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Impacts of Irrigation on Agricultural Productivity in Egypt

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Abstract: This paper investigates the impacts of the main primary production factors (e.g. seed, nitrogen, phosphorus, etc.), on the total production of the main crops produced in Egypt (cotton, berseem, maize, rice and wheat), with special emphasis on the role of irrigation. Specifically, the paper estimates the isoquant curves for the inputs irrigation water and fertilizer (used in quantity) on productivity of these crops and assesses the value of marginal products of irrigation water with special emphasis on elasticity of the production factors and the economics of returns to scale. Farm level data for 2011-2012 were collected for a sample of 152 producers in South El Husainia Plain, Egypt. The data was used to estimate the Cobb-Douglass production function and isoquant curves. Empirical findings showed increasing returns to scale for berseem and cotton, but decreasing returns to scale for wheat, rice and maize production was identified. Except for berseem and wheat, the irrigation water productivity for rice, cotton and maize have been found relatively low compared to the world average levels reported by FAO (1.09, 0.65 and 1.80 kg m^{-3} for rice, cotton and maize, respectively). Overall, marginal productivity of irrigation water for the studied crops, especially for cotton, has been low. These results suggest that farmers could increase the production of these crops by applying water more efficiently. This highlights the need to improving irrigation performance through improved and known water management practices which will largely preserve water resources. In particular, there is a need for greater political and institutional involvement to design and develop policy instruments that will facilitate adoption of the farmer participatory water management practices.

Key words: Cobb-Douglas, irrigation water, agricultural productivity, returns to scale, Egypt.

Irrigation water is becoming an increasingly scarce resource for the agricultural sector in many arid and semi-arid countries. Factors such as rapid urbanization, population growth and climate change are placing these resources in a continuous challenge. To combat the physical scarcity of water, increasing its use efficiency, improving its productivity in every production sector, and its allocation to the most valuable uses remains the most effective strategies that has the highest degree of proven effectiveness to achieve more efficient water use.

Egypt is the largest and most populous economy in the North African region. The rapid increase of population growth and its corresponding economic activities caused a reduction of the per capita share of the already limited fresh water resources, as well as degradation of the water quality (Abdel-Shafy and Aly, 2002). Despite the fact that the vast majority of Egyptian land is desert, with agricultural land constituting less than 5% of the total land area, the agricultural sector is highly important for the country's economy. In 2012 agriculture accounted for 16% of GDP and 29% of total employment (World Development Indicators, 2013). Due to very sparse and erratic rainfall, crop production in Egypt is almost fully dependent on irrigation. Irrigation water is taken from the Nile River, and so far the government has provided it to farmers free of charge. However, with increasing expansion of the agricultural areas due to population growth, water scarcity is likely to grow in the near future. It is, therefore, important to identify efficient ways of using scarcely available irrigation water resources.

According to Khalifa *et al.* (2010), irrigation management of crops in Egypt is characterized

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by the application of more water than the crops require. In fact, large volume of water is supplied without any estimates of the soil water content at the root zone. The rationale for doing so is that farmers assume that more irrigation water means greater yield. Eliminating unnecessary irrigation water beyond the crop requirement would help saving water, provided that this can be done with low yield losses (Khalifa *et al.,* 2010).

As production factor, water can be characterized by several features, which make the issues of efficient utilization of this resource different from those pertaining to other production factors. In this research study, we investigated the impact of the production factors on the yield of the main crops produced in Egypt named berseem, wheat, cotton, maize and rice with special focus on irrigation water and its relationship with nitrogen. Thus, it is critical to understand the marginal products of irrigated water and the rest of inputs in the production process of these crops to establish their values and means to maximize productivity of irrigation (and other inputs).

We also strive to better understand the assessment of the economic return to scale regarding the production of the selected crops. We do believe that results of this study can be helpful in policy planning regarding irrigation and agronomic management for prioritizing crops and therefore maximizing revenue from limited resources.

The manuscript is organized into five sections: Section 1 provides the background information about the research questions and the objectives of the study. Section 2 shows a comprehensive review of past studies on economic impact of irrigation around the world and in Egypt; Section 3 describes the research methodology; Section 4 presents and discusses empirical results; and the last section (Section 5) highlights the main concluding remarks and policy implications.

Review of Past Studies Regarding the Economic Impact of Irrigation

Crop yields everywhere are consistently higher in irrigated than rainfed areas (Lipton *et al.,* 2005). Water is a necessary input of agricultural production, and in many developing countries water needs for crop production are covered partly or fully by irrigation (Calzadilla *et al.,* 2011). The use of irrigation can generate a number of benefits for the agricultural sector (Hamilton and Chaipant, 1983). First of all, irrigation allows expansion of cultivatable areas beyond that is possible under rainfed conditions. Secondly, irrigation results in increase in yields due to prevention of crop water stress and to the combined effect of using irrigation with high yielding crop varieties, fertilizers, and pesticides (Turner *et al.,* 2004).

According to the literature review, the concepts of water use efficiency (WUE) and water productivity (WP) are considered as different terms. Hence, they are used differently by different professionals (economists, agronomists, etc.). The first use of the concept 'water use efficiency' to mean the ratio of crop production to evapotranspiration was introduced by Viets in 1966 (Kijne *et al.,* 2000). For instance, Willardson *et al. (*1994), introduced the concept of consumed fractions and others such as Perry (1996a), Clemmens and Burt (1997) and Molden (1997), have referred to beneficial and non-beneficial depleted or consumed fractions of water.

As the concept of water productivity is different from one topic to another (engineering, social science, agronomic) it is worth to indicate that economists use factor productivity as the value of output divided by the value of all inputs. Most analysts in the water sector agree to the statement that water use efficiency "includes any measures that reduce the amount of water used per unit of any given activity, consistent with the maintenance or enhancement of water quality" (Tate, 1994). Depending on how the terms in the numerator and denominator are defined, water productivity can be expressed in physical or economic terms (Seckler *et al.,* 1998a). Economic efficiency of irrigation water is defined as maximizing social net benefits from water resources, which often requires improved water management (Wichelns, 2002). Similarly, optimal irrigation management includes the choice of crops, varieties of seeds, management framework and techniques, cultural practices, policy, and institutions that may increase the productivity of each unit of water used for irrigating the cultivated crops (Pereira *et al.,* 2002). Thus, in order to improve water productivity in the rainfed areas of dry lands, there is a need to combine on-farm water-productive techniques (reallocation of water from low-value crops to higher value crops, combining *in-situ* soil moisture conservation and balanced nutrient supply - case of water vs. nitrogen) with the agronomic (better crop selection and appropriate cultural practices) and management practices (improved irrigation management options and timely socioeconomic interventions). Conventional water management guidelines should be revised to ensure the maximization of water productivity instead of land productivity (Oweis and Hachum, 2005).

Playan and Mateos (2006) reported that particular attention has to be paid to the improvement of irrigation management, which shows much better economic return than the improvement of the irrigation structures. The hydrological effects of these improvements may be deceiving, since they will be accompanied by larger crop evapotranspiration and even increased cropping intensity. As a consequence, less water will be available for alternative uses. Clemens and Burt (1997) indicated that evaluation of the irrigation system performance should rely on accurate hydrologic water balance over the area considered. They provided equations, 330 procedures and examples for making these calculations and recommended that confidence interval be included in all reporting of irrigation performance parameters. Sadras (2009) reported that considering the investment cost and management complexity of implementing partial root-zone drying, it is critical to identify the rare conditions where this method could be economically justified.

Methodological Framework

Data sources and data collection procedure

The study area: The target site of this research is located in the South El Husainia Plain, El Husainia District, Sharkia Governorate, South East of Delta region in Lower Egypt (Fig. 1). South El Husainia Plain is one of six newly reclaimed areas in East Delta Region and covers an area of about 24,000 ha, of which about 16, 000 ha (representing 66.5% of the total area) is cultivated (Sayaf, 2011; East Delta Newlands Agricultural Services Project "EDNASP", 2009).

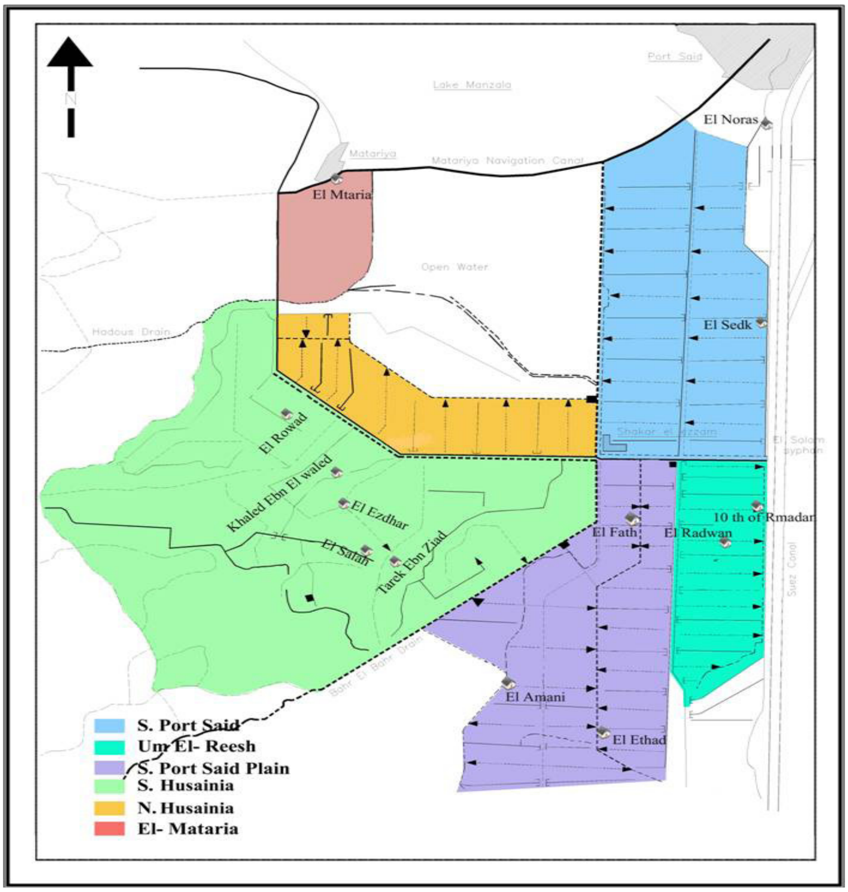

Fig. 1. Map and location of study area [Source: WLI-Water Livelihood Report - Egypt (2012)].

However, gradual settlement occurred in the South El Husainia in 1993/94. This region is inhabited by recent settlers who received plots of land from the government. The soil structure and lack of fresh irrigation water, in addition to poor social and cultural services, made the region unattractive for many farmers.

Sample selection and data collection: Data was collected through a socio-economic household survey conducted during 2011/2012 in El Husainia Plain. A sample of 152 households, representing 7.7% of the total number of land holders were randomly selected for this purpose. The distribution of farm households across the defined five villages (clusters) was determined based on the weighted proportional importance of the total number of holders in each Village (proportional to the number of holders of each holding category in the population). Stratified sampling approach was employed based on holding categories (graduates, beneficiaries, small investors and new holders), to ensure representativeness of each holder category. Interviewed farmers were randomly selected using lists obtained from census offices.

The questionnaire consists of eight sections: the first is related to agricultural activities and costs of production. The remaining sections focus on outputs and revenue of crop production, institutional framework, sustainable water saving and soil conservation practices using recommended water management technologies, support and extension services, and the most problems facing farmers in addition to the main socio-economic characteristics of the farmers.

Model specification

According to Ekpebu (2002), there are many functional forms that could be used to describe production relationship, but in practice the commonly used forms are linear, quadratic, Cobb-Douglas and *translog* functional forms. In this research, we used the linear, double logarithmic (i.e. Cobb-Douglass[1]), production function and isoquant curve approaches.

The linear production function is used to measure linear relationships between inputs and outputs. Given five variable inputs (X_1 to X_5), the function can be mathematically expressed as:

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + u \quad (1)$$

where, Y is the production quantity of the selected crop (ton/feddan[2]); α is a multiplicative constant; X_1 represents the seeds quantity (kg $feddan^{-1}$); X_2 is quantity of phosphorus fertilizer (kg $feddan^{-1}$); X_3 is labor (man day^{-1} $feddan^{-1}$), X_4 represents the water volume (cubic meter $feddan^{-1}$), and X_5 is quantity of nitrogen (kg $feddan^{-1}$). Parameters α_1, α_2, α_3, α_4, and α_5 are to be estimated and they determine efficiency of the inputs on output; and *u* is an error term. This linear function was criticized and according to Kalaitzandonakes *et al.* (1992), this function is not a good measure of an optimum production because the coefficients assume constant marginal productivity and lacks to account the interactions between the inputs.

Therefore, the Cobb-Douglas production function was used to deal with such shortcomings of linear specifications. It is widely used to represent the technological relationship between the amounts of two or more inputs, particularly physical capital and labor, and the amount of output that can be produced by those inputs (Miller, 2005). This function is explicitly specified as follows (for five variables):

$$Y = A X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} e \quad (2)$$

where, Y; A; X_1; X_2; X_3; X_4 and X_5 are as defined in equation 1 and *e* is an error term. The coefficients of X_1, X_2, X_3, X_4 and X_5 represent direct measures of elasticity of the respective factors of production. In double logarithmic form, the CD is specified as:

$$Log(Y) = \beta_0 + \beta_1 Log(X_1) + \beta_2 Log(X_2) + \beta_3 Log(X_3) + \beta_4 Log(X_4) + \beta_5 Log(X_5) + u \quad (3)$$

The production elasticity measures the responsiveness of output to a change in the level of one factor used in production, ceteris paribus. The total, average, and marginal physical product are just one way of showing production relationships. They express the quantity of output relative to the amount of variable input used, while holding fixed inputs constant. The returns to scale show the productive factor shares of the production. The Marginal Rate of Technical Substitution (MRTS) is the amount by which the quantity of one

[1] For more details on the Cobb-Douglass production function, see Miller (2005).
[2] One feddan = 0.42 hectares.

input must be reduced when one additional unit of another input is used, so that output remains constant. In other words, it shows the rate at which one input (e.g. nitrogen fertilizer or irrigation water) may be substituted for another, while maintaining the same level of output.

Regarding the case of water, economists consider the value of marginal product of irrigation water as a very good estimates of its opportunity cost. The value of marginal product is a measure of a firm's revenue contributed by the last unit of a productive factor employed. The value of marginal products of irrigation water for a given crop can be derived from the estimated production functions. In agricultural water management, CD production function were widely used to assess and predict the yield of crops given some input parameters (Igbadun *et al.,* 2007).

For the linear form, the production elasticities of irrigation water for each crop were calculated by dividing the marginal physical product of the irrigation water to the corresponding average physical product of irrigation water for each crop. For double logarithmic forms, the marginal products are calculated by multiplying the production elasticity of the irrigation water by the corresponding average products for each crop. The values of marginal products of irrigation water are calculated by multiplying the marginal product by the farm-gate price of the corresponding crop.

The last step of the analysis is the use of isoquant curves in order to assess all possible combinations of two inputs that result in the production of a given level of output. Water-nitrogen relationships or production functions were considered as useful tools in the management of water and nitrogen application for optimization of crop productivity. It was used to measure the influence of inputs on the level of production or output that can be achieved. There are important relationships between irrigation water and the nitrogen fertilizers utilization. Therefore, all possible combinations of irrigation water and nitrogen fertilizer which yield equal output or production can be derived from the double logarithmic production function. This is with an attempt to assess how water productivity can be substantially and consistently increased (decreased) for the studied crops in the region when limited irrigation water is combined with appropriate (misappropriate) nitrogen fertilizer management. These functions can be used in managing water resource for achieving maximum returns with minimum amount of water application as irrigation (English and Raja, 1996).

Results and Discussion

Relationship between crop yield and inputs

The strength and direction of the relationship between the yield of the studied crops and the inputs used have been measured by calculating the simple correlation coefficient matrix among the quantities produced from the selected crops and the quantities used from the studied inputs. Results in Table 1 show that the relationships among the produced quantities of cotton, and maize, and the quantities used of seeds, nitrogen and phosphorus fertilizers, labor, and irrigation water were positive and mostly significant at the 0.05 level (using t-student statistical test). In addition, statistically significant positive relationships were observed between produced quantities of wheat, rice, and berseem and the used quantities of inputs (seeds, phosphorus

Table 1. Correlation coefficients between the crops yields and the quantity used of inputs (Logarithmic vs. Linear)

Inputs	Units	Berseem		Wheat		Rice		Maize		Cotton	
		Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin
Seeds	kg feddan^{-1}	*0.37	**0.38	**0.54	**0.54	**0.51	**0.52	**0.74	**0.76	**0.97	**0.98
Nitrogen	kg feddan^{-1}	0.11	0.12	**0.51	**0.50	**0.51	**0.58	**0.65	**0.75	**0.94	**0.94
Phosphorus	kg feddan^{-1}	**0.55	**0.58	*0.13	0.12	0.09	0.10	**0.66	**0.66	*0.72	**0.84
Labor	Manday feddan^{-1}	**0.61	**0.60	**0.50	**0.56	**0.37	*0.34	**0.75	**0.54	*0.73	**0.97
Irrigation water	M^3 feddan^{-1}	**0.68	**0.71	**0.42	**0.43	**0.38	*0.38	**0.53	**0.75	**0.96	**0.96

Source: Compiled and calculated from field survey, 2011/2012.
*Significance at 5%; **Significance at 10% and ***Significance at 1%.

fertilizers, labor, and irrigation water). This indicates that using more inputs leads to increased crop yields for the studied crops. Basically this positive correlation is an argument validation of the data used and how it is consistent with the agronomic expectations.

Results from production functions analysis

Due to the demand that the production functions for the different crops should incorporate the different inputs uses, the economics theory does not provide criteria to choose *ex ante* among the possible formulations of more flexible functional forms (Cobb Douglas, translog, quadratic, linear, etc.).

In this study, two production functions were selected and estimated using Ordinary Least Squares (OLS) regression and t-Student statistical tests: CD and linear. Empirical findings from these two functional forms are displayed in the table below (Table 2). These findings reveals strong similarity between the two functional forms (coefficients and their significance, R^2 and F-statistics). This would imply a difficult decision on the selection between the two functions.

Nevertheless, the functional form chosen here is the CD production functions. This decision was made for two reasons: First, the CD function provide a non-constant MRTS (the fact that a production function shows constant or increasing returns to scale says nothing about whether or not there may be diminishing returns to a single input) and second, its computational simplicity (the exponent for any input term in a CD function represents the productive elasticity of that input.)

The estimated parameters of the linear and CD production function for the five crops are presented in Table 2. All the first-order parameters (α_i and β_i) have the anticipated (positive) signs and magnitudes.

The elasticity coefficient of the "effectively irrigated area" of berseem is positive (0.31) and significant. It is also found to be the second highest production factor affecting the berseem output among the four input factors. With R^2 of 0.65, the highest factor is phosphorus (with 0.58) followed by irrigation water and seeds (with 0.15), while labor (with 0.057) have relative small influence on the wheat production. The sum of elasticity of the four input factors was 1.108 (>1) which showed that the returns to scale (RS) is increasing. This suggest that berseem farmers in the area can increase their berseem output by increasing the use of phosphorus, water and seeds.

The results in Table 2 revealed that seeds input is the most influential factor on wheat production (with a positive and significant coefficient - p-value ≤0.05). The water coefficient was also positive and significant at 5% level. The wheat output variation in the study area, which is around 50%, is explained by the set of inputs used in the CD production function. The returns to scale value suggests that wheat production exhibits a decreasing return to scale (with RS=0.623). This implies that an increase in all inputs leads to a less than proportional increase in wheat production. In other words, if these resources are increase by 1%, the wheat production would only increase by less than 1%.

Analysis of the rice production function indicates that all inputs were positively related to the output of rice. The R^2 of 0.46 implies that 46% of rice output variation in the area is explained by the inputs specified in the CD production function. Furthermore, water and seeds significantly affect the output of rice at 10% level of significance. The rest of inputs (labor and nitrogen) affect the production of rice to a lower extend (lower significance level). It can be inferred that a unit increase in seeds will lead to 33.4% increase in the output of rice, while an increase of one cubic meter of irrigated water will lead to an increase of 24.8% in the quantity of rice produced. For rice production, results also show a decreasing return to scale (with 0.88) which indicates that productivity of the inputs is decreasing and the increasing of inputs factors should be addressed in more efficient way. This findings highlighted the research institutions and extension services to intensify efforts on this crop in order to have improved varieties that give high farm yield and to provide technical assistance on using the recommended seed package.

The examination of the maize production function shows a decreasing return to scale (with RS=0.71). Results of this function also showed that water and maize seeds significantly affected the production of maize at 10% level.

Table 2. Parameters estimates of the linear and Cobb Douglas production functions

Cobb-douglas production function			Linear production function		
Variables	Parameters	Coefficients	Variables	Parameters	Coefficients
Dependent variable: Log (Y)			Dependent variable: Y		
Berseem					
Intercept	β_0	2.71	Intercept	α_0	14.79**
Ln (seeds)	β_1	0.15 **	Seeds	α_1	0.167**
Ln (phosphorus)	β_2	0.586***	Phosphorus	α_2	0.019**
Ln (labor)	β_3	0.057***	Labor	α_3	0.0257**
Ln (water)	β_4	0.315***	Water	α_4	0.003***
R^2	0.65		R^2	0.65	
F-ratio	15.25**		F-ratio	15.50**	
Wheat					
Intercept	β_0	0.11	Intercept	α_0	1.64*
Ln (seeds)	β_1	0.252***	Seeds	α_1	0.008***
Ln (labor)	β_2	0.034**	Labor	α_2	0.02***
Ln (nit)	β_3	0.089***	Nitrogen	α_3	0.0003**
Ln (water)	β_4	0.248***	Water	α_4	0.004***
R^2	0.50		R^2	0.49	
F-ratio	30.00**		F-ratio	22.80**	
Rice					
Intercept	β_0	0.022	Intercept	α_0	0.691
Ln (seeds)	β_1	0.334***	Seeds	α_1	0.014***
Ln (labor)	β_2	0.099**	Labor	α_2	0.013**
Ln (nit)	β_3	0.101**	Nitrogen	α_3	0.008***
Ln (water)	β_4	0.346**	Water	α_4	0.002**
R^2	0.46		R^2	0.48	
F-ratio	24.00**		F-ratio	26.90**	
Maize					
Intercept	β_0	0.078	Intercept	α_0	1.184
Ln (seeds)	β_1	0.24***	Seeds	α_1	0.049**
Ln (nit)	β_2	0.08**	Nitrogen	α_2	0.003***
Ln (phos)	β_3	0.057**	Phosphorus	α_3	0.03**
Ln (water)	β_4	0.34**	Water	α_4	0.0004**
R^2	0.80		R^2	0.81	
F-ratio	36.40**		F-ratio	37.50**	
Cotton					
Intercept	β_0	0.013	Intercept	α_0	0.37**
Ln (seeds)	β_1	0.563***	Seeds	α_1	0.011***
Ln (nit)	β_2	0.973***	Nitrogen	α_2	0.02***
Ln (phos)	β_3	0.021**	Phosphorus	α_3	-0.001***
Ln (labor)	β_4	0.001**	Labor	α_4	-0.001***
Ln (water)	β_5	0.24**	Water	α_5	0.00008***
R^2	0.85		R^2	0.87	
F-ratio	483.60**		F-ratio	356.78**	

Source: Own elaboration based on survey data (2013).
*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

The elasticity coefficient of water (0.34) was the highest among other factors indicating that water is the major determinant of maize output followed by seeds (with 0.24), while nitrogen and labor have small influence on maize production. This suggests that maize farmers in the study area can increase their maize output by increasing the using efficiency of water and nitrogen. For the cotton production function, the results showed that all inputs are positive and significant at 5 and 10% level. The R^2 of 0.85 indicates that 85% of variation in the cotton production in the area is explained by the use of seeds, nitrogen, phosphorus, labor and water but with different magnitudes. Nitrogen application, seeds and water are the main determinant of cotton production, while labor and phosphorus have small effect. The total production elasticity is about 1.79 indication increasing return to scale of cotton production in the area.

Opportunity costs of irrigation water

The average and marginal physical products, production elasticities of the irrigation water, farm-gate prices and the marginal monetary (value) products of the five studied crops are presented in Table 3. Empirical findings from the linear production function indicates the production elasticities of the irrigation water are positive and less than one. This means that production increases at a decreasing rate, and the average and marginal physical product are declining, and the farmers can increase their production of the studied crops by using more irrigation water until the marginal products of irrigation water are equal zero.

Therefore, irrigation water productivity for berseem, wheat, rice, cotton and maize crops were relatively low, i.e. 9.4 kg m^{-3}, 1.9 kg m^{-3}, 0.7 kg m^{-3}, 0.4 kg m^{-3}, 1.2 kg m^{-3}, respectively. On the other hand, marginal productivity of irrigation water for the studied crops was positive. This implies farmers could increase their production by using more irrigation water until the marginal products of irrigation water is zero. Therefore, the optimum input/output combination for the farmer will be in stage-II. Indeed, the marginal monetary products of irrigation water for all the studied crops are relatively low (i.e. less than one Egyptian pound[3]/kg). This means that the volumetric effective water applied (irrigation) as farmers can provide excessive irrigation in certain periods of the crop season, resulting in losses. It is clear that there is ample scope for improving water productivity in irrigated agriculture through improved and known water management practices.

Influence on water and nitrogen on yield

In order to help farmers on optimizations of the inputs use in their farms, this section discusses the isoquant curves and their use in the economic modeling of the firm. How these curves are designed, and the economic interpretation of each of these curves for the selected crops is presented. The following section then examines their use in determining the optimal combination between the water and nitrogen use for a farm to choose in its production process.

Substituting the averages of quantities of seeds used, labor, and quantity produced of the selected crops (wheat, rice, maize, cotton and berseem) is analyzed. The relationship between the quantities used of nitrogen and irrigation water which yields the same level of wheat (rice, maize, cotton and berseem, respectively) can be estimated using the following equations (Table 4).

Table 3. Elasticities of production, average and marginal physical products, farm-gate prices and value of marginal products of irrigation water during the cropping season 2011-2012 (CD production function)

Crops	Production elasticity	Average physical product (kg m^{-3})	Marginal physical product (kg m^{-3})	Farm-gate price (LE/kg)	Marginal monetary (value) product (LE/kg)
Berseem	0.32	9.40	2.96	0.29	0.85
Wheat	0.25	1.90	0.47	2.42	1.14
Rice	0.35	0.70	0.24	1.87	0.45
Cotton	0.24	0.40	0.10	7.72	0.74
Maize	0.34	1.20	0.40	1.39	0.56

Source: Compiled and calculated from field survey, 2011/2012.

[3] 1 Egyptian pound = 0.13 US$ (Average Jan-Sep 2015).

Table 4. Isoquant curves equation results (water versus nitrogen)

Crops	Isoquant curves: water vs. nitrogen
Wheat	$wat_w = (1.1\ (nit_w)^{-0.089})^{1/0.248}$
Rice	$wat_r = (3.22\ (nit_r)^{-0.1})^{1/0.346}$
Maize	$wat_m = (2.51\ (nit_m)^{-0.075})^{1/0.337}$
Cotton	$wat_c = (111.69\ (nit_c)^{-0.973})^{1/0.240}$
Berseem	$wat_b = (11.69\ (nit_b)^{-0.568})^{1/0.315}$

Source: Compiled and calculated from field survey, 2011/2012.

The previously estimated relationship between nitrogen fertilizer and irrigation water for the six selected crops can be illustrated in the following figures (Fig. 1-6). For the analysis of this relationship, the MRTS was used. The assessment of the figures below indicates that the MRST among the nitrogen and irrigation water is declining for the six studied crops.

It is clear that from an agronomic perspective, pesticides are typically complementary to water use. However, our results show a substitution relationship, which indicates one possible fact that liquid pesticides are diluted excessively with increased irrigation application. Our results are in concordance with the findings of Cai *et al.* (2008). Indeed, both water and nitrogen are subjected to losses by many pathways if not managed properly. Therefore, there is a considerable interest in strategies that enhance nitrogen use efficiency and productive use of applied irrigation water leading to increased productivity.

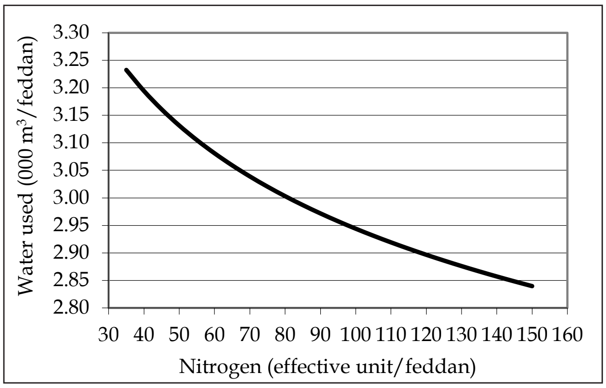

Fig. 1. Relationship between nitrogen and irrigation water in wheat production (Source: Own elaboration 2014).

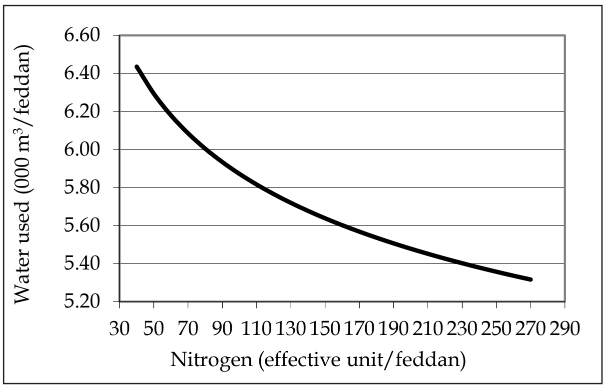

Fig. 2. Relationship between nitrogen and irrigation water in rice production (Source: Own elaboration 2014).

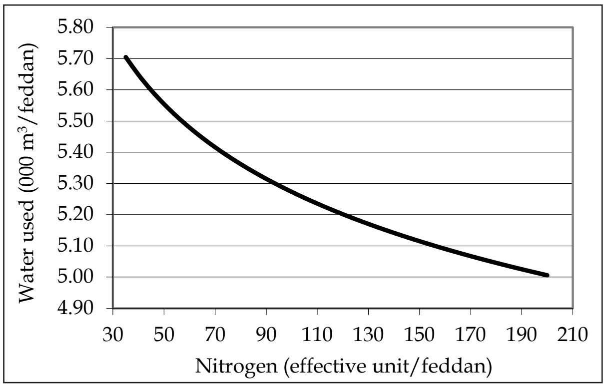

Fig. 3. Relationship between nitrogen and irrigation water in maize production (Source: Own elaboration 2014).

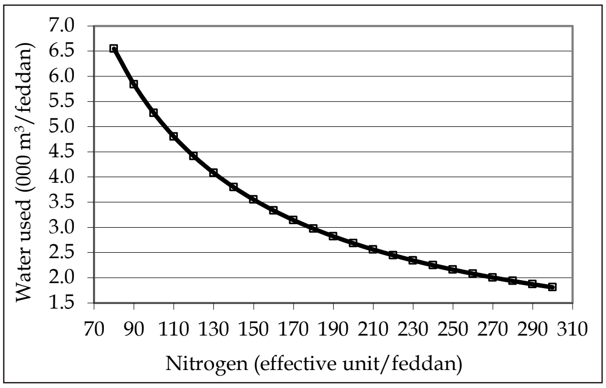

Fig. 4. Relationship between nitrogen and irrigation water in cotton production (Source: Own elaboration 2014).

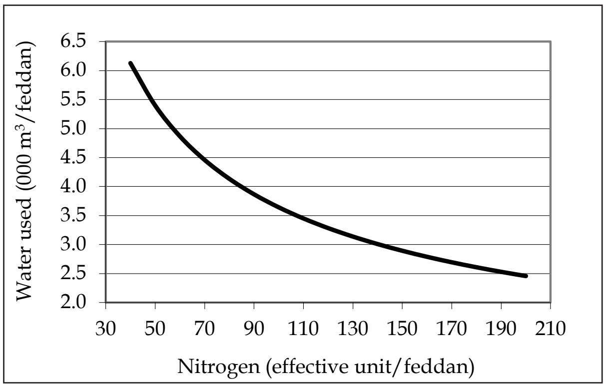

Fig. 5. Relationship between nitrogen and irrigation water in berseem production (Source: Own elaboration 2014).

Concluding Remarks and Policy Implications

This paper aims to estimate the impacts of the main primary production factors (e.g. seeds, nitrogen, phosphorus, irrigation water) on the total production of wheat, rice, cotton, maize and berseem crops with special emphasis on the examination of the potential substitution between water and other agricultural inputs (such as nitrogen). This analysis was conducted through an empirical analysis using a linear and Cobb Douglas production function using survey data from 150 farms located in two villages in Sharkia governorate, Egypt; and taking into consideration farmers' objectives about crop yield, production and net profit in their own farms.

Based on the empirical findings of this study, few conclusions can be drawn:

- The correlation coefficient matrix show a positive and significant relationships between the quantities produced of studied crops (i.e. wheat, rice, cotton, maize and berseem) and the quantities used from seeds, nitrogen and phosphorus fertilizers, labor, and irrigation water.
- Returns to scale for berseem and cotton production are increased but the returns to scale for wheat, rice and maize production are decreased.
- Irrigation water consumption for studied crops are economic utilization stage where the production elasticities of the irrigation water input are positive and less than one.
- Irrigation water productivity in wheat, rice, cotton and maize crops are relatively low.
- The marginal productivity to irrigation water for the studied crops are quite low, especially for cotton. This means the farmers can increase their production of the studied crops by using more irrigation water until the marginal products of irrigation water equal zero.
- The values of marginal products for irrigation water in berseem, wheat, rice, cotton and maize production are 0.09 LE M^{-3}, 0.60 LE M^{-3}, 0.64 LE M^{-3}, 1.85 LE M^{-3} and 0.46 LE M^{-3}, respectively.
- The marginal rates of technical substitution among the nitrogen and irrigation water in the five selected crops production are decreasing but with different degrees across these crops. These results imply that, given the substitution level between water and nitrogen, there would be profitable to focus on crops where the level of substitution is low (e.g. wheat and maize) through long term strategies that enhance nitrogen use efficiency and productive use of applied irrigation water leading to increase productivity.

These findings indicate that wheat, rice and maize farmers in the study area are technically inefficient regarding the use of farm resources. This could be as a result of high cost of fertilizers, seeds, and herbicides and/or their availability at the optimal time. The berseem and cotton farmers are more efficient on the use of resources. This implies that technical efficiency of wheat, rice and maize production could be enhanced through better use of such inputs.

Water and seeds are found to be the highest influential factors for the production of the five crops. To ensure efficiency in the use of resources in the five crops production in the target area, concerted efforts from farmers, research, extension and governmental institutions is highly imperative. This implies that farmers should increase their efforts for better management of water use. Research institutions should intensify efforts on these crops in order to have improved varieties that give high farm yield. The government should ensure that farm inputs are made available to the farmers at the right time and at appropriate prices.

Finally, information about substitution and complementarity of inputs with respect to water can be important for policy design in agriculture and water management. Indeed, complementarity between water and nitrogen fertilizer implies a more efficient use of both inputs under improved water management. For the Egyptian case, and in areas with water stress caused by several factors (mainly salinity), substitution between water and nitrogen could provide an opportunity to save agricultural water, which can be transferred to urban uses, where economic returns are generally higher.

The results in this study has provided relevant information for developing efficient use of inputs mainly irrigation to improve crop water productivity and help to maintain sustainable development of agriculture in the studied area. In fact, it provides strong support for continuing investment in irrigation infrastructure in Egypt. Although water resources are limited and scarce in Egypt, great efforts have been and are being conducted to increase water use efficiency and water productivities.

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