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Technical efficiency of maize production in Northern Ghana

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The ability of maize farmers in Ghana to increase yield levels and attain sustainable production depends on efficient farm practices, hence technical efficiency. This study applied the stochastic frontier methodology to examine the technical efficiency of maize production for the 2011/2012 cropping season. Multi-stage sampling procedure was used to obtain 360 maize households for the study. The determinants of maize output in northern Ghana were farm size, seed, fertilizer and weedicides. The mean technical efficiency estimate was 74% with minimum and maximum values of 12 and 98%, respectively. Agricultural mechanization, experience and gender statistically influenced technical efficiency. The Agricultural Mechanization Services Enterprise Centres programme of the Ministry of Food and Agriculture should be scaled-up to increase access to farm tractor for agricultural mechanization services in order to increase farmers' production efficiency. Similarly, maize production could improve if younger farmers learn from the accumulated knowledge of experienced farmers. Policies which would stress gender equality as regards access to economic resources, education, information and decision-making would help develop self-confidence in women.

Key words: Stochastic Fontier, Technical Efficiency, maize production, northern Ghana.

INTRODUCTION

Agricultural growth is at the centre of the Comprehensive African Agriculture Development Programme (CAADP, 2009) agenda because increasing agricultural productivity is necessary to achieving its poverty reduction and food output targets, while at the same time reducing production costs and food prices for the poor. Ghana's Medium Term Agriculture Sector Investment Plan (METASIP, 2010) seeks to modernize agriculture which will culminate in a structurally transformed economy evident in food security, employment opportunities and poverty reduction. To this end, as per (CAADP, 2009) directives, the country is to allocate 10% of government expenditure to achieve an agricultural gross domestic product (GDP) growth of at least 6% annually to meet the millennium development goal 1 (MDG1) of halving poverty and hunger before the target year of 2015.

Agriculture in Ghana accounts for more than 30% of GDP (MoFA, 2011) and three-quarters of export earnings. Yields of most crops in Ghana however are generally low (20–60% below their achievable level). For example, the yield for cassava is at 12.4 Mt/ha against a potential yield of 28.0 Mt/ha (MoFA, 2011). The yield of 1.7 Mt/ha for maize is less than a third of the achievable yield of 6.0 Mt/ha. Accelerated growth in agriculture needs to be driven by enhanced productivity like the Green Revolution in Asia rather than land expansion. Potential for such productivity-led growth exists in Ghana, exemplified by significant gaps between current and

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achievable yields for many crops. The main reasons for the low productivity (yield/ha) of maize include extensive use of unimproved maize seeds, depletion of soil fertility, erratic rainfall, prevalence of pests and diseases, little improvement in agronomic technologies, limited use of yield-enhancing purchased inputs such as fertilizers and agrochemicals (Sserunkuuma et al., 2001).

Agricultural productivity can be improved either through the development and adoption of new technologies or through the efficient use of the existing technologies without damaging the natural resource base (Bhasin, 2002). The mechanization of farm operations is a very important step toward increasing production efficiency (Kibaara, 2005). According to MoFA`s 2005 baseline survey, about 40% of farmers use some form of mechanization. The use of tractors in land preparation reduces technical inefficiency through timely land preparation and planting. Maize is a very important staple food in Ghana accounting for more than 50% of total cereal production in the country and grown in all agro-ecological zones (Akramov and Malek 2012). The bulk of maize produced goes into food consumption and it is arguably the most important food security crop.

The ability of maize farmers in Ghana to improve yield levels and achieve sustainable production depends on efficient farm practices, hence technical efficiency. The aim of this study is to analyse the extent to which socio-economic, technological as well as location factors affect the ability of farmers to improve maize yields in northern Ghana. Even though a number of technical efficiency studies have been done in Ghana and elsewhere, technical efficiency is time-, location- and even crop-specific. This raises the research questions, what are the levels of technical efficiency in maize production in northern Ghana and what factors influence such levels? Considering the large number of Ghanaians who grow and consume maize, any technology that succeeds in increasing the productivity of resources devoted to maize production will bring about real income gains for the vast majority of the rural population. To the extent that increases in productivity are translated into lower prices for maize, the income gains will also be passed on to urban dwellers.

MATERIALS AND METHODS

Study area

The data were collected between January and February, 2013 in the three regions (Northern, Upper East and Upper West shown in Figure 1) of northern Ghana for the 2011/2012 cropping season. The three regions of northern Ghana together make up about 41% of the country's total land area. Rainfall distribution is uni-modal giving a single growing season of 180 to 200 days with an annual mean of 1,100 mm. The dry season starts in November and ends in March/April with maximum temperatures of about 42°C occurring towards the end of the dry season. The data collection was carried out in six districts in northern Ghana, two districts in each of the three regions. Multi-stage sampling procedure was used in identifying the districts where six communities were randomly selected in each district and from which 10 maize households were also randomly sampled to get a total of 60 respondents for each district. Each region had a sample size of 120 respondents, thus a total of 360 maize households for the three regions of northern Ghana.

Stochastic frontier production function

This study uses the stochastic frontier approach (SFA) to estimate and analyse the technical efficiency of maize farmers. The stochastic frontier model decomposes the error term into a two-sided random error that captures the random effects outside the control of the firm (farmer) and the one-sided inefficiency component. Thus, the stochastic approach allows for statistical noise (Thiam et al., 2001). The general stochastic model is given as:

$$Y_i = f(X_i; \beta)\exp(V_i - U_i) \quad (1)$$

where Y_i is the output of the i*th* farmer; X_i is a vector of farm inputs; β is a vector of parameters to be estimated; while V_i measures the random variation in output (Y_i) due to factors outside the control of the farm, U_i are factors within the control of the farm responsible for its inefficiency. V_i is assumed to be identically and independently distributed as $N(0, \sigma_v^2)$ and independent of U_i which has a half-normal non-negative distribution. The composed error term, ε_i is defined as:

$$\varepsilon_i = V_i - U_i \quad (2)$$

Jondrow et al. (1982) specified a decomposition method from the conditional distribution of u given e. Given the normal distribution of v, and the half-normal distribution of u, the farm specific conditional inefficiency ($^{u}/_{\varepsilon}$) for each observation is derived from the conditional distribution of u, where $u = \varepsilon + v$. Therefore, the conditional mean of u is:

$$E(^{u}/_{\varepsilon}) = \sigma^2\left[\frac{f\left(^{\varepsilon\lambda}/_{\sigma}\right)}{1-F\left(^{\varepsilon\lambda}/_{\sigma}\right)} - \frac{\varepsilon\lambda}{\sigma}\right] \quad (3)$$

Where *f* and *F represent* the standard normal density and cumulative distribution functions, respectively, and:

$$\lambda = \sigma_u / \sigma_v \quad (4)$$

Equation (4) is the ratio of the two standard errors as used by Jondrow et al. (1982) and it measures the total variation of output from the frontier that can be attributed to technical efficiency. The estimation of γ which is the ratio of the variance of u to the total variance is given as:

$$\gamma = \sigma_u^2 / \sigma_v^2 \quad (5)$$

where σ_v^2 and σ_u^2 are variance of the stochastic model (systematic) and the inefficiency model respectively.

Technical efficiency is the ability of a firm to obtain maximum Output from a given set of inputs. Thus, technical inefficiency occurs when a given set of inputs produces less output than what is possible given the available production technology. The level of technical efficiency (TE) is measured by the distance of a particular firm from the production frontier. Thus, a firm that sits on the production frontier is said to be technically efficient. TE is measured as a ratio of actual to potential output (Aigner et al., 1977; Meeusen and van den Broeck, 1977), given as:

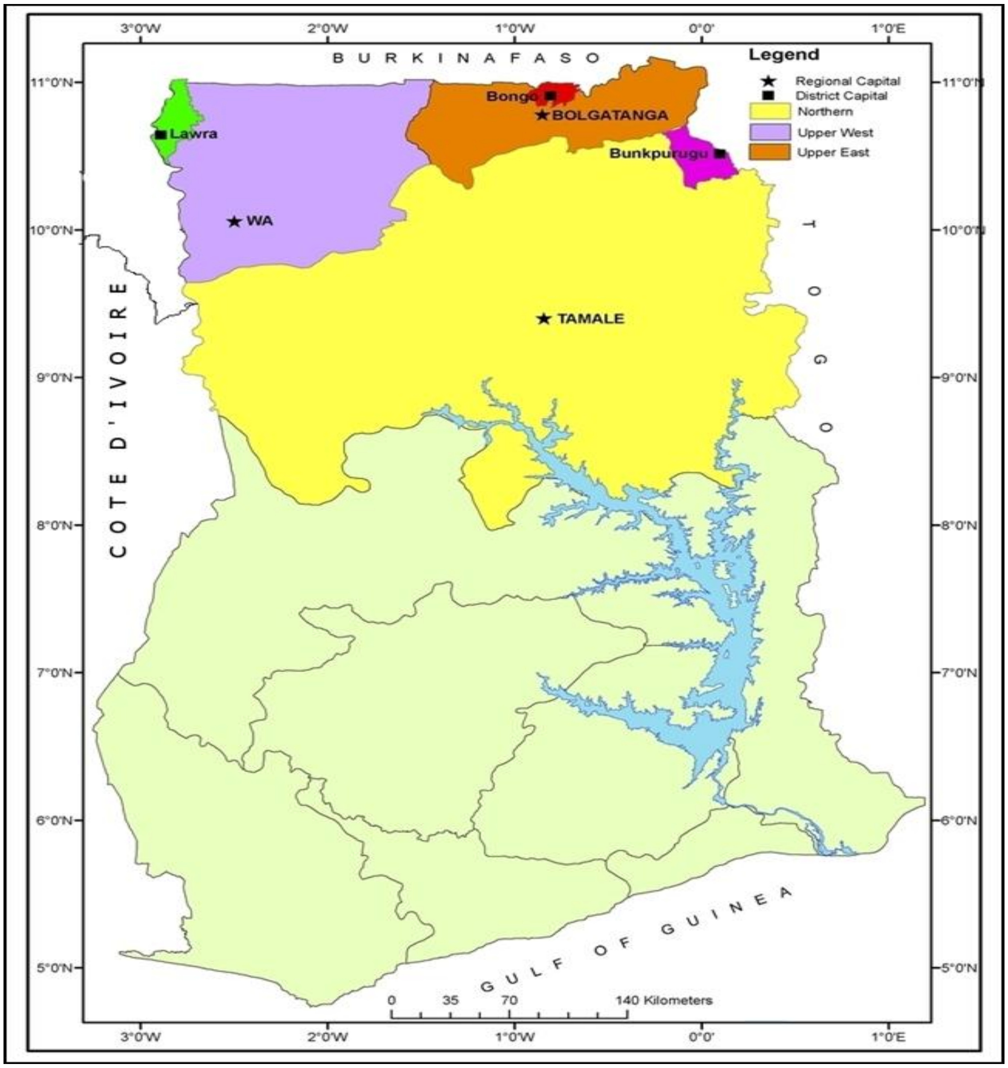

Figure 1. A map of Ghana showing the study area.

$$TE = \frac{Y_i^*}{Y_i} = \frac{f(X_i;\beta)\exp(V_i - U_i)}{f(X_i;\beta)\exp(V_i)} = \exp(-U_i) \quad (6)$$

Therefore, the technical efficiency (TE) of a firm is defined as, $TE = \exp(-U_i)$. We also adapt the model proposed by Battese and Coelli (1995), in which the technical inefficiency, TI effects are defined by:

$$U_i = Z_i\delta + w_i \quad (7)$$

where $Z_i$is a $(1 \times m)$vector of explanatory variables associated with the TI effects; $\delta$is a $(m \times 1)$ vector of unknown parameters to be estimated; and $w_i$is an unobservable random variable. The parameters indicate the impacts of variables in Zon TE. A negative value suggests a positive influence on TE and vice versa.

Empirical model

In terms of the functional form of the stochastic frontier model, the two commonly used are Cobb-Douglas and the translog. The main advantage of the translog is that it is flexible, and does not impose assumptions about constant elasticity of production nor elasticities of substitutions between inputs. But, it can cause multi-collinearity problems (Dawson et al., 1991). The Cobb-Douglas functional form however is not only simple but it is self-dual and has been widely applied in agricultural production technologies in many developing countries (Battese et al., 1993; Bravo-Ureta and Pinheiro, 1993; Djokoto, 2012). Nonetheless, Abdulai and Huffman (2000), Kibaara (2005), Obwona (2006), Onyenweaku and Okoye (2007) and Alhassan (2008) have used the translog functional form. Ahmad and Bravo-Ureta (1996), however, argue that TE measures do not appear to be affected by the choice of the functional form.

The generalized likelihood ratio test is used to ascertain the appropriateness of the use of either the Cobb-Douglas or the translog functional form to determine the relationship between maize output (dependent variable) on one hand, and the socioeconomic, institutional and farm-specific factors (explanatory variables) on the other hand. The Cobb-Douglas functional form is specified as follows:

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + V_i - U_i \quad (8)$$

And the translog functional form is given as:

Table 1. Results of hypotheses tests.

Null hypothesis	Log Likelihood function (H_0)	Test statistic λ	Critical value	Decision
$H_0: \delta_1 = \cdots = \delta_6 = 0$	-307.748	37.562	12.592 (6)	Reject H_0: U_i present
$H_0: \beta_1 = \cdots = \beta_{20} = 0$	-301.598	25.262	24.996 (15)	Reject H_0: Translog appropriate

Critical values are at 5% significance level and obtained from χ^2 distribution table. Figures in brackets are the number of restrictions.

$$\ln Y_i = \beta_0 + \sum_{k=1}^{5} \beta_k \ln X_{ik} + {}^1/_2 \sum_{k=1}^{5} \sum_{j=1}^{5} \beta_{kj} \ln X_{ik} \ln X_{ij} + V_i + U_i \quad (9)$$

where $\ln$ represents logarithm to base e; Y is output of maize (in Kg); X_1 is farm size in hectares; X_2 is the quantity of own/purchased seed (kg) used for planting; X_3 is quantity of fertilizer used in kg; X_4 is the labour cost and X_5 cost of weedicides (in GH¢) and X_i are the five inputs for the translog model.

The inefficiency model is also given as follows:

$$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + w_i \quad (10)$$

where Z_1 is access to tractor services as proxy to level of agricultural mechanization; Z_2 is the number of years of farmer in maize cultivation; Z_3 is number of years in school; Z_4 is number of agricultural extension visits; and Z_5 is gender of the farmer (categorized as 1 for males and 0 for females); Z_6 is the value of credit received during the cropping season (in GH¢); ε_i is the two-sided error term and δ_i is a vector of parameters to be estimated. Equations (8) to (10) are estimated by Maximum Likelihood which yields consistent estimates for β, δ, γ and σ_u^2.

RESULTS AND DISCUSSION

Tests of hypotheses

The first hypothesis is that socio-economic indicators in the inefficiency model do not explain the inefficiency term, U_i, for farm firms engaged in maize production. The test result in Table 1 shows the null hypothesis should be rejected since at least one of the socio-economic variables is statistically not equal to zero. The second is that the Cobb-Douglas functional form is an adequate representation of the data, given the specification of the translog functional form. The result shows the rather popular but inflexible Cobb-Douglas functional form should be rejected since at least one of the interaction terms is statistically different from zero.

Determinants of maize output in Northern Ghana

The results of the maximum likelihood estimates of the translog functional form for maize in northern Ghana are presented in Table 2. The input variables used in the translog functional form had been mean-centered (each variable was deflated against its mean value) before estimation and therefore the first order coefficients could be interpreted as partial production elasticities.

The first term variables, with the exception of labour, were all statistically significant at 1%. The coefficients of these variables were also positive and thus had significant effect on output at the initial stage. For example, the coefficient on farm size (0.324) meant that when farm size was increased by 100%, holding all other inputs constant, output would also increase by about 32%. Similarly, seed, fertilizer and weedicides which had partial production elasticities of 0.365, 0.206 and 0.387, respectively, would increase output by 36.5, 20.6 and 38.7%, respectively when each of these production inputs was increased by 100%. A major reason for the non-attainment of achievable yields is low fertility of the soils which is partly due to low use of fertilizers (METASIP, 2010). The production input with the highest partial elasticity was weedicides. Weeds remain a major challenge to increasing crop output as they compete with the crop plants for nutrients and water among others. Weedicides are increasingly being substituted for other methods of weeds control during land preparation and immediately after sowing in northern Ghana.

Some of the interaction terms for the translog model were statistically significant with some having positive and others negative signs. “Fertilizer squared”, “farm size and fertilizer” and “fertilizer and weedicides” were statistically significant at 5%. For example, the squared value of fertilizer was -0.246. This implied that continuously increasing the quantity of fertilizer by 100% would at a point decrease output by 24.6%. The other two interaction terms explained whether the production inputs were substitutes or complements. For instance, “farm size and fertilizer”; and “fertilizer and weedicides” were significant at 5%. These interaction terms had positive values of 0.224 and 0.158 respectively meaning they were complements. Likewise, the interaction terms of variables such as “labour and weedicides” as well as “farm size and seed” had negative signs of -0.102 and -0.119 respectively meaning that were substitutes to each other.

The value of 0.786 of the gamma was statistically significant at 1%. This means that 78.6% of the total variation in output was as a result of factors within the control of the farmer and that variation in maize output could be attributed to inefficiency. This might also be interpreted to mean that the differences between actual (observed) and frontier output had been dominated by technical inefficiency (that is, factors within the control of the farmers). The returns to scale value of 1.383 indicated increasing returns to scale. This implied that

Table 2. MLE estimates for stochastic production function for northern Ghana.

Variable	Parameter	Coefficient	Standard error
Constant	β_0	0.136	0.093
Farm size	β_1	0.324***	0.087
Seed	β_2	0.365***	0.084
Fertilizer	β_3	0.206***	0.052
Labour	β_4	0.101	0.073
Weedicides	β_5	0.387***	0.069
Farm size squared	β_6	-0.143	0.209
Seed squared	β_7	-0.177	0.164
Fertilizer squared	β_8	-0.246***	0.105
Labour squared	β_9	-0.005	0.303
Weedicides squared	β_{10}	0.137	0.104
Farm size*seed	β_{11}	-0.005	0.303
Farm size*fertilizer	β_{12}	0.224**	0.101
Farm size*labour	β_{13}	0.033	0.128
Farm size*weedicides	β_{14}	-0.119	0.110
Seed*fertilizer	β_{15}	-0.027	0.093
Seed*labour	β_{16}	0.158	0.133
Seed*weedicides	β_{17}	0.113	0.116
Fertilizer*labour	β_{18}	-0.085	0.092
Fertilizer*weedicides	β_{19}	0.174**	0.069
Labour*weedicides	β_{20}	-0.102	0.109
	Inefficiency		
Constant	δ_0	2.542**	0.813
Agric. mech.	δ_1	-0.435**	0.194
Experience	δ_2	-0.106**	0.047
Education	δ_3	-0.177	0.130
Extension	δ_4	-0.236	0.215
Gender	δ_5	-1.023*	0.388
Credit	δ_6	-0.002	0.003
Sigma squared	σ_v^2	-1.522***	0.142
Gamma	γ	0.786***	0.382
Mean efficiency		0.740	
Returns to scale		1.383	
Log-likelihood function		-288.967	

***, **,* indicate values statistically significant at 1, 5 and 10%, respectively.

maize production in the study area during the 2011/2012 cropping season was in stage one of the production function. Therefore, an increase in the use of the conventional variable inputs in the production process would lead to a more than proportionate increase in output. There is therefore the need to support staple crops such as maize as an important driver of growth and poverty reduction especially in northern Ghana. Under (CAADP, 2009) agricultural growth scenario of 6% per annum, by 2015, the national and rural poverty rates will fall to 12 and 17.5%, respectively.

Distribution of technical efficiency estimates in Northern Ghana

The mean technical efficiency estimate for the sampled maize farmers in northern Ghana was 74% with 12 and 99% as the minimum and maximum, respectively. Estimates across the three regions of northern Ghana are presented in Table 3.

Similar studies in northern Ghana on technical efficiency include Alhassan (2008) who found mean efficiencies of 51 and 53% for irrigated and non-irrigated

Table 3. Technical efficiency estimates across the three regionsof northern Ghana.

Region	Minimum	Maximum	Mean
Northern	0.15	0.94	0.71
Upper East	0.13	0.93	0.74
Upper West	0.14	0.98	0.85

Source: Authors' computation.

Table 4. Technical efficiency distribution for northern Ghana.

Efficiency range	Frequency of respondents	Percent
≤ 0.5	24	6.6
0.51-0.60	28	7.8
0.61-0.70	53	14.7
0.71-0.80	97	26.9
0.81-0.90	141	39.2
0.91-1.00	17	4.7
Total	360	100.0

Source: Authors' computation.

rice production. Abdulai and Huffman (2000) also obtained a mean technical efficiency of 81% for rice farmers in northern Ghana with 19% of potential maximum output lost to inefficiency. Generally, technical efficiency distribution for the sampled maize farmers showed higher levels of efficiency estimates as presented in Table 4.

Determinants of technical inefficiency in maize production in Northern Ghana

The sources of inefficiency are discussed using the estimated (δ) coefficients associated with the inefficiency effects in Table 2. Variables with negative coefficients had negative relation with inefficiency. The opposite was the case for variables with positive coefficients. The variables we examined included agricultural mechaniza-tion, experience, educational status, agricultural extension service, gender of respondent and credit. All the six variables had negative signs and agricultural mechanization, experience and gender were statistically significant. For instance, the negative sign on the coefficient of agricultural mechanization indicated that farmers with no access to agricultural mechanization services were more technically inefficient (less technically efficient) than those who had access to and patronized agricultural mechanization services as shown in Figure 2. Similarly, farmers who engaged the services of the farm tractor for "ploughing, threshing and carrying farm produce from farms to homes" had the highest efficiency estimate of 81%, followed by 78% for farmers who used the tractor for only two activities such as "ploughing and threshing" or "threshing and carrying farm produce". This finding is consistent with Kibaara (2005) who found agricultural mechanization statistically significant in a study of the technical efficiency of maize production in Kenya where households that used tractors for land preparation increased their technical efficiency by 26%. A farmer who uses only hand hoes could prepare about 0.5 ha only for planting per season (Fronteh, 2010). Farmers who do not have access to agricultural mechanization services at the time of need use human muscle power which places limitations on the amount of land that could be brought under cultivation, resulting in low yield, low income and food insecurity to farmers (Benin et al., 2011).

The second variable, "experience" also had a negative effect on technical inefficiency and was statistically significant at 5%. Farmers with many years of experience were more technically efficient than those with few years (Figure 3). Lapple (2010) argues that increase in farming experience provides better knowledge about the production environment in which decisions are made. Similar studies in which experience was significant are Oyewol (2009) and Abdulai and Huffman (2000).

The gender of maize farmers had a negative sign and statistically significant at 10%. Male farmers on the average were more technically efficient (77%) than females whose efficiency estimate was 61% as shown in Figure 4. Women performed crucial roles in the domestic and economic life of society which affected their technical efficiency. This included the unmeasured non-economic activities (such as child care, cooking, cleaning, etc) performed by females in the household. Moreover, some customs, traditions, religious beliefs, and social norms placed restrictions on women's activities both on- and off-farm and hence their ability to access new information and use technologies.This finding is in line with that of Solís et al. (2006) on technical efficiency and soil conservation in El Salvador and Honduras where female-headed households exhibited lower technical efficiency than male-headed households.

DISCUSSION

Farm size, seed, fertilizer and weedicides were statistically significant and had positive effects on maize output in northern Ghana. The determinants of technical efficiency included agricultural mechanization, experience and gender. Agricultural mechanization reduces drudgery and tedium associated with agriculture which in turn leads to increased production, productivity and increased rural employment (Benin et al., 2011). Given the high capital cost of farm machinery and implements, the Agricultural Mechanization Services Enterprise Centres (AMSECs) of the Ministry of Food and Agriculture (MoFA) which had 41 centres in northern Ghana as of 2011 could be expanded to cover many locations so as to contribute

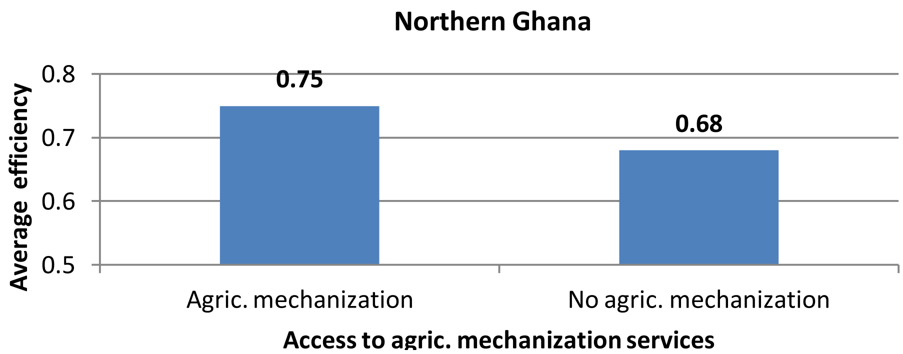

Figure 2. Average efficiency and access to mechanization services in northern Ghana.

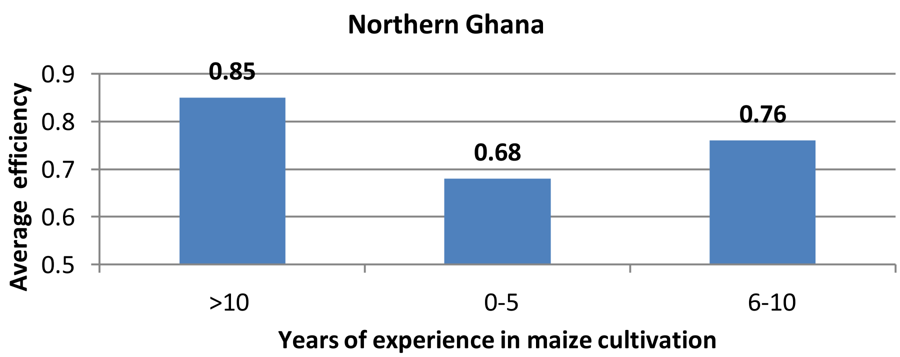

Figure 3. Average efficiency and experience in maize cultivation in northern Ghana.

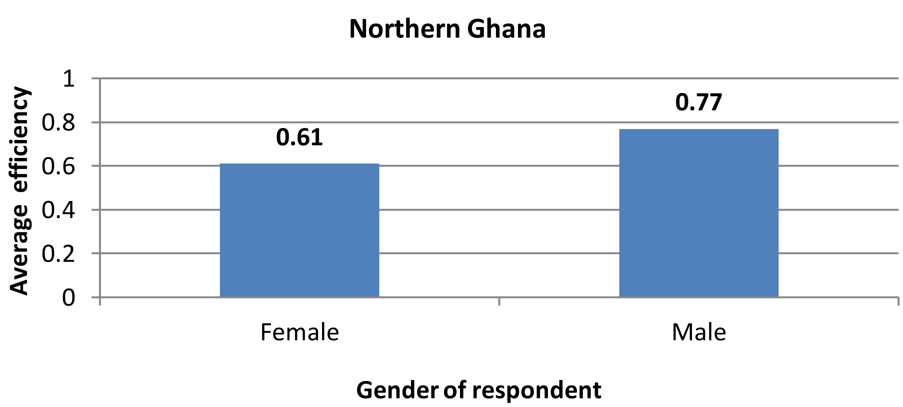

Figure 4. Average efficiency and gender of respondents in northern Ghana.

more effectively to improving access as well as improve the tractor to farmer ratio of 1:1800. The AMSECs programme is a credit scheme in which an average of 5 tractors with matching implements (plough, harrow and trailer) are given at a subsidized price and interest to qualified private sector companies and groups of individuals so that they can make agricultural mechanization services readily available in a timely and affordable manner to the majority of rural farmers. Qualified applicants are however, required to pay a deposit of 10 to 17% of the value as down payment with the balance payable over five years. An evaluation of the AMSECs programme in 2011 brought to the fore some challenges. There were structural defects on the tractor implements due to the failure of farmers to notify the tractor drivers of tree stumps in their farms. Mechanics also had limited training and work carried out on the new tractors was done in a trial and error manner. METASIP recognizes this problem and intends to train more agricultural mechanization technicians to provide routine maintenance services. Similarly, the Savannah Accelerated Development Authority (SADA) with a focus on northern Ghana should double up its efforts in the area of agricultural mechanization in line with its concept of, among other things, modernization of agriculture.

Also, farmers with many years of experience were more technically efficient than those with few years in maize cultivation. Okike et al. (2004) argue that experience is an important factor contributing to technical efficiency because of acquisition of dexterity in doing the same task (maize cultivation) over a period of time. Therefore, opportunities (nucleus farms, farmer field schools etc.) that bring the younger farmers to tap the accumulated knowledge of older farmers will improve maize production.

Lastly, female farmers appeared to be less technically efficient than their male counterparts. Women are often excluded from decision-making in the traditional spheres even though they perform triple roles of household chores, reproductive roles and income generating activities. Women are disadvantaged when compared with men because of the gender related socio-cultural barriers pertinent in the society and policies that stress equality as regards access to economic resources, education, information and decision-making will help develop self-confidence in women. In this regard, governmental and non-governmental bodies as well as gender practitioners should work on advocacy, raising awareness and lobbying to correct the traditions and the wrong perceptions about women to bring change.

Conclusion

Farm size, seed, fertilizer and weedicides had positive effects on maize output in northern Ghana. The determinants of technical efficiency of maize production in northern Ghana for the 2011/2012 cropping season included agricultural mechanization, experience and gender. The Agricultural Mechanization Services Enterprise Centres of the Ministry of Food and Agriculture should be expanded to increase access to farm tractor for agricultural mechanization services in order to increase farmers' production efficiency. Similarly, maize production could improve if younger farmers learn from the accumulated knowledge of experienced farmers. Women are disadvantaged because of some gender related socio-cultural barriers in the society and policies that promote equality regarding access to economic resources, information and decision-making will help develop self-confidence in women.

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Abbreviations: AMSECs, Agricultural Mechanization Services Enterprise Centres; **CAADP,** Comprehensive African Agriculture Development Programme; **GDP,** gross domestic product; **METASIP,** medium term agriculture sector investment plan; **MDG,** Millennium Development Goal; **MoFA,** Ministry of Food and Agriculture; **TE,** Technical Efficiency; **TI,** Technical Inefficiency; **SADA,** savannah accelerated development authority; **SFA,** Stochastic Frontier Approach.

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