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Nexus of Crop Water Productivity to Sources of Irrigation Water: the Case of Wheat Farms in Egypt and Sudan

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Keywords

Water productivity, wheat, Egypt, Sudan, Endogenous switching regression.

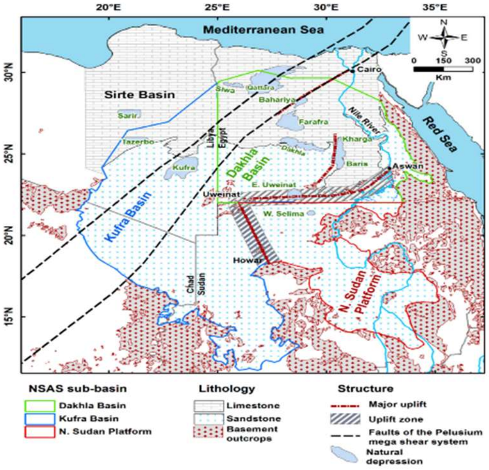
Abstract

With the advance of climate change, population growth, and competition for limited water supply, efficient utilization of water resources in Egypt and Sudan has become of more pertinent than ever. This study aims to compare the impacts of source of irrigation water on water productivity (WP) of wheat in both countries. Endogenous switching regression was applied to data from a systematic sample of 1,272 wheat growing farms to identify the determinants of the choice of water source and its impact on WP in both countries.

Results show that 23% and 3% of wheat farms are irrigated from underground water with an average WP of 0.899 and 0.137 kg per m^3 of wheat in Egypt and Sudan, respectively. WP which is 0.039 kg/m^3 higher was attributed to irrigation from the Nile in Egypt while in Sudan, underground water led to the 0.072 kg/m^3 higher WP relative to the use of irrigation water from the Nile. Adoption of improved production technologies such as the recommended number and interval of irrigations and the use of recommended input levels were significant determinants of WP in both countries. Membership in cooperatives and large schemes led to higher levels of irrigation water withdrawal from the Nile in Egypt while adoption of irrigation technologies, share of wheat in total land holding and amount of water available from the Nile are significant determinants of underground water pumping for wheat production in Sudan. The study recommends focused utilization of underground water and introduction of water saving techniques in Sudan and efficient planning to blend Nile and underground water for wheat self-sufficiency in Egypt.

1. Introduction:

The water subsector is a key element in the “water, energy and food (WEF)” nexus and enhancing its efficient utilization implies better integration and food security (Bekele et al, 2012). Although agriculture plays an important role in the economies of the Nile Basin countries, these countries have not realized the desired levels of food security for various reasons. The total irrigated area in this region is 5.54 million ha, out of which 3.65 million ha is found in Egypt and 1.89 million (World Fact book, 2023). The demand for water in most upstream countries is expected to rise with drastic implications on poverty and food security in downstream countries (Bekele et al, 2012, Wilson, 2007) which determine present and future access to water in the sub-basins (Molden et al., 2003) and incidence of poverty (Kristjanson et al., 2005). Egypt covers very arid regions situated between the Sahara and Arabian deserts (Ahmed, 2009). Water resources in Egypt are limited to the Nile River, limited rainfall and deep groundwater in the deserts and Sinai, and potential desalination of sea and brackish water. Egypt receives about 95% of its fresh water supply from outside its national borders (Abdeen and Gaafar, 2009). Egypt’s municipal, agricultural and industrial water requirements increase with time due to the increase in population and the improvement of living standards. In order to rationalize water use in the agricultural sector, water-intensive crops such as rice and maize were excluded from the cropping pattern “liberalization” in the country.



Water withdrawal from the Nile in the Sudan has increased substantially over the last decades (Muhamed et al, 2023). The highest magnitude of water withdrawal was observed during the last decade (2011–2020). The lack of significant canal and pump system expansion is a major driver of newly built farms being groundwater-dependent despite negative economic incentives (Lahymeyer, 2006). Macalister et al. (2012) estimate that only 60,000 ha out of a potential of 1.4 million ha of Sudan's irrigated area are supplied solely from groundwater. Much of this potential groundwater irrigation area exists within the deserts of the Northern State underlain by the Nubian Sandstone Aquifer. Analysis of the WEF nexus (Babiker et al (2019) showed that the slow improvement in agricultural productivity for Sudan is a consequence of inefficient use of available water and energy resources. The total water resources in Sudan amount to 103.3 billion cubic meters with surface water storage estimated at 21 billion cubic meters in 2011 and is expected to increase to 59.2 billion cubic meters by 2050 with irrigation water needs of 42.5 billion cubic meters (Sudan Policy and Strategy on Integrated Water Resources Management, 2007).

Climate change in Sudan will lead to a reduction in groundwater recharge, reduction in the main winter crop-growing season and increase in crop water requirements (Fragaszy and Closas, 2016). The average temperatures during the flood season and main wheat-growing season are expected to increase over one degree centigrade and up to four degrees (IFAD, 2013). Most of the regional groundwater recharge occurs during the flood peak and so any increase in evaporation will reduce groundwater infiltration (Niestle, 1993). Also, increased winter temperatures will reduce the already short wheat-growing season in the Sudan and increase heat stress, both of which have negative impacts on crop yields (Ageeb, 1994).

A useful indicator of the performance of irrigated farming in water-scarce areas is the crop water productivity (WP) which is defined as the ratio of benefits produced, such as yield, to the amount of water required to produce those benefits (Molden et al., 2010). When multiple crops or land use types are involved, the use of gross margins per cubic meter provides more information. This indicator can further help with planning water allocation among different uses while ensuring water availability for agro-ecosystem functioning (Loeve et al., 2004; Molden et al., 2007). However, when comparing efficiency of water use in a single crop across geographic locations, the use of WP becomes sufficient. Water productivity across all Nile Basin countries is low except for Egypt (Bekele et al, 2012) where high productivity zone includes the delta and irrigated areas along the Nile River in the northern part of the basin. This zone is characterized by intensive irrigation, high yields and high-value crops. These characteristics contribute to the high level of WP attained and are in fact correlated higher income. WP is relatively low in Sudan due to high reliance on rain-fed farming. A good example that shows how irrigation can bring in improvements is the Gezira scheme where irrigation has resulted in significantly higher WP in the scheme compared to its surrounding rain-fed areas (Yasir et al 2011).

Wheat which is a major food security crop, is used to investigate the nexus between water and food in Egypt and Sudan and for comparing WP between water from the Nile and underground sources in both countries. Wheat is the most important cereal crop in Egypt. However, Egypt is not able to produce enough to feed its growing population. According to (MALR, 2009), there are considerable achievements by the government in increasing productivity. However, given the limited scope for expansion of the arable area in the country, this target can be achieved using two complementary approaches namely, raising productivity through agricultural intensification using recommended technology packages involving high yielding varieties and associated agronomic practices and reducing food loss and waste along the entire value chains of wheat (Yigezu et al., 2021a). One major recommendation to increase WP is to adopt a recommended frequency of 3-4 irrigations and the amount of irrigation water in farmer fields not to exceed 5500 m^3/ha per season. This leads to a reduction in the amount of irrigation water of between 25-30%. Similarly, wheat is an important crop in the Sudan contributing largely to its international trade. However, as a result of decreased production and increased demand, Sudan has turned to be net wheat importer with low self-sufficiency ratio that ranged between 20%-39% during 2001-2011. Most recently, the self-sufficiency rate decreased drastically reaching to a minimum of 10% in 2021.

2. Objectives

This study aims to analyze the impact of alternative irrigation water sources on water productivity (WP) in Egypt and Sudan within the “water, food and energy” nexus framework. Our hypothesis is that managing transboundary resources of irrigation water will lead to improved water productivity and food security in a sustainable and rational manner. The estimation of potential water productivity for wheat using irrigation water from the Nile or underground sources will help planning wheat production in both countries under various levels of water stress arising from factors beyond their control. We hypothesize that enhanced food security with higher self-sufficiency rates of wheat can be realized by enhancing water productivity in both countries.

3. Methodology

3.1. Model used

This study uses endogenous switching regression which is an econometric model that specifies a decision process. In this approach, the regression models associated with each decision option in which observations are allocated depend on the value of a latent decision variable relative to a threshold value based on the expected utility.

The endogenous switching regression has been used in many studies recently for its robustness compared to other models. Yigezu and Elshater (2021), Yigezu et al. (2021b, 2019), Kopczuk and Lupton (2007), Arunachalam and Logan (2006), Caudill (2003), Dickens and Lang (1985). These studies have established the feasibility of maximum likelihood and other estimation techniques in this situation. To estimate the treatment effects of a binary variable on count dependent variable, Terza (1998, 2008, 2009) proposed nonlinear models that take into account the nonlinear nature of dependent variable. Terza (1998) considers a model where the binary treatment variable shifts the intercept inside the conditional mean function and provides estimating equations that can be implemented by using the observable variables. Also in later works, Terza (2008, 2009) extended the earlier model by incorporating the counterfactual framework where the treatment status puts the individual in a different regime. The ESR is widely used in applied studies. Kyriazidou (1997) proposed a two-step estimation method which provides consistent and asymptotically normal estimators for estimating a panel data sample selection model with latent individual specific effects in both the selection and regression equations. In the first step, the unknown coefficients of the selection equation are consistently estimated and in the second stage, the estimates are plugged into the regression equation of interest. In her methodology, the sample selection effect and the unknown coefficients are differenced out from the equation of interest. Barachina and Engracia (1999) likewise introduced a two-step estimation method for a panel data sample selection model with individual specific effects in both the selection and regression equations. The endogenous switching regression model may also be estimated by the full information maximum likelihood method FIML which yield efficient estimators of the model. Terza (1998) used FIML to estimate an endogenous switching regression model with count data as well.

Studies which employ the endogenous switching regression are reasonably documented in the literature, (Gronau (1974, Lewis, 1974, Heckman, 1974, Lee and Trost, 1978, Charlier, Melenberg and van Soest, 2001, Willis and Rosen, 1979). However, Mundaca (2001) and Gowrisankaran and Town (1999) also documented its shortcomings with small samples in which it yields biased estimators of the regression coefficients. Nawata and McAleer (2001) demonstrated that the finite sample problem with the t-test is alarming and more severe for binary choice and sample selection models. This emphasizes the need for avoiding the use of ERS with small sample sizes.

The endogenous switching model can be specified in the reduced form as follows (Mare and Winship, 1988).

$$Z_i^* = \sum_k \pi_k X_{ki} + \varepsilon_{1i} \qquad (1)$$

$$Y_{0i} = \sum_k \beta_{0k} X_{ki} + \varepsilon_{2i} \qquad (2)$$

$$Y_{1i} = \sum_k \beta_{1k} X_{ki} + \varepsilon_{3i} \qquad (3)$$

Where,

i denotes the household id (i=1,…,n).

Z_i is a dichotomous variable equal which takes a value of 1 for irrigation from the Nile and 0 from underground water with a latent tendency Z_i^* that indexes the likelihood to select either options.

Y_i is the outcome variable that takes two values Y_0 and Y_1 for Irrigation from the Nile and underground water pertaining to the same individual, i.

X_{ki} is the on the k*th* measured independent variable (k = 1,…,k).

β_{0k} and β_{1k} are parameters to be estimated.

ε_{2i} and ε_{3i} denote stochastic disturbances.

The interest of this model centers on the expected difference between the two outcomes namely $E(Y_1)$-$E(Y_0)$

Although two outcomes are hypothesized for each individual, but only one outcome is observed, and the other outcome is a counterfactual. The objective of studying treatment effects call for the knowledge of counterfactual outcomes for both participants and non –participants. Comparison of the coefficients across equations 3 and 4 yields the treatment effects conditional on the covariates (Mare and Winship, 1988).

Sample-selection and disequilibrium models belong to the general class of switching models with the switch determined endogenously (Maddala and Nelson, 1975). A decision whether or not to adopt a new technology may be based on productivity gains and cost of adoption.

3.2. Data

A systematic sample of 1272 wheat farmers (691 from Egypt and 581 from Sudan) were selected and interviewed during 2016. The total sample size and sub-samples from each source of irrigation is shown in Table 1. Irrigation from the Nile is dominant, comprising 77% and 92% of water supply sources for wheat growing households in Egypt and Sudan, respectively. Underground water is drawn from shallow or deep wells depending on scheme location while irrigation from the Nile is mostly organized through irrigation schemes and agricultural cooperatives in both countries. The survey was carried out during wheat growing season of 2016 at the same time in Egypt and Sudan.. Version 15 of the Stata software (Stata Corp LP, College Station, TX, USA) was used for all econometric estimation in this study.

Table 1: Sample distribution of wheat farmers by source of irrigation in Egypt and Sudan. 2016.

Country	Source of irrigation water		
	Nile	Underground	Total
Egypt	532	159	691
Sudan	526	55	581
Total	1058	214	1272

Source: Field survey, 2016.

4. Results and discussion

Some descriptive statistics on the major characteristics of the wheat farming households are presented in Tables 2 and 3. The average farm area in Sudan which is 3.5 ha is higher than the 1.15 ha in Egypt. Similarly, the average area cultivated with wheat was 2.80 ha in Sudan compared to 0.88 ha in Egypt where wheat life cycle is longer compared to Sudan (153 days on average versus 115 days in Sudan) as winter season extends in Egypt beyond that in Sudan thereby offering more time for non-stressed vegetative growth required by the crop.

Table 2: Farm and water use characteristics of wheat producing farms in Egypt and Sudan, 2016

Source of irrigation water	farm area (ha)		wheat area (ha)		wheat life cycle (days)	
	Egypt	Sudan	Egypt	Sudan	Egypt	Sudan
The Nile	1.20	3.0	1.10	2.20	155	120
Underground```	1.10	4.0	0.66	3.40	150	110
Average	1.15	3.50	0.88	2.80	153	115

Source: Field survey, 2016.

As shown in Table 2, more land is allocated for wheat from underground water compared to irrigation from the Nile in Sudan (3.4 ha and 2.2 ha, respectively) unlike the situation in Egypt where irrigation from the Nile is more dominant (1.1 ha versus 0.66 ha, respectively). Wheat crop is irrigated more frequently in Sudan (Table 3) leading to higher number of irrigations per season (6 irrigations in Sudan and 4 in Egypt). As a result, and also due to the higher amount of applied water per unit area, the total quantity of water applied per season is significantly higher in Sudan (5667 m^3/ha) compared to Egypt (1156 m^3/ha). More water is pumped from underground sources in Sudan compared to irrigation from the Nile (6664 m^3/ha and 4760 m^3/ha from each source, respectively. This is unlike the situation in Egypt where more water is pumped from the Nile (1178 m^3/ha) compared to underground water (1133 m^3/ha). Irrigation intervals follow similar patterns to the number of irrigations in both countries, where irrigation cycle using Nile water is longer than that of underground water, the situation for Sudan is different with more irrigation cycle occurring with underground water compared to pumping from the Nile.

Table 3: Description of irrigation practices of wheat producing farms in Egypt and Sudan, 2016

Source of irrigation water	number of wheat irrigations (Av.)		Water quantity (m^3/ha)		Irrigation interval (days)	
	Egypt	Sudan	Egypt	Sudan	Egypt	Sudan
The Nile	4	5	1178	4760	22	13
Underground	4	7	1133	6664	21	14
Average	4	6	1156	5667	18	14

Source: Field survey, 2016.

The results of endogenous switching regression are presented in Tables 4 and 5 and predicted average water productivities and comparisons of means in Tables 6 and 7. There is a significant influence of farmer’s membership in agricultural cooperatives on the decision to use Nile water to irrigate wheat in Egypt, probably due to their well-coordinated efforts and some historical rights and experience of the cooperatives to utilize Nile water. This influence is insignificant for Sudan. All other tested factors were not significant determinants of the decision to irrigate from the Nile in Egypt, whereas time taken to complete one irrigation cycle, and farmer's age significantly increased the likelihood to use Nile water, while commitment to the recommended number of irrigations and shortage of laborers for irrigation at the field level are associated with higher likelihood to use underground water in Sudan.

Table 4: The estimated endogenous switching regression of wheat producing farms in Sudan, 2016

	Coefficient	SE ±	Z	P>|z|	[95% Conf. Interval]	
Water Productivity 0						
Age category (0=young farmers)	-0.13449	0.045073	-2.98	0.003	-0.22284	-0.04615
Apply irrigation recommendation	-0.02268	0.02641	-0.86	0.391	-0.07444	0.029085
Wheat/farm area (%)	-0.11346	0.037707	-3.01	0.003	-0.18736	-0.03955
Attend water managt. t field days	0.143505	0.027636	5.19	0	0.08934	0.19767
Participation in technology transfer	0.109601	0.042586	2.57	0.01	0.026135	0.193067
Experience (years)	-0.00723	0.002423	-2.98	0.003	-0.01198	-0.00248
Use recommended irrigation frequency	-0.02112	0.029354	-0.72	0.472	-0.07866	0.036409
Constant	0.407446	0.074636	5.46	0	0.261162	0.553731
Water Productivity 1						
Age category	0.014331	0.010605	1.35	0.177	-0.00645	0.035116
Apply irrigation recommendation	0.016637	0.01375	1.21	0.226	-0.01031	0.043586
Wheat/farm area (%)	0.060331	0.020002	3.02	0.003	0.021129	0.099534
Area under irrigation (ha)	-0.00208	0.0029	-0.72	0.473	-0.00776	0.003603
Attend water Managt. field days	-0.03678	0.011721	-3.14	0.002	-0.05976	-0.01381
Participation in technology transfer	0.060506	0.010619	5.7	0	0.039694	0.081319
Experience (years)	-0.00028	0.000324	-0.86	0.392	-0.00091	0.000357
Use recommended irrigations	0.000189	0.014561	0.01	0.99	-0.02835	0.028729
Constant	0.085373	0.022831	3.74	0	0.040624	0.130121
Cost of irrigation (SDG/ha)	-0.00701	0.004924	-1.42	0.155	-0.01666	0.002641
Cooperative membership	0.632832	1.18	0.238	-0.49361	1.987045	
Age (years)	0.024559	0.014482	1.7	0.09	-0.00383	0.052943
Number of irrigation workers	-0.76364	0.375381	-2.03	0.042	-1.49937	-0.0279
Wheat/farm area (%)	1.105058	0.273084	4.05	0	0.569823	1.640293
Time of one irrigation (days)	-0.0612	0.016715	-3.66	0	-0.09396	-0.02844
Total cost of irrigation (SDG)	-0.00065	0.000797	-0.82	0.413	-0.00221	0.000909
Days per one irrigation	0.311939	0.093706	3.33	0.001	0.128278	0.495599
Use of irrigation frequency	0.692504	0.436555	1.59	0.113	-0.16313	1.548137
Age category	1.143155	0.315876	3.62	0	0.524051	1.76226
Use recommended irrigation	-1.72391	0.888234	-1.94	0.052	-3.46482	0.016993
Constant	4.214641	3.346182	1.26	0.208	-2.34376	10.77304
/lns0	-3.00827	0.167071	-18.01	0	-3.33572	-2.68082
/lns1	-2.36854	0.029527	-80.22	0	-2.42641	-2.31067
/r0	-7.5827					
/r1	7.713414					
sigma0		0.049377	0.035589	0.068507		
sigma1		0.093617	0.088353	0.099195		

Number of orbs = 586, Wald chi^2 (7) = 95.88, Log likelihood = 566.04514 and Prob > chi^2 = 0.0000

Source: Field survey, 2016.

Once a decision has been taken on the source of irrigation, higher water productivity is significantly realized in farms with higher percentage of wheat within the crop mix, regular attendance of technology transfer and water management sessions in Sudan while relatively young farmers and farmers who apply water less than the recommended attain higher water productivity levels in Egypt.

Table 5: The estimated endogenous switching regression of wheat producing farms in Egypt, 2016

		Std Err.	Z	P>|z|	[95% Conf. Interval]	
Water Productivity 0						
Water quantity (m^3)	-0.00055	2.42E-05	-22.73	0	-0.0006	-0.0005
Age (years)	-0.0007	0.000518	-1.35	0.177	-0.00171	0.000316
Wheat area (ha)	-0.00702	0.005874	-1.19	0.232	-0.01853	0.004496
Number of total irrigations	0.073869	0.016517	4.47	0	0.041496	0.106241
Constant	1.841038	0.093841	19.62		1.657112	2.024963
Water Productivity 1						
Water quantity (m^3)	-0.00052	2.33E-05	-22.39	0	-0.00057	-0.00048
Age (years)	-0.00088	0.000468	-1.88	0.06	-0.0018	3.71E-05
Wheat area (ha)	0.001564	0.000947	1.65	0.099	-0.00029	0.003421
Number of irrigations	0.102288	0.011484	8.91	0	0.079781	0.124796
Constant	1.670783	0.062487	26.74	0	1.548312	1.793255
Selection equation						
Total area (ha)	0.01636	0.011621	1.41	0.159	-0.00642	0.039137
Number of irrigations	-0.11809	0.125536	-0.94	0.347	-0.36413	0.127957
Cooperative membership	-0.8938	0.340595	-2.62	0.009	-1.56136	-0.22625
Age (years)	0.007706	0.005029	1.53	0.125	-0.00215	0.017563
Constant	1.686465	0.763173	2.21	0.027	0.190674	3.182257
/lns0	-2.59171	0.056072	-46.22	0	-2.70161	-2.48181
/lns1	-2.23564	0.035939	-62.21	0	-2.30608	-2.1652
/r0	-0.13444					
/r1	-0.25193	0.163142	-1.54	0.123	-0.57168	0.067821
sigma0	0.074892	0.004199	0.067097	0.083592		
sigma1	0.106924	0.003843	0.099651	0.114727		
rho0	-0.13364	.	-1	1		
rho1	-0.24673	0.153211	-0.5166	0.067717		

Number of obs = 691 Wald chi^2(4) = 563.70 Log likelihood = 263.902 Prob > chi^2 = 0.0000
LR test of indep. eqns. : chi^2(2) = -0.02 Prob > chi^2 = 1.0000
Source: Field survey, 2016.

The change in water productivity is summarized in Tables 6 and 7. The conventional t test for mean differences shows that water productivity is higher for Nile schemes in Egypt and for underground schemes in Sudan. The reason is that excessive water is used with Nile irrigation in Sudan compared with underground water pumping and this result is consistent with the descriptive statistics presented in Table 1.

Table 6: Mean comparison of water productivity by source of irrigation in Egypt, 2016

Source	Count	Mean	Std. Error	Std. Deviation	[95% Conf. Interval	
Nile	532	0.919323	0.004513	0.104097	0.910457	0.928189
Underground	532	0.879579	0.004997	0.115253	0.869763	0.889395
Combined	1064	0.899451	0.00342	0.111551	0.892741	0.906161
Difference		0397438***	.0067333		.0265317	.0529558

Source: Field survey, 2016.
Symbol *** indicates significant difference at 0.01 level.

An average of 0.039 kg/m^3 can be added in wheat water productivity when Nile water is used instead of underground water under the current conditions in Egypt. On the contrary, 0.0486 kg/m^3 can be added in Sudan when using ground water instead of the Nile water. In general, the average water productivity in wheat is higher in Egypt compared to Sudan because in Egypt, yield is significantly higher and water applied is lower.

Table 7: Mean comparison of water productivity by source of irrigation in Egypt, 2016.

Source	Count	Mean	Std. Error	Std. Deviation	[95% Conf. Interval	
Nile	572	0.161554	0.001407	0.033645	0.158791	0.164317
Underground	572	0.11293	0.005457	0.130504	0.102213	0.123648
combined	1144	0.137242	0.002907	0.098312	0.131539	0.142945
Difference		0.048624***	0056351		0375676	05968

Source: Field survey, 2016.
Symbol*** indicates significant difference at 0.01 level.

Based on the estimated water productivity levels, Table 8 presents the total amount of water required to produce 10 m ton of wheat in Egypt and 2 m ton of wheat in Sudan disaggregated by sources of irrigation water. An amount of 397 million cubic meters of water can be saved in Egypt when using Nile water alone while 97,000 cubic meters can be saves in Sudan using underground water as a source of irrigation water. The reason of this disparity is that water use efficiency is higher in Egypt compared to Sudan.

Table 8: Estimated mounts of water to realize wheat self-sufficiency in Egypt and Sudan.

Sudan	Source	WP (kg/ m^3)	WR (m^3 /ton)	Water for wheat target
Egypt	Nile	0.919323	919	9,193,230
	Underground	0.879579	880	8,795,790
	Average	0.899451	899	8,994,510
	Difference	0.03974	39	397,440
Sudan	Nile	0.161554	162	323,108
	Underground	0.11293	113	225,860
	Average	0.137242	137	274,484
	Difference	0.04862	49	97,248

Source: Calculated based on field survey, 2016.

5. Conclusion and recommendations

This study aims to analyze the impact of alternative sources of water on water productivity (WP) in Egypt and Sudan. In order to compare the impacts of irrigation from the Nile and underground water sources on water productivity of wheat, the endogenous switching regression method was applied to data from a systematic sample of 1,272 wheat growing farms to identify the determinants of resource selection and its impact on WP in both countries. Water productivity is significantly realized in farms with higher percentage of wheat within the crop mix, regular attendance of technology transfer and water management sessions in Sudan while relatively young farmers and farmers who apply less water than what is recommended attain higher water productivity levels in Egypt, showing that recommended water levels are not optimal. An average of 23% and 3% of wheat farms are irrigated from underground water with an average water productivity of 0.899 and 0.137 kg per m^3 of wheat in Egypt and Sudan, respectively. Irrigation from the Nile significantly increases water productivity by 0.039 kg/m^3 in Egypt while the gain is 0.072 kg/ m^3 for underground water in Sudan. Higher water productivity is significantly attributed to adoption of improved production technologies such as the recommended number and interval of irrigations and the use of recommended input levels in both countries. Membership in cooperatives and large schemes was found to be an important determinant that significantly increases irrigation from the Nile water in Egypt while adoption of irrigation technologies, wheat area percentage and adequacy of Nile water supply are significant determinants to use underground water in Sudan. The study recommends increased utilization of underground water and introduction of water saving techniques in Sudan and efficient planning to blend Nile and underground water for wheat self-sufficiency in Egypt. Egypt can also save irrigation water from the Nile by revising down the recommended irrigation water application levels.

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