American-Eurasian J. Agric. & Environ. Sci., 13 (8): 1114-1123, 2013
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2013.13.08.11019

The Impacts of an Improved Technology Package on Production Efficiency: The Case of Wheat Farms in the Northern State of Sudan

[1]*Elrashid A. Fageer,* [2]*Boubaker Dhehibi,* [2]*Ahmed Mazid,*
[3]*Abdalraheem A. Hussein and* [2]*Aden Aw-Hassan*

[1]Agricultural Economics and Policy Research Center (AEPRC),
Agricultural Research Corporation (ARC), P.O. Box: 35, Dongola, Sudan
[2]Social, Economic and Policy Research Program (SEPRP), International Center for
Agricultural Research in the Dry Areas (ICARDA), P.O. Box: 950764, Amman 11195, Jordan
[3]Wheat Research Program (WRP), Agricultural Research Corporation (ARC),
P.O. Box: 30, Wad Medani, Sudan

Abstract: Technical efficiency among wheat farms in the Northern State of Sudan was estimated using a stochastic frontier production function approach. Empirical findings show that technical inefficiency is important in explaining the variations in yield among a sample of 100 wheat farms. Specifically, there was an average yield difference of 23% that can be bridged in the short-run only by removing the causes of inefficiency among farms. Average technical efficiency among improved technology package adopters is 94%, which is quite higher than the 67% of non-adopters. Technical efficiency was 96% for participant farmers and 72% for non-participant farmers in the 'Enhancing Food Security in Arab Countries' project. The average yield losses because of inefficiency are 0.5 ton ha^{-1} for adopters and 3.8 ton ha^{-1} for non-adopters. Proper extension services, farmer training and availability of finance are the most significant factors that affect technical efficiency in the study area. At the current levels of input use, an average loss of about 1.47 ton ha^{-1} could be prevented by improving the extension services and technology transfer activities. These results have important policy and institutional implications for governments, non-governmental organizations and extension agents working in the area as it could guide their decisions and areas of focus in the future.

JEL Classification: C21, D24, Q12.
Key words: Wheat · Stochastic frontier production function · Cobb-Douglas function · Technical efficiency · Northern State of Sudan

INTRODUCTION

According to the national statistics of Sudan, the average annual production of wheat for the period 2006-2009 was about 578,000 ton and the average wheat area harvested was 290,000 ha. About 99% of this area was cultivated mainly on irrigated farms in central and northern Sudan. Wheat yield varied from 1.5 ton ha^{-1} to 2.1 ton ha^{-1} [1]. The Northern State (lying between 16°and 2°N and 30° and 32°E) is the most important region for wheat production in Sudan. It has the coolest and longest winter season in the country, providing lower stress conditions for vegetative and reproductive growth of the crop as compared with other parts of Sudan. Wheat is one of the most important cereals produced and consumed in the northern region and it is the main staple cereal in urban areas. It is produced almost exclusively under irrigation and occupies the largest area in the irrigated system [2]. In previous years, a remarkable expansion had been reported in wheat consumption because of the high rate of growth of the population, rural to urban migration, increasing awareness of consumers about nutrition and subsidized imported wheat. This led to an increase in the gap between local production and

Corresponding Author: Boubaker Dhehibi, Social, Economics and Policy Research Program (SEPRP); International Center for Agricultural Research in the Dry Areas (ICARDA). P.O. Box: 950764 - Amman 11195, Jordan.
Tel: (+962) (6) 5903120, Fax: (+962) (6) 5525930.

consumption [3]. As with many developing countries, the Sudan depends on small-scale farms to produce wheat. Nonetheless, wheat production has decreased in recent years compared with faba bean and other winter crops, which provide acceptable financial profit for small-scale producers in the Northern State of Sudan [4].

Wheat production in Sudan is characterized by low productivity and a high cost of production as a consequence of the low rate of adoption of improved production technologies. The lack of quality seed of improved varieties, insufficient application of fertilizers and irrigation water, plus poor adoption of improved weed and pest control practices are important factors causing low wheat productivity at the farm level. Sowing wheat outside the recommended dates and a low rate of adoption of the recommended crop management practices package have also led to the presence of a wide gap between farmers' and potential productivity levels [5].

It is within this framework that his study was carried out as part of the activities of the "Enhancing Food Security in the Arab Countries (EFSAC)" project jointly implemented by the Agricultural Research Corporation (ARC) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The project is designed to narrow the gap between researchers' and farmers' crop productivity levels by disseminating improved wheat production technologies demonstrated on-farm under the supervision of national research and extension agencies.

Therefore, the main research questions addressed in this study are:

- What is the efficiency level of wheat farmers in the Northern State in using inputs to produce a given level of wheat yield?
- Which factors have the most important influence on technical efficiency in wheat production in the Northern State of Sudan?
- What is the impact of adopting the improved wheat production package recommended by the ARC on wheat yield in the Northern State of Sudan?

As mentioned above, the primary objective of this study is to measure farm-specific technical efficiency (TE) for a sample of wheat farmers and identify the sources of inefficiency between full package adopters and non-adopters. This was addressed by investigating the socioeconomic characteristics of farmers and checking whether these influence the farmers' level of TE. Another objective of this work was to formulate some recommendations for stakeholders, such as farmers, researchers, extension agents and policy makers, to improve wheat production in Sudan.

The remainder of the paper is organized as follows. Section 2 presents the theoretical background of the stochastic frontier model and describes the data analysis and empirical models assumed for the north Sudan sample of wheat farms. Section 3 presents and discusses the empirical results and the last section contains the main concluding remarks, emphasizing the implications for public policy.

MATERIALS AND METHODS

Theoretical Background: In order to achieve the outlined objectives, this study used a stochastic frontier production function (SFPF) analysis to estimate the production function and TE at the farm level. The stochastic frontier production model proposed by Aigner *et al*. [6] and Meeusen and Van Den Broeck [7] was widely applied in the analysis of farm-related cross-sectional data. The advantage of this approach over other non-parametric approaches, such as the data envelopment analysis (DEA) method, is that it includes a measurement error in its specification and estimation of the frontier production function. The SFPF differs from the traditional production function in that the former consists of two error terms. The first error term accounts for the existence of technical inefficiency and the second accounts for other factors beyond the control of the producer, such as measurement error in the output variable, weather and the effects of unobserved exogenous factors on production.

The frontier production function model is based on the stochastic efficiency model developed by Parikh and Shah [8], which is based on the composed error model of Aigner *et al.* [6], Meeusen and van den Broeck [7] and Forsund *et al.* [9]. The frontier production model begins with a stochastic production function with a multiplicative disturbance term of the form:

$$Y_i = f(X_{i,} \beta)\ \varepsilon_i(v, u) \quad (1)$$

where Y_i is the quantity of agricultural output; X_i is a vector of input quantities; β is *a* vector of parameters and ε_i is a stochastic disturbance term consisting of two independent elements, u and v.

The error component, v, accounts for the random variation in output arising from factors outside the farmer's control, such as weather and diseases. It is assumed to be independently and normally distributed as $N(0, \sigma^2_v)$. u_i is a one-sided component. The value of u_i determines the presence or absence of TE. A value of $u \geq 0$ reflects the presence of a certain degree of technical inefficiency relative to the SFPF. Thus, $u = 0$ for a farm the output of which lies on the frontier and $u \leq 0$ for one whose output is below the frontier. The error term variance (σ^2) of ε is, therefore,

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \quad (2)$$

Battese and Corra (1977) [10] define γ as the total variation in output from the frontier which is attributed to differences in TE. That is:

$$\gamma = \sigma_u^2/\sigma^2 \quad (3)$$

where, the parameter γ has a value that falls between zero and one. If the estimate for the variance parameter, γ, is significantly different from zero it implies the presence of significant inefficiency effects affecting the level and variability of output. The measurement efficiency score at the individual farm level can be obtained from the error term $\varepsilon = u + v$ [11]. For each farm, the measure is the expected value of u conditional on ε. That is:

$$E(u|\varepsilon) = \sigma_u \sigma_v/\sigma = \{f(\varepsilon\lambda/\sigma)/1 - F(\varepsilon\lambda/\sigma) - \varepsilon\lambda/\sigma\} \quad (4)$$

where f and F are the standard normal density and distribution functions respectively, each evaluated at $\varepsilon\lambda/\sigma$. The estimated values for ε, λ and σ are used to evaluate the density and distribution functions.

Technical efficiency for each farm can be calculated as:

$$TE = Exp[E(u|\varepsilon)] \quad (5)$$

Recently, a number of studies have been carried out using this approach to estimate TE and to determine the factors that influence the efficiency of farmers, especially in the agricultural sector (Parikh and Shah, [8]; Llewellyn and Williams, [12]; Amaza and Olayemi, [13]; Onumah and Acquah, [14]; Kumbhakar *et al.* [15]; Oyewo, [16]; Edeh and Awoke, [17] and Yigezu *et al.* [18]). These studies have investigated the determinants of TE by estimating the predicted efficiencies obtained from an estimated stochastic frontier on a number of farmer-specific factors, such as age, educational level, access to extension, etc. It is assumed that the inefficiency factors are independently distributed and that u is defined by the truncation of the normal distribution with mean μ and variance σ^2, where u in equation (5) is defined as:

$$u = f(Z_i, \beta, \delta) \quad (6)$$

where Z_i is a vector of farmer-specific factors and δ is a vector of parameters. β and δ are unknown parameters to be estimated.

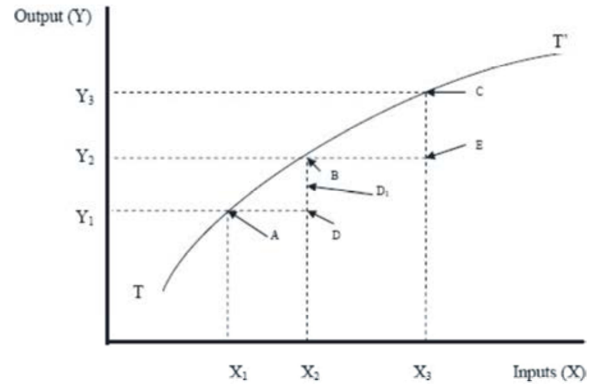

Fig. 1: A production frontier

The output-oriented SFPF approach used to measure efficiency in this analysis can be illustrated as shown in Figure 1.

The horizontal axis represents the inputs used in production while the vertical axis measures the total level of output. The curve TT′ represents the production frontier which is the highest level of output that can be produced given the level of inputs and the available technology. The frontier shows the range of technically efficient options available to farmers. Points A to E in the figure represent the positions of individual farms. For example Farm A uses X_1 level of inputs to produce Y_1 level of output, while Farm E uses X_3 level of inputs to produce Y_2 level of output. Farms A, B and C are equally efficient because they lie on the frontier. All farms that are below the frontier are inefficient. Other farms (such as A and B) show that it is possible to produce the same level of output (Y_1) with less inputs (Farm A), or using the same inputs (X_2) it is possible to produce more output (Farm B).

Technical efficiency identifies the most efficient producers and measures the performance of other producers accordingly. A technically efficient farmer is one who is adopting the best production technologies. Thus, TE is the ratio of actual production to the maximum possible production given the level of inputs used.

Data Collection and Statistical Analysis

Study Area: A stratified sample of 100 farmers was selected to estimate the TE of wheat production in the Northern State of Sudan. Stratification was based on participation in the EFSAC project activities during the growing season 2011/12. Participant farmers followed the improved wheat production package recommended by the ARC. This includes sowing from mid-November to early December using a seed rate of 119 kg ha^{-1} of the recommended improved wheat variety (Imam), applying 238 kg ha^{-1} of urea and119 kg ha^{-1} of triple superphosphate, weed control, using the recommended number of and intervals for irrigation and mechanical harvesting. Structured questionnaires and personal interviews were used to collect the responses from farmers in two projects areas – Elburgeig and Eldafufa (45 km north of Dongola).

The number of farmers surveyed who had project demonstration trials in their fields was 28 and the total area of the demonstration farms was 17 ha. Implementation of the recommended wheat production package was supervised jointly by extension staff from ARC and the Ministry of Agriculture in the Northern State of Sudan.

Descriptive Statistics: Summary statistics of the variables used in the empirical model, including mean, minimum and maximum values and standard deviations and the inefficiency variables are summarized in Table 1. The model variables show high variability among wheat farms being the case for the discrete variables of the inefficiency model. This variation is justified as the different levels of inputs used to produce the wheat represent the different levels of adoption of the recommended package.

Empirical Model: To implement the model, cross-sectional data from 100 wheat producing farms participating in the Elburgeig and Eldafufa projects (northern Sudan) was used. Data on output, production inputs (seed, fertilizer, labor, etc.) and other explanatory variables, such as socio demography (the education level and age of farmers, family size, etc.), socioeconomics (ratio of the wheat area to total crop area, productivity in the previous year, land ownership, etc.) and institutional variables (credit, extension, etc.) were chosen for the empirical analysis.

Given the above, the stochastic frontier production model to be estimated is defined in equation (7) and the technical inefficiency effects are defined in equation (8) as follows:

$$\text{Ln } Y_i = \beta_0 + \beta_1 \text{Ln } K_i + \beta_2 \text{ Ln } L_i + \beta_3 \text{ Ln } F_i + \beta_4 \text{Ln } I_i + \beta_5 \text{ Ln } SR_i + V_i - U_i \quad (7)$$

$$U_i = \delta_0 + \delta_1 FS_i + \delta_2 LA_i + \delta_3 WA_i + \delta_4 PPY_i + \delta_5 WR_i + \delta_6 A_i + \delta_7 TL_i + \delta_8 IS_i + \delta_9 F_i + \delta_{10} RI_i + \delta_{11} PO_i + \delta_{12} RL_i + \delta_{13} ED_i + \varepsilon_i \quad (8)$$

where Y_i is the amount of wheat produced by the i^{th} farm (ton ha^{-1}); K_i is the amount of capital[2] used on the i^{th} farm (SDG ha^{-1}); L_i is the cost of labor on the i^{th} farm (SDG ha^{-1}); F_i is total cost of the fertilizers used on the i^{th} farm (SDG ha^{-1}); I_i is the number of irrigations applications; and SR_i is the seed rate used on the i^{th} farm (kg ha^{-1}).

The variables used in the inefficiency model are the following: FS is family size (persons); LA is total land area (in ha); WA is the cultivated wheat area in the 2011/12 season (in ha); PPY is the productivity of the previous year (ton ha^{-1}); WR is the ratio of the wheat area to the total cultivated area; A is the farmers age (years); TL is a dummy variable that indicates whether the recommended technology package was used[3]. (TL = 1 if the farmer uses the full recommended package, 0 otherwise); IS is a dummy variable which captures the use of improved seeds from reliable sources (IS = 1 if the farmer uses improved seeds, 0 otherwise); F is a dummy variable expressing the availability of a proper credit system (F =1 if there is a proper credit system, 0 otherwise); RI is a dummy variable indicating whether the recommended number of irrigations was used, (RI =1 if the farmer used the recommended number of irrigations, 0 otherwise); PO is a private ownership dummy variable (PO = 1 if the farm is privately owned, 0 otherwise); RL is a dummy variable for rented land (RL = 1 if the land is rented, 0 otherwise); ED is a dummy variable for education (ED = 1 if the farmers is educated, 0 otherwise) and v_i and ε_i are random errors.

[2]Capital refers to the monetary value of the remaining inputs used for wheat production, measured in Sudanese pounds (SDG)

[3]Technology level is determined by regressing the package components (use of the recommended sowing date, improved variety, number of irrigations, pest and weed control and fertilizer application) against wheat productivity per unit area. Weights were given to each package component with reference to its effect on productivity. The weights sum to 1. The total score for each farmer is the sum of the relative scores from each package component. Farmers with scores above 0.8 were considered as high adopters of technology. With a score below 0.8 the farmer was not considered to be a high adopter of technology

Table 1: Summary statistics of the variables used in the frontier model for wheat producing farms in North Sudan

Notation	Unit	Mean	Standard deviation	Min	Max
Stochastic production function model					
Capital	SDG ha^{-1}	4585	828	3115	5948
Labor	SDG ha^{-1}	13178	2994	5030	19831
Fertilizer	kg ha^{-1}	176	55	60	326
Irrigation	number	8	1.57	3	12
Seed rate	kg ha^{-1}	167	49	95	238
Inefficiency model					
Family size	persons	9.7	4.55	2	31
Total land area	ha	15.4	8.35	3	50
Wheat area	ha	4.63	5.44	1	35
Productivity of previous year	ton ha^{-1}	2.6	1.04	0.72	5.7
Wheat area/total area	%	0.28	0.17	0.05	0.75
Age	years	51.4	10.4	31	79

Source: Calculated by the authors from the survey data, 2012.
SDG – Sudanese pound. SDG1 = USD0.23 (average for 2012).

RESULTS AND DISCUSSION

The Estimated Cobb-Douglas Production Function and Marginal Effects: Maximum likelihood estimates of the parameters of the Cobb-Douglass stochastic frontier production and technical inefficiency models were generated using Frontier version 4.1 software [19]. Parameter estimates, together with their corresponding standard errors and t-ratios, are presented in Table 2.

The estimate for the variance parameter, γ, being significantly different from zero implies that the inefficiency effects are significant in determining the level and the variability of the north Sudan wheat producing farms. Thus, the computed value of gamma ($\gamma = 0.87$) is an indicator of the relative variability of the two random error sources. The estimate for the variance parameter, γ, is significantly different from zero implying that the inefficiency effects are significant in determining the level and the variability of Sudan wheat production. The value of 0.87 indicates that output-oriented TE is important in explaining the total variability of output produced. The remaining portion (0.13) arises from factors outside the control of the farmer (weather, diseases, etc.).

As γ approaches zero, the discrepancy between the observed and the frontier production levels is primarily because of random factors beyond the control of the farmer. Similarly, when the coefficient, γ, becomes large, the discrepancy between the observed and the frontier outputs is mainly the result of heterogeneity (technical inefficiency) across farms, which can cause departures from the maximum potential efficiency. The value of γ, the ratio of farm-specific variability, is significant at the 1% level, which implies that farm-specific TE is important in explaining the total variability of the wheat output produced. This affirmation confirms that the stochastic production function is justified from an empirical point of view.

The results of the model show that wheat production exhibits decreasing returns to scale (0.76). The expected values of the logged coefficients are 0.17 for capital and 0.08 for labor. The two coefficients sum to 0.25 which indicates that, with respect to the capital and labor marginal productivity analysis, wheat expansion would expand by a quarter. This suggests that capital is more productive than labor as indicated by their respective coefficients. However, the effect of labor is not statistically significant at the 10% level as compared with capital at that level. This result signals the importance of adopting more capital intensive techniques in order to maximize wheat production in the State. A similar result was proved in an earlier study carried out to investigate the efficiency of wheat and faba bean production in the Northern State [20]. The relative efficiency of fertilizer, irrigation water and using the recommended seeding rate are shown also in the table above. Adopter farmers/project participants used an average seeding rate of 144 kg ha^{-1} while non-adopter farmers/non-participants used a seeding rate of 173 kg ha^{-1}. These values should be compared with the recommended seed rate of 119 kg ha^{-1}. This difference is significant at $p = 0.05$, indicating real disparities between farmers all of whom use unnecessary quantities of seed. This statement was confirmed by Amin *et al*. [21] indicating that farmers in northern Sudan usually tend to use almost double the recommended seed rate to produce wheat. The adverse effects of this practice are reflected in greater competition for nutrients, poor crop performance and, subsequently, lower yields per unit area. Moreover, the additional cost of the excess quantity of seed increases the total cost of production to varying degrees.

Table 2: Parameter estimates of the production function and inefficiency model

Model	Coefficient	SE ±	t-ratio
Production function			
β_0 Intercept	4.68	1.00	4.67*
β_1 Ln Capital (SDG ha^{-1})	0.17	0.12	1.42***
β_2 Ln Labor (SDG ha^{-1})	0.08	0.09	0.89
β_3 Ln Fertilizer quantity (kg ha^{-1})	0.12	0.06	1.96**
β_4 Ln Number of irrigations	0.09	0.10	0.93
β_5 Ln Seed rate (kg ha^{-1})	0.20	0.06	3.15*
Inefficiency model			
δ_0 Intercept	1.18	1.32	0.89
δ_1 Ln Family size (persons)	0.13	0.25	0.54
δ_2 Ln Total land area (ha)	- 0.04	0.12	- 0.38
δ_3 Ln Wheat area (ha)	0.20	0.19	1.01
δ_4 Ln Productivity of previous year (ton ha^{-1})	- 0.44	0.13	- 3.27*
δ_5 Ln (wheat area/total area)	0.19	0.20	0.94
δ_6 Ln Age (years)	0.64	0.36	1.78**
δ_7 Technology level	-1.07	0.46	- 2.32**
δ_8 Use of improved seeds	0.08	0.11	0.73
δ_9 Availability of finance	0.01	0.10	0.15
δ_{10} Use of recommended irrigation	- 0.27	0.12	- 2.22**
δ_{11} Private land ownership	0.06	0.11	0.52
δ_{12} Rented land	0.13	0.16	0.81
δ_{13} Education level	- 0.03	0.20	- 0.16
Sigma-squared (σ^2)	0.08	0.02	3.11*
Gamma (γ)	0.87	0.05	17.02*
Log likelihood function = 29			

Source: Calculated by the authors from the field survey data (2012).

Notes: The dependent variable is the natural logarithm of wheat production (kg ha^{-1}).

* indicates significance at the 1% level, ** indicates significance at the 5% level and *** indicates significance at the 10% level.

Fertilizer use is always below that recommended and farmers usually tend to ignore the application of triple superphosphate and give different doses than the recommended 238 kg ha^{-1} of urea. The average urea dose given by farmers is 175 kg ha^{-1} with no significant differences between technology adopters and non-adopters. The fertilizer coefficient in the model is significant at the 5% level, indicating that it has a real effect in determining wheat yield. Research addressing the appropriate selection of nutrient sources and the optimum doses is expected to greatly contribute to improving wheat productivity and yield, especially in the newly developed marginal land areas in Northern State.

Irrigation is one of the most important determinants of wheat production in Northern State. Research findings showed that variations in the amount and timing of irrigation greatly affect wheat production. The cost of pumping irrigation water constitutes more than 40% of the small-scale farmer's total cost of wheat production in Northern State, Sudan [22]. Problems with reliable power sources and the efficient pumping and distribution of irrigation water have resulted in low productivity per unit volume of water.

Applying the recommended number of irrigations has a highly significant effect on wheat yield –a marginal effect of 9%. Our findings are similar to those reported in many previous studies, showing that a shortage of irrigation is one of the most important agricultural constraints in the Northern State as it is in many other parts of Sudan (Nimir, [23] and El Feil, [24]). Furthermore, Al Awad [25] found that the number of irrigations significantly affected crop production in the State. The shortage of irrigation is a consequence of an inadequate supply of water and various other factors, including inadequate pumping and distribution, lack of proper maintenance and low efficiency of the pumping units [4]. The positive and significant effect of using the right number of irrigations in the estimated model indicates that improving the irrigation system can greatly enhance the production of wheat.

Technical Inefficiency Model: The inefficiency model captures the different effects of the explanatory variables on the TE of wheat farms. Four variables in the regression equation are statistically significant either at the 1%, 5%, or 10% levels. Wheat area has a critical influence on TE as

Table 3: Distribution of TE groups by technology level and participation within EFSAC

	Technology level		Participation with EFSAC	
TE range	Low adoption	Full package	Non-participants	Participants
0.00 – 0.40	0.39 (2)	0	0.39 (2)	0
0.41 – 0.60	0.50 (21)	0	0.49 (21)	0
0.61 – 0.80	0.71 (23)	0.75 (2)	0.71 (25)	0
0.81 – 1.00	0.87 (16)	0.95 (36)	0.91 (32)	0.96 (20)
Total	0.67 (62)	0.94 (38)*	0.72 (80)	0.96 (20)*

Source: Calculated by the authors from the field survey data (2012).

Notes: Figures in parentheses are the number of farmers.

* indicates significance at the 1% level, ** indicates significance at the 5% level and *** indicates significance at the 10% level.

indicated by the positive sign of its coefficient. The efficiency of wheat production increases as the wheat area decreases. This result could be explained on the grounds that more attention may be paid when the wheat area is small. The effect of wheat productivity (kg ha^{-1}) in the previous year on the current TE yield is positive and significant at the 1% level indicating that farmers generally tend to pay less attention to wheat based on the previous year's poor crop performance. The effect of adoption of the full production package on wheat TE is negative and significant at the 1% level. This means that the more the components of the technology package are used, the higher their TE, which is consistent with the theoretical expectation. Low productivity is expected because only few wheat farmers in the Northern State have adopted the full production package [5]. The TE is negatively affected by the farmer's age and the share of the wheat area in the total farm area, implying that young farmers are more efficient than old ones. It also implies that farmers with relatively lower wheat areas on the farm can pay more attention to this small manageable wheat area with a higher TE.

Technical Efficiency Scores and Their Determinants: The average TE of wheat farmers in the study area was 77%, indicating that in the short-run it is possible to increase wheat production by 23% through improvements at the farm level while using the same amount of inputs. Technical efficiencies varied between 37 and 98%. Higher TEs are related to increased adoption of the wheat production technology as shown in Table 3. From this table, it appears that the highest value belongs to the farmers participating in the project. This demonstrates the effect of using the improved technical package on wheat productivity.

The average TE of farmers participating in the project and those who adopted the full production package is 96%. This compares very favorably with the TE levels of

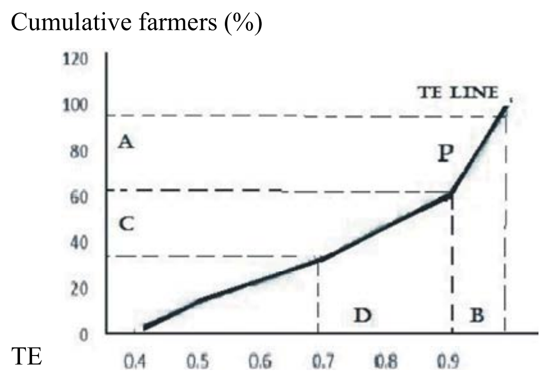

Fig. 2: Cumulative TE of wheat farmers in the Northern State

Source: Calculated by the authors from the field survey data (2012)

the non-participants (72%). In contrast, the average efficiency of farmers adopting the full package is 94% and that of the non-adopters is 67%.

The behavior of TE with the cumulative percentage of farmers is shown in Figure 2. Two distinct phases can be observed based on the TE line. Farmers with a TE level of less than 0.9 (point P) can easily gain higher TE because the TE line is less steep in this segment than in the segment beyond point P.

Potential yield losses resulting from technical inefficiency are substantial for farmers who did not adopt the recommended wheat production package. The results presented in Table 4 show that the average potential yield loss is around 80% for non-adopting farmers. The yield gap is higher for farmers in the low TE range; it is about 156% for farmers in the TE range 0.0 to 0.4 and 108% for farmers in the TE range 0.41 and 0.60.

Increasing TE to 80% would reduce the yield loss by more than 300%. Thus, an effective improvement of extension and technology transfer activities could produce an extra 1.47 ton ha^{-1} of wheat using the same

Table 4: Effect of technology level on actual and potential wheat yield losses in the Northern State farms

Technology adoption/ participation	TE range (%)	Mean TE (%)	No. of farms (N)	Actual yield (ton ha^{-1})	Potential yield (ton ha^{-1})	Potential yield gap (ton ha^{-1})	Yield loss (%)
Non-adopters	00 – 40	0.39	2	1.48	3.79	2.31	156
	41 – 60	0.48	21	1.85	3.85	2.00	108
	61 – 80	0.71	23	2.73	3.85	1.12	41
	81 – 100	0.87	16	3.24	3.72	0.48	15
	Total	0.61		2.33	3.80	1.48	80
Adopters	60 – 80	0.75	2	2.62	3.49	0.87	33
	81 – 100	0.95	36	3.91	4.12	0.21	5
	Total	0.85	38	3.27	3.81	0.54	19
Non-participants	00 – 40	0.38	2	1.49	3.92	2.43	163
	41 – 60	0.49	21	1.85	3.78	1.93	104
	61 – 80	0.72	25	2.72	3.78	1.06	39
	81 – 100	0.91	32	3.47	3.81	0.34	10
	Total	0.63	80	2.38	3.82	1.44	79
Participants	81 – 100	0.96	20	4.08	4.25	0.17	4
Total no. of farms	00 – 40	0.38	2	1.48	3.89	2.41	163
	41 – 60	0.49	21	1.85	3.78	1.93	104
	61 – 80	0.71	25	2.72	3.83	1.11	41
	81 – 100	0.93	52	3.71	3.99	0.28	8
	Total	0.77	100	2.44	3.87	1.47	79

Source: Calculated by the authors from the field survey data (2012).

Note: Potential yield represents the maximum yield attainable (Potential yield = Actual yield/TE).

Table 5: Distribution of farmers according to TE and some institutional variables

	Availability of extension		Availability of training for farmers		Availability of finance	
	Proper extension	Weak extension	Available	Not available	Available	Not available
Low TE	0	6	0	0	0	4
Medium TE	28	88	07	29	38	58
High TE	72	06	93	71	62	38
Mean TE	0.87*	0.55	0.87*	0.52	0.81**	0.72**

Source: Calculated by the authors from the field survey data (2012).

Note: * indicates significance at the 1% level, ** indicates significance at the 5% level and *** indicates significance at the 10% level.

levels of inputs. Moreover, farmers participating in the EFSAC project reduced their potential yield loss by 0.17 ton ha^{-1} with an average TE of 96%. This can be attributed to the effective extension services within the project.

A comparison of the mean TEs and the relationship statistics are provided in Table 5. The data show that extension and farmer training contribute significantly ($p = 0.01$) to improved TE in the north Sudan farms. The mean TE was higher for farmers who had received formal extension services (85%) as compared with farmers who did not receive these. Effective extension lead to high TE levels for 78% of the farmers in the study area.

A similar magnitude was found for farmer training, with a higher percentage (93%) in the high TE category. Empirical values for the availability and access to formal finance variable show a significant effect on the TE at the 10% level of significance, but with most of the farmers (49%) falling in the medium TE category. The Chi squared statistic shows the global significance of the model. This relationship indicates the clear positive impact of extension, training and source of finance on wheat production TE of north Sudan farms.

The mean TEs are 87% for farmers who received formal extension, 87% for those who received other training and 81% for those who benefitted from finance services. The TEs for those who did not receive formal extension is 55%, for those who did not receive other training is 52%, for those who did not benefit from finance services is 72%. Making use of extension leads to a 32% gain in TE (87 - 55), whereas farmers' training leads to a 35% gain and availability of finance leads to a 9% gain in TE. The higher effect of training can be explained by the fact that training encompasses provision of doses of extension, therefore revealing the dual effect of training and extension.

Concluding Remarks and Policy Implications: The main objective of this study was to estimate the TE of farmers and identify sources of inefficiency in wheat production in Northern State, Sudan. Empirical findings indicate that the average TE is higher for the farmers who adopted the full recommended production package as compared with the non–adopters. Likewise, participation in the EFSAC project led to higher TE levels. Farmers' training, education and effective extension programs were found to be the most important factors influencing TE. The empirical results also indicate that fully adopting the recommended package (as opposed to selected components) resulted in the greatest increase in TE levels among wheat farmers in the area. The sowing date was the most important component of the recommended package.

Knowledge of the variation in the level of TE among farmers gives a better understanding of how all interested groups can improve wheat production by the more efficient use of inputs and sustainable practices. The recommendations from this study are classified into two parts (management and technological):

- Improving the extension services in Northern State to more effectively transfer technology will lead to more efficient use of the available inputs to produce more outputs. The policy implication drawn from this study should include more efforts to strengthen technology transfer services and construct effective in-field demonstrations and farmers' field schools. These are considered as operative ways to improve the effectiveness of technology transfer to farmers. Both provide training and facilitate communication between farmers, extension workers and researchers.
- Improvement of the agricultural finance system can lead to large gains in efficiency levels.
- Use of the recommended seed rate of the improved varieties, taking into consideration adaptability to different soils and the age of each variety, will likewise lead to TE improvement.
- Training farmers, by establishing effective farmers' field schools, will serve also as a means for the participatory evaluation of improved production technologies.
- Further study of the wheat yield gap analysis and its determinants, by using updated geo-spatial data and spatial econometric techniques, will help to explain the nature of this gap across the different geographic groups in northern Sudan. Specifically, the use of spatially-disaggregated production data for wheat, as well as satellite data on agro-climatic and socioeconomic factors, will give more emphasis to the situation of wheat production in northern Sudan.

Finally, policy implications drawn from the results of this study should emphasize the role of proper extension services, farmers' training in agriculture and education in enhancing wheat production TE. Policy measures to encourage sowing at the optimum date, timely application of inputs, use of agricultural machinery and adequate irrigation also could be examined.

ACKNOWLEDGEMENTS

The authors would like to acknowledge that this work is an output of the socioeconomic research activities of the project 'Food Security in Arab Countries' implemented by ICARDA with financial support from the Arab Fund for Economic and Social development (AFES), Islamic Development Bank (IDB), Kuwait Fund for Arab Economic Development (KFAED) and OPEC Fund for International Development.

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