these low ratios of on-farm WUE for tomatoes, wheat and sunflower.

The survey also confirms that wheat plays an important role in farmers' crop rotations. The most common winter summer rotations are wheat–rice (20% of the cultivated area), berseem (clover)–cotton (12%), wheat–maize (10%) and berseem–maize (8%). Four-fifths of the wheat farmers in Egypt grow wheat every year. Wheat farmers devote one-half of their winter cropland (or slightly less than one quarter of their total sown area) to wheat. In terms of the value of production, the most important crops grown by wheat farmers are cotton (24% of the total), wheat (19%) and rice (15%). Cotton, fruits and vegetables account for a larger share of the value of production than of area because value per hectare is higher than for staple foods.

The objectives of this paper are to present concepts and definitions necessary to account for water use, depletion and productivity. The accounting procedures and standards given here are designed to be universally applicable for evaluating water management within and among all sectors.

A goal of this approach is to develop 1) The terminology and a procedure that can be applied to describe the present status and consequences of water resources related actions carried out in agriculture and other water sectors; 2) Examples of water accounting at two levels of rotations to test and demonstrate the utility of the methodology; and to determine which scheme can achieve the highest yields compared to the amount of water applied while maximizing profit.

Levels of Analysis: Agricultural researchers often focus on a field level or a plot level dealing with crop varieties and farm management practices. Irrigation specialists focus on a set of fields tied together by common resource water. On-farm irrigation specialists are concerned with other uses of water in agriculture and extension.

A perceived improvement in water use at the farm level may improve overall productivity of water in a basin, or it may reduce productivity of downstream users. Only when the intervention is placed in the context of a larger scale of analysis can the answer be known. Similarly, basin-wide studies may reveal general concepts about how water can be saved or productivity of water increased, but field level information on how to achieve savings or increase water productivity is required. Therefore, micro level of water use in agriculture is defined for which water accounting procedures are developed:

Micro Level: Use level, such as an agricultural field, a household, or an environmental use. The water accounting methodology is developed in a manner such that it can be generically used for irrigation, municipal, industrial, environmental, or other uses of water. But the focus of this paper will be on irrigation services and use of water and emphasis will be on quantities of water at the field and irrigation service levels. In the future phases, concepts and examples will be presented from multiple uses of water and water quality.

Water Balance Approach: The water accounting methodology is based on a water balance approach. Water balances consider inflows and outflows from field. Water accounting components at field are inflow, storage change, process depletion, non-process depletion and outflow. The inflow components are irrigation application, rainfall, subsurface contributions and surface seepage flows. Storage change component is soil moisture change in active root zone. Process depletion components are actual evapotranspiration, outflow components are deep percolation, seepage and surface runoff. Estimates of actual crop consumptive use at a regional scale are questionable. And drainage outflows are often not measured, as more emphasis has been placed on knowledge of inflows to irrigation systems. In spite of the limitations, experience has shown that even a gross estimate of water balances for use in water accounting can be quite useful to managers, farmers and researchers.

Water Accounting Definitions: The water accounting is to classify water balance components into water use categories that reflect the consequences of human interventions in the hydrologic cycle. Water accounting integrates water balance information with uses of water. Inflows into the domain are classified into various use categories as defined below.

Gross inflow is the total amount of water flowing into the field from rainfall and surface and subsurface sources.

Net inflow is the gross inflow plus any changes in storage. If water is removed from storage over the time period of interest, net inflow is greater than gross inflow; if water is added to storage; net inflow is less than gross inflow. Net inflow water is either depleted, or flows out of the field of interest.

Balance approaches have been successfully used to study water use and productivity at the field level (for example, [7, 8, 9, 10, 11]).

Water depletion is a use or removal of water from field that renders it unavailable for further use. Water depletion is a key concept for water accounting, as it is often the productivity and the derived benefits per unit of water depleted we are interested in. It is extremely important to distinguish water depletion from water diverted to a service or use, because not all water diverted to a use is depleted. Water is depleted by three generic processes, the first two described by [12, 13]. A third type of depletion occurs when water is incorporated into a product.

The Two Generic Processes Are:

- Transpiration: it is water transpired by crops plus that amount incorporated into plant tissues.
- Evaporation: water is vaporized from surfaces or transpired by plants
- Incorporation into a product: by a process such as incorporation of irrigation water into plant tissues. *Process depletion* is that amount of water diverted and depleted to produce an intended good. For agriculture, it is water transpired by crops plus that amount incorporated into plant tissues.

Performance indicators for water accounting follow depleted fraction and effective efficiency concepts are presented [13, 14].

Water accounting performance indicators are presented in the form of fractions and in terms of productivity of water.

Depleted Fraction (DF) is that part of the inflow that is depleted by both process and non-process uses. Depleted fraction can be defined in terms of net, gross and available water.

$$DF_{net} = \frac{Depletion}{NetFlow} \quad (1)$$

$$DF_{gross} = \frac{Depletion}{Gross\,inflow} \quad (2)$$

Productivity of Water (PW) can either be related to the physical mass of production or the economic value of produce per unit volume of water. Productivity of water can be measured against gross or net inflow, depleted water, or process depleted water. Productivity of water has a broader basis than water use efficiency [15], which relates production of mass to process depletion (transpiration or evapotranspiration for irrigated agriculture). Here it is defined in terms of net inflow, depleted water and process depletion.

$$PW_{inflow} = \frac{Productivity}{Netflow} \quad (3)$$

$$PW_{depleted} = \frac{Productivity}{Depletion} \quad (4)$$

$$PW_{process} = \frac{Productivity}{ProcessDepletion} \quad (5)$$

The following relationships exist between productivity and water indicators.

$$PW\ depleted = PW_{net\ inflow} / DF_{net} \quad (6)$$

For an irrigated service area, these are external indicators of system performance relating the output of irrigated agriculture to its main input, water. IIMI's external indicators [16, 17] draw from this water accounting list for a minimum set of indictors and include the productivity of water related to process depletion.

Accounting Components at Field Level: The use level of analysis for irrigation is taken at the field level with inflows and outflows shown in Table 1. This is the level where crop production takes place the process of irrigation. Agricultural research at this level is often aimed at increasing productivity per unit of land and water and conserving water. The key question is: Which water? Again, it is important to understand the category of water against which production is being measured, or the category of water that is being conserved.

At the field level, the magnitudes of the components of the water balance are a function of crop and cultural practices. Different crops and even different varieties of crops, will transpire water at different rates. Irrigation techniques influence evaporative losses and volumes of deep percolation and surface runoff. For example, drip irrigation minimizes these components, while surface application induces depletion by evaporation. Also, the amount of water delivered influences runoff and deep percolation. Other cultural practices such as mulching and crop spacing affect the amount of water stored in the soil and the amount of runoff and deep percolation.

Table 1: Field level water accounts in North Delta: RSCW rotation.

	Rice	Sugar beet mm	Cotton	Wheat	Two annuals
Inflow					
Irrigation	1520	680	952	571	3723
Effective rainfall	0.0	50	0.0	50	100
Subsurface	0.0	0.0	0.0	0.0	0.0
Lateral seepage flows	0.0	0.0	0.0	0.0	0.0
Gross inflow	**1520**	**740**	**952**	**621**	**3833**
Storage change	**0.0**	**16**	**17**	**17**	**67**
Net inflow	1520	756	969	638	3883
Depletion					
Actual Evapotranspiration (process)	840	610	671	390	2511
Total Depletion	840	610	671	390	2511
Outflow					
Surface runoff	0.0	0.0	0.0	0.0	0.0
Deep percolation	680	70	281	181	1212
Total outflow	680	70	281	181	1212
Performance					
Depleted Fraction (gross)	0.55	0.89	0.70	0.63	0.66
Delectated Fraction (net)	0.55	0.81	0.69	0.61	0.65
Production (kg ha^{-1})	9341	63874	2261	8830	
Production per net inflow (kg mm^{-1})	6.1	83.6	2.1	13.6	
Production per total depletion and process (kg mm^{-1})	11.1	104.7	3.4	22.6	
Production per net flow per depletion fraction (net)	11.1	103.2	3.0	22.3	
Irrigation cost in US$	223	84	94	67	468
Net return in US$	587	652	405	643	2286

Table 2: Field level water accounts in North Delta: CWRW rotation.

	Cotton	Wheat	Rice mm	Wheat	Two annuals
Inflow					
Irrigation	952	571	1520	571	3614
Effective rainfall	0.0	50	0.0	50	100.0
Subsurface	0.0	0.0	0.0	0.0	0.0
Lateral seepage flows	0.0	0.0	0.0	0.0	0.0
Gross inflow	**952**	**621**	**1520**	**621**	3714
Storage change	17	17	0.0	17	51
Net inflow	969	638	1520	638	3765
Depletion					
Actual Evapotranspiration (process)	671	390	840	390	2291
Total Depletion	**671**	**390**	**840**	**390**	2291
Outflow					
Surface runoff	0.0	0.0	0.0	0.0	0.0
Deep percolation	281	181	680	181	1323
Total outflow	281	181	680	181	1323
Performance					
Depleted Fraction (gross)	0.70	0.63	0.55	0.63	0.62
Delectated Fraction (net)	0.69	0.61	0.55	0.61	0.61
Production (kg ha^{-1})	2412	7174	9840	6350	
Production per net inflow (kg mm^{-1})	2.3	11.0	6.5	9.8	
Production per total depletion and process (kg mm^{-1})	3.6	18.4	11.7	16.3	
Production per net flow per depletion fraction (net)	3.3	18.0	11.8	16.1`	
Irrigation cost in US$	94	67	223	67	451
Net return in US$	432	560	669	496	2003

Water accounting procedures attempt to capture the effects of different crop and cultural practices on how water is used and depleted at the field level.

At the field level, it is sometimes impossible and oftentimes unnecessary to know the fate of outflows. By accounting for water use at the field level, then placing it in the context of irrigation service and basin levels, it is possible to match field level interventions with requirements at the irrigation service level, or water basin level, or both.

A field experiments was conducted during four successive seasons of summer 2010, winter 2010/2011, summer 2011 and winter 2011/2012 in farmers' farms of the command area in North Delta. Two cropping rotations were applied to measure water productivity indicators on crop rotations of wheat. All cropping sequences were selected as a dominant in North Nile Delta region.

1. Rice Sugar beet – Cotton – Wheat (RSCW)
2. Cotton – Wheat- Rice - Wheat (CWRW)

Each year's crop rotation treatments included rice-sugar beet – cotton – wheat (RSCW) and cotton – wheat-rice - wheat (CWRW). RSCW were compared to a two-year cycle of CWRW. The researchers used seeding rates, fertility and pest control practices common in the region.

Example of Water Accounting: To illustrate water accounting, example is chosen from the use levels. The use level example is taken from the crop rotations followed by farmers in North Delta in Egypt.

Field-Level Accounting Example: As a field-level example, results of agricultural trials based on field experiments carried out in farmers' farms of the command area in North Delta in Egypt are reported in a water accounting format (Table 1). In this area, the water duty falls short of potential crop requirements as water is scarce relative to land. In response, farmers typically have a strategy of deficit irrigation, or giving less water than the potential crop requirement, thus giving them the opportunity to irrigate more land.

Yields were reported as 9.34 tons per hectare for rice, 63.87 tons per hectare for sugar beet, 2.26 tons per hectare for cotton and 8.83 tons per hectare for wheat in RSCW rotation (Table 1). While yields in CWRW rotation were 2.41 t ha^{-1}, 7.17 t ha^{-1}, 9.84 t ha^{-1} and 6.35 t ha^{-1} for cotton, wheat rice and wheat, respectively as shown in Table 2. All of the irrigation and rainfall applied is depleted leading to a depleted fraction $_{gross}$ of 0.55, 0.89, 0.70 and 0.63 for rice, sugar beet, cotton and wheat, respectively and they were 0.70, 0.63, 0.55 and 0.63 for cotton, wheat, rice and wheat to a depleted fraction $_{gross}$ (Table 2),. The depleted fraction $_{net}$ of 0.55, 0.81, 0.69 and 0.61 for rice, sugar beet, cotton and wheat, respectively, while they were 0.69, 0.61, 0.55 and 0.61 for cotton, wheat, rice and wheat in the second crop rotation. On a two annual basis, the depleted fraction $_{net}$ is quite middle at 0.65 in the RSCW and 0.61 in CWRW rotations, due to a high amount of evapotranspiration and small amount of rainfall in winter season. The depletion fraction of net inflow was, with an average of 0.65 lower than 1.0 as a result of the practice of deficit irrigation used. In this case, evapotranspiration is reported so that productivity per total depletion and per process depletion can be calculated.

The water application by crop for winter cropping is 860 mm for sugar beet and 571mm for wheat. For summer cropping, water application, as an average for the sample farms, is 952 mm for cotton, 1520 mm for rice.

Cropping systems evaluated were rice- sugar beet – cotton – wheat (RSCW) and cotton – wheat- rice - wheat (CWRW). Net inflow and depletion in RSCW was 3883 mm and 2511 mm, respectively, greater than CWRW which was 3765 mm, 2291 mm, respectively; however, the depleted fraction for gross and net decreased by 6.1 and 6.2% compared with RSCW. Net inflow of rice was 1520 mm greater following cotton and sugar beet than wheat in RSCW and wheat in CWRW. Total outflow was higher in RSCW than CWRW (1323 vs. 1212 mm). Irrigation cost was higher (US$486 vs. 451) in RSCW compared to CWRW. The RSCW rotation had the highest net returns, about US$2286 ha^{-1} compared with US$2003 ha^{-1} for a CWRW rotation.

Water productivity according to the defined in technical terms used, is the highest for sugar beet compared to wheat in winter cropping and rice compared to cotton in summer cropping.

Seasonal irrigation water-use efficiency was highest in rotation of RSCW and the current status of on-farm water-use efficiency of wheat under specific farm conditions in the Kafr El-Sheikh province, northern Delta, Egypt, where the recent use of irrigation deficit has been expanded to increase wheat production in areas. The resulting indicators of on-farm water-use efficiency are very useful in guiding policies toward improving irrigation efficiency. Improving water-use efficiency to sustain and improve wheat production in Northern Delta, Egypt is vital especially that the country has been classified as irrigation deficit.

It is meaningful to compare values of mass of production per unit of water diverted or depleted, when comparing like crops. But when different crops are compared, mass of output is not as meaningful. There is a clear difference between 1 kg of sugar beet and 1 kg of rice produced per mm of water depleted within the same crop rotation of RSCW and between 1 kg of cotton yield and 1kg of wheat in CWRW rotation. One approach is to convert yields into value of production using local prices. A second approach is to use Standardized Gross Value of Production (SGVP). Standardized Gross Value of Production is used to measure economic productivity to allow comparisons across different agricultural settings by using world prices of various crops [16, 17 and 18]. To calculate SGVP, yield of a crop is converted into an equivalent yield of a predominant, traded field crop using local prices. Then this mass of production is converted into a monetary unit using world prices. This investigation has been to create a decision tool with user interaction to examine crop rotation and limited water allocations within land allocation constraints to find optimum net economic returns from these combinations. This decision aid is for intended producers with limited water supplies to allocate their seasonal water resource among a different of crops. But, it may be used by others interested in decisions concerning allocating limited water to crops. Decisions are intended as a planning tool for crop selection and season allocations of land and water to crop rotations.

In the various rotations, price determines profitability. But a rotation of RSCW consistently provides higher profit than CWRW rotation. One of the objectives of this research is to improve the growers' ability to make such investment decisions and to provide them with decision aids like Irrigator Pro to better manage irrigation based on economics and not simply yields.

The survey results also highlight the intensity of wheat production in Egypt. Wheat crop in rotation of RSCW produce US$643, while in the CWRW rotation, wheat crop produce UD$469. Wheat farmer harvests 8.83 metric tons of wheat obtained from RSCW rotation. While it was 6.35 metric tons of wheat obtained from CWRW rotation. It has been a while since agricultural researchers discovered and then proved the benefits of crop rotation. Since then, most farmers have embraced the practice of switching a piece of ground from one crop to another to improve yields, reduce erosion potential and break insect and disease cycles [19]. We got a higher return for our water with rotation of RSCW and used its limited water more efficiently than CWRW rotation. Higher market prices for rice might swing the water-value factor in favor of the rice-wheat rotation in the CWRW and RSCW rotations.

To obtain the required amount of water to produce the average yield levels, the estimated crop water balance are used. This is done by calculating the amount of water required for each crop at the mean levels of the independent variables appearing in that water balance. For winter and summer cropping, both fixed allocatable input model and variable input model are used in estimating the amount of water required for them.

Growers depend on several factors such as proper irrigation methods, good crop rotations and effective marketing to secure the best price for the product. Researchers at Sakha Agricultural Research Station (SARS) in Kafr El-Sheikh, Egypt are conducting long-term, multicrop research at a farm location to define the best irrigation management practices for growers of rice, sugar beet, cotton and wheat crops. They have completed the two year of study to determine the impact on profitability of irrigation, crop rotation and price.

For all iterations, net return to land, management and irrigation equipment is calculated:

Net return = (commodity price X yield) – (irrigation cost + production cost)

where:

commodity prices were determined from user inputs, crop yields were calculated from yield-irrigation relationships based on field research, irrigation costs were calculated from lift, water flow, water pressure, fuel cost, pumping hours, repair, maintenance and labor for irrigation and production costs were calculated from user inputs. User inputs including water supply, irrigation costs, crop production costs, commodity prices and maximum crop yields can be tailored to user circumstances. These inputs directly influence the selection of the optimum crop rotation, water allocation among those crops and ultimate net return of the cropping system.

REFERENCES

1. El-Bably, A.Z., M.E. Meleha and A.A. Abd Allah, 2008. Enhancing water use efficiency, rice productivity and saving water in North Delta, Egypt. The 3rd International conference on water resources and arid environment at King Fahed Cultural center, Riyadh, KSA, Proc. Water resources, pp: 326-332

2. Abd El-Hafez, S.A., A.A. El-Sabbagh, A.Z. El-Bably and E.I. Abo-Ahmed, 2001. Evaluation two methods of rice planting grown under sprinkler irrigation system at north delta, Egypt. Minufiya J. Agric. Res., 26(2): 377-386.
3. Abd El-Hafez S.A., A.A. El-Sabbagh, A.Z. El-Bably and E.I. Abo-Ahmed, 2001. Response of maize crop to drip irrigation in clay soils. Alex J. Agric. Res., 46(2): 153-159.
4. Oweis, T., A. Hachum and j. Kijne, 1999. Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas. SWIM paper 7. IWMI, Sri Lanka, 1999.
5. Oweis, T. and A.B. Salkini, 1992. Socio-economic Aspects of Supplementary Irrigation. Paper presented at the International Conference on Supplemental Irrigation and Drought Water Management, September 27 to October 2, 1992, Bari. Italy.
6. Oweis, T., 1997. Supplemental Irrigation – A Highly Efficient Water-Use Practice. ICARDA. 1997, Aleppo, Syria, pp: 16.
7. Molden, D., 1997. Accounting for water use and productivity. SWIM Paper 1. International Irrigation Management, Colombo, Sri Lanka. Institute.
8. Mishra, H.S., T.R. Rathore and V.S. Tomar, 1995. Water use efficiency of irrigated wheat in the tarai region of India. Irrigation Science, 16(2): 75-80.
9. Rathore, A.L., A.R. Pal, R.K. Sahu and J.L. Chadhary, 1996. On-farm rainwater and crop management for improving productivity of rainfed areas. Agricultural Water Management, 31: 253-267.
10. Bhuyian, S.I., M.A. Sattar and M.A.K. Khan, 1995. Improving water use efficiency in rice irrigation through wet seeding. Irrigation Science, 16: 1-8.
11. Tuong, T.P., R.J. Cabangon and M.C.S. Wopereis, 1996. Quantifying flow processes during land soaking of cracked rice soils. Soil Science Society of America Journal, 60(3): (May–June 1996).
12. Seckler, D., 1996. The new era of water resources management: From "dry" to "wet" water savings. Research Report 1. Colombo, Sri Lanka: International Irrigation Management Institute.
13. Keller, A. and J. Keller, 1995. Effective efficiency: A water use concept for allocating freshwater resources. Water Resources and Irrigation Division Discussion Paper 22. Arlington, VA, USA: Winrock International.
14. Willardson, L.S., R.G. Allen and H.D. Frederiksen, 1994. Universal fractions and the elimination of irrigation efficiencies. Paper presented at the 13th Technical Conference, USCID, Denver, Colorado, October 19-22, 1994.
15. Viets, F.G., 1962. Fertiliser and efficient use of water. Advances in Agronomy, 14: 223-264.
16. Perry, C.J., 1996. Quantification and measurement of a minimum set of indicators of the performance of irrigation systems. January, 1996. Colombo, Sri Lanka: International Irrigation Management Institute.
17. Molden, D.J., 1999. Indicators for Comparing Performance of Irrigated Agricultural Systems. Research Report 20, IWMI, Sri Lanka
18. Mahmoud, M.M.A., 2010. Effect of cropping pattern on soil properties in north delta region. Thesis of M.Sc. Soil Sci. department, Faculty of Agriculture, Kafrelsheikh Univ., Egypt.