Journal of Agricultural Economics and Development Vol. 1(6), pp. 138-144, December 2012
Available online at http://academeresearchjournals.org/journal/jaed
ISSN 2327-3151 ©2012 Academe Research Journals

Full Length Research Paper

Factor productivity in smallholder pigeonpea production systems: Empirical evidence from Northern Tanzania

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Accepted 17 December, 2012

The paper uses panel data originated from two sessions of household surveys: a baseline survey conducted in 2008 and a follow up survey in 2010, in northern Tanzania. Using a flexible transcendental logarithmic (translog) production function, results showed that the productivity of pigeonpea is positively and significantly associated with the size of pigeonpea cultivated land, labor, interaction between plot size and seed quantity, and the interaction of seed-use with time. The study also revealed that there was technological progress in pigeonpea production systems over the period of 2008 to 2010. Furthermore, results from elasticity analysis indicated that smallholder pigeonpea producers were experiencing increasing returns to scale, suggesting that the output of pigeonpea could respond positively and with higher proportion for a given simultaneous percentage change in the quantity of seed, manure and labor. Therefore, support for human capital development of farmers and increased access to improved pigeonpea seed varieties could be important intervention areas to increase pigeonpea productivity in northern Tanzania. Moreover, farmers should also be encouraged to use more manure, seed and labor to increase pigeonpea production without the expansion of land cultivated.

Key words: Factor productivity, pigeonpea, translog production function, Tanzania.

INTRODUCTION

Tanzanian economy is mainly agriculture-based that contributes about 43% to GDP, provides employment for about 80% of the labor force and that smallholders contribute 75% of the total agricultural production (Salami et al., 2010). Thus, the sector plays a critical and multidimensional role in the country's important macroeconomic performances such as economic growth, poverty reduction, universal food security and per capita income.

The agricultural sector in Tanzania has continued to experience low level of productivity leading to a growing concern that the agricultural commercialization process has not enhanced agricultural productivity in the country (Meertens, 2000; Skarstein, 2005). For instance, the majority of the poor (33.3%) in the country reside in the rural areas (Salami et al., 2010). In addition, the country's experience shows that market reforms though necessary, are not sufficient for increasing agricultural productivity (Salami et al., ibid) suggesting that improving the productivity of smallholder agriculture needs a critical analysis of the sector particularly from factor productivity point of view in order to achieve poverty reduction strategy of the country.

Globally, the issue of increasing agricultural productivity has become the main concern to governments following considerable increase in food price over the last two years that follows decades of low food price (Conradie et al., 2009). According to Isaksson (2007), growth of productivity provides with an opportunity to increase the welfare of people. Todaro (1969), discussed in Rezek et al. (2011), also indicates that there is positive spillover effects of agricultural productivity improvements which

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can improve outcomes in the other sectors of the developing economies in terms of welfare of both the urban and rural people alike.

Pigeonpea is an important legume crop in the smallholder production systems of several countries in eastern and southern Africa, primarily Tanzania, Uganda, Kenya, Malawi and Mozambique (Shiferaw et al., 2007). The crop is a drought-tolerant crop grown in many semi-arid and drought prone areas in the region. It is a nutritious and cheap source of protein for many poor and rural families. It is also a nitrogen-fixing legume, which has the potential to enrich soil fertility, and can be grown by cash-constrained farmers without the application of fertilizers (Shiferaw, ibid). The crop is commonly grown as an intercrop with cereals such as maize, sorghum and finger millet in densely cultivated areas where land is scarce (Shiferaw, ibid).

In Tanzania, the crop accounts for about 5% of total output of pulses and 4% of total area under pulses, making it the third most produced pulse after beans and cowpeas in the country (Simtowe et al., 2011). It is one of the few cash crops with a high potential to enhance productivity per unit area due to its complementarities with maize. Pigeonpea is intercropped with maize to maximize land use, spreading economic risk and improving soil productivity through nitrogen fixation (Høgh-Jensen et al., 2007).

However, the pigeonpea industry in Tanzania has been affected by problems of supply linked to poor productivity and limited marketed surplus produce from smallholder farmers (Asfaw et al., n.d) and so far, to the best of the authors' knowledge, no study has been conducted to examine the factor productivity of pigeonpea production systems in the study areas. Thus, having understood the contribution of pigeonpea to the national and rural economies and its role in food and nutrition security of rural poor families, this paper examined the factor productivity of pigeonpea, the direction of technological change in the production process and identified the major productivity determinants. The findings can assist to formulate evidence based policy options to increase productivity of the crop and enhance the livelihood of households in the study areas.

The rest of the paper is organized as follows. Subsequently, the study area, sampling techniques, data collection procedure and empirical modeling strategy are described followed by a description of the results and discussion. Then, conclusion and recommendations are presented.

METHODOLOGY

Study area and sampling techniques

Multi-stage sampling procedure was used to select study districts, divisions, wards, villages and households in the northern zone of Tanzania. In the first stage, four districts namely Babati, Kondoa, Arumeru and Karatu were selected from the major legume producing areas based on the intensity of pigeonpea production, agro-ecology and accessibility. These districts represent some of the major pigeonpea growing areas in the country where improved varieties are beginning to be adopted by farmers. In each of the four districts three major divisions were randomly selected, giving a total of 12 divisions. Subsequently, two wards were sampled in each of the selected divisions resulting in a total of 24 wards from which farm households were randomly sampled and surveyed.

Data collection procedure and source

The study uses farm household level panel data originated from surveys conducted by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) and Selian Agricultural Research Institute (SARI). The data were collected in two waves: a baseline survey conducted in 2008 and a follow up survey in 2010. The baseline survey was done in two stages. First, a reconnaissance survey was conducted by a team of scientists to have a broader understanding of the production and marketing conditions in the survey areas. During this exploratory survey, discussions were held with different stakeholders including farmers, traders and extension staff working directly with farmers. The findings from this stage were used to refine the study objectives, sampling methods and the survey instrument. A survey instrument was prepared and trained enumerators collected the information from 613 households through personal interview. The follow up survey was done to 605 households in 2010. The sample size, after dropping those observations that did not produce pigeonpea, is reduced to an unbalanced panel data of 562 households (2008) and 339 households (2010).

The surveys collected information on several factors including household composition and characteristics, land and non-land farm assets, livestock ownership, household membership in different rural institutions, varieties and area planted, costs of production, yield data for different crop types, indicators of access to infrastructure, household market participation, household income sources and major consumption expenses for both surveys.

Model specification

The analytical approach in this study is based on the framework of a stochastic frontier approach (SFA) independently and simultaneously introduced by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The models of stochastic production frontier address technical efficiency and recognize the fact that random shocks beyond the control of producers may affect the production output. As noted in Movshuk (2004), while initially SFA models were mainly employed for cross sectional data, a SFA model formulated by Battese and Coelli (1995) is capable of dealing with panel data which may also be unbalanced. In this analytical approach all parameters are estimated by maximum likelihood method. One critical advantage of this modeling approach is that it is a time-varying stochastic frontier method given a sample of *N* decision making units (DMUs) for *t* time periods. Moreover, unlike other stochastic frontier approaches, the model does not require any priori assumption regarding the distribution of efficiency across DMUs (Stephan et al., 2008).

Regarding the functional form of the production function, transcendental logarithms (translog) production function was used, which is a second order (all cross-terms included) log-linear form. The transcendental logarithms production function is an attractive flexible function which has both linear and quadratic terms with the ability of using more than two factor inputs (Allen and Hall, 1997; Khalil, 2005). One of the main advantages of the respective production function is that, unlike Cobb-Douglas production function, it does not assume rigid premises such as perfect or smooth substitution between production factors or perfect competition on the factor markets (Klacek et al., 2007). The concept of the translog production function also permits to pass from a linear relationship between the output and the production factors to a nonlinear one. Due to its properties, the translog production function can be used for the second order approximation of a linear-homogenous production, the estimation of the Allen elasticities of substitution, the estimation of the production frontier or the measurement of the total factor productivity dynamics.

The generalized form of translog production function, which takes into account a number of *n* inputs (production factors), can be expressed as:

$$\ln Y = \ln A_{\alpha i, \beta ij} + \sum_{i=1}^{n} \alpha_i . \ln X_i + \left(\tfrac{1}{2}\right). \sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} . \ln X_i . \ln X_j \quad (1)$$

In a translog production function, it is important to note that the marginal product of the production function is a Cobb-Douglas production function (Pavelescu, 2011). Moreover, Ferguson (1979) demonstrated that the marginal product is equal to the elasticity of scale.

Following Kumbhakar et al. (2000), a flexible transcendental logarithmic production function model is also specified with time variable included in the stochastic production function as:

$$\begin{aligned} \ln Y_{it} = {} & \alpha_0 + \sum_j \alpha_j \ln X_{jit} + \alpha_i t + \\ & \tfrac{1}{2} \sum_j \sum_k \alpha_{jk} \ln X_{jit} \ln X_{kit} + \\ & \tfrac{1}{2} \alpha_{it} t^2 + \sum_j \alpha_{jt} \ln X_{jit} t + v_{it} - u_{it} \end{aligned} \quad (2)$$

where Y_{it} is the natural logarithm of output of the i^{th} farm at time *t*, X_{jit} is a k×1 vector of input quantities of the i^{th} farm, *t* is a time-specific effect, ln represents the natural logarithm, the subscript *i* represents the i^{th} farm, $\alpha_0, \alpha_j, \alpha_i, \alpha_{jk}, \alpha_{it}$ and α_{jt} are a vector of unknown parameters to be estimated, v_{it} are the random error term which is assumed to be iid N $(0, \sigma_v^2)$ and independent of the u_{it} which are non–negative random variables, accounting for technical inefficiency in production and assumed to be iid N $(0, \sigma_u^2)$.

The variables considered in the analysis include natural logarithm form of output of pigeonpea as dependent variable, and independent variables include labor (both family and hired ones), plot size, quantity of seed and manures. Moreover, the model includes a time variable to capture the effect of technological progress through time representing technical efficiency across farmers during the period of 2008 to 2010.

RESULTS AND DISCUSSION

Socio-economic characteristics of households

The socio-economic characteristics of all surveyed households both in 2008 and 2010 production seasons are presented using Table 1. Results showed that the mean level of age of the household head, education level of the household head and family size have significantly increased between 2008 and 2010. However, experience of growing pigeonpea did not significantly change.

Results also indicated that both the proportion of household heads who have a role in their community and membership to farmer associations increased from 13.4 to 19.5% and 18.3 to 24.9%, respectively. Moreover, while the percentage of female headed households in the survey increased from 10.6% in 2008 to 12.2% in 2010, farmers' access to credit improved from 4.1 to 15.5%, suggesting that an average farmer seemed to have better access to inputs in 2010.

Determinants of Pigeonpea productivity

In order to identify the underlying determinants of pigeonpea productivity, the panel data on the crop output were analyzed using the random effect maximum likelihood method. Table 2 presents the random effect maximum likelihood estimation results of the transcendental logarithm production function. Among the factors regressed on the output of pigeonpea, inputs such as plot size (*lnplotsize*), amount of labor used (*lntotlabr*), interaction between plot size and quantity of seed (*lnplotsizelnseed*), and the interaction of quantity of seed with time (*lnseedtime*) found positively and significantly affecting pigeonpea productivity.

Furthermore, the interaction between the amount of labor used and quantity of manure applied (*lnlabrlntotmanu*)

Table 1. Summary statistics of all households in 2008 and 2010 production seasons.

Characteristics		2008 (N=613)	2010 (N=605)		
		Mean	**Mean**	***t*-ratio**	**Sig.**
Age of the household head (year)		46.89 (13.42)	48.74 (13.12)	-2.44***	0.01
Pigeonpea growing experience (year)		14.43 (10.89)	14.50 (10.86)	-0.11	0.91
Education of the household head (year)		5.80 (2.88)	6.06 (2.74)	-1.61*	0.10
Family size		6.12 (2.24)	6.39 (2.30)	-2.03**	0.04
Dummy variables	***Response***	***Freq. (percent)***	***Freq. (percent)***		
Household head's role in the community	No (0)	531 (86.6)	487 (80.5)		
	Yes (1)	82 (13.4)	118 (19.5)		
Households' membership to farmer associations	No (0)	501 (81.7)	454 (75.1)		
	Yes (1)	112 (18.3)	151 (24.9)		
Gender of the household head	Female (0)	65 (10.6)	74 (12.2)		
	Male (1)	548 (89.4)	531 (87.8)		
Access to credit	No (0)	588 (95.9)	512 (84.6)		
	Yes (1)	25 (4.1)	93 (15.5)		

[a]Values in the parentheses are standard deviations
*, ** and *** denote significance at 10, 5 and 1% probability levels, respectively.

contributed positively and significantly to pigeonpea productivity. On the other hand, interaction between plot size with labor use (*lnplotlntotlabr*) and interaction between plot size with time (*lnplotsizetime*) affected productivity of pigeonpea negatively and significantly. The finding of this study is consistent with those from similar studies where plot size has a positive and statistically significant effect on crop productivity (Baten et al., 2009; Goyal and Suhag, 2003). However, it is contrary to the findings by Mwakalobo (2000) where the contribution of land to coffee productivity is found to be negative. Moreover, interaction between plot size and seed use and the interaction between seed use and time in this study suggests that a simultaneous increase in the amount of seed use with plot size as well as with time could significantly and positively contribute to increased level of pigeonpea productivity. The results are in line with other empirical findings reported by authors such as Goyal and Suhag (2003) where seed use contributed positively and significantly to productivity.

In the current study, human labor affected the productivity of pigeonpea positively and significantly which is also similar with the findings by Goyal and Suhag (ibid) where labor contributes positively and significantly to wheat productivity in northern India but in contrary with the findings by Baten et al. (2009).

The significant and negative coefficient for plot size interacted with time and the significant and positive coefficient for the interaction between the level of seed used with time implied that the type of technical change has been seed-using but land-saving. This result suggests that technological progress for smallholder pigeonpea production mainly depends on factors, such as improvement and access to quality seed. On the other hand, the negative but significant coefficient for the interaction between plot size with labor use implies that a simultaneous increase in plot size and amount of labor employed, while other factors kept constant, could negatively affect productivity. This might be due to mainly their interaction with time which showed that the type of technical change has been land-saving but labor-using. Moreover, the positive coefficient for time squared revealed that there has been technological improvement in smallholder pigeonpea production systems over the period of 2008 to 2010, although it is insignificant.

Elasticity analysis

Table 3 presents the elasticity of mean output to input changes. Elasticities of output for manure, quantity of seed and labor were statistically significant. Results also indicate that seed was the most determinant factor of pigeonpea production process.

The elasticity of pigeonpea output with respect to a change in the amount of seed was 0.591, implying that if the seed of pigeonpea were to be increased by one percent, then the total output of pigeonpea could be increased by 0.59%. This suggests that technological improvements in pigeonpea seed and farmers' access to it could have significant contribution towards increasing output, reducing poverty and achieving nutrition and food security of poor families in the study areas.

In addition, the elasticity of labor was 0.41 and that of manure had an elasticity of 0.179. These results suggest that a one percent increase in employment of labor and application of manure could result in 0.41 and 0.179%,

Table 2. Translog production function for pigeonpea production (Random effects maximum likelihood method) (Unbalanced panel data).

Variable	Description	B	S.E.	*z*
constant	Constant	1.533***	0.387	3.96
Lnplotsize	Natural log of plot size (acres)	1.096***	0.317	3.46
Lntotmanu	Natural log of total manure used(ton)	-0.335	0.367	-0.91
Lnseed	Natural log of quantity of seed use(kg)	0.200	0.315	0.64
Lntotlabr	Natural log of total labor used(man-days)	1.222***	0.315	3.89
Hlftimesqr	Half of time squared	-0.763*	0.436	-1.75
Lnplotlntotlabr	Interaction between plot size and labor	-0.24***	0.09	-2.65
lnplotlntotmanu	Interaction between plot size and manure	0.034	0.08	0.42
lnplotsizelnseed	Interaction between plot size and seed	0.201***	0.072	2.82
Lnplotsizesqr	0.5 *of squared natural log of plot sizes	0.071	0.112	0.63
Lntotmanusqr	0.5* of squared natural log manure uses	-0.140	0.13	-1.05
Lnseedsqr	0.5 *of squared natural log of seed uses	-0.18**	0.086	-2.13
Lntotlabrsqr	0.5 *of squared natural log of labor uses	-0.137	0.111	-1.25
lnlabrlntotmanu	Interaction between labor and manure	0.218**	0.106	2.05
lntotlabrlnseed	Interaction between labor and seed	-0.026	0.08	-0.33
lnseedlntotmanu	Interaction between seed and manure	-0.21**	0.019	-2.35
Timesqrd	Time squared	0.220	0.22	1.00
Lnplotsizetime	Interaction between plot size with time	-0.53***	0.12	-4.42
Lntotmanutime	Interaction between manure use with time	0.16	0.22	0.74
Lnseedtime	Interaction between seed use with time	0.45***	0.12	3.60
Lntotlabrtime	Interaction between labor use with time	0.036	0.13	0.28
Sigma_u		0.362	0.048	
Sigma_e		0.696	0.027	
Rho		0.213	0.054	

Log likelihood = -1039.1761

Likelihood-ratio test of *sigma_u* = 0: χ^2 (01) =13.90 Prob > = χ^2 = 0.000

*, ** and *** denote significant at 10, 5 and 1% probability levels, respectively.

Table 3. Elasticities of conventional inputs.

Inputs	Elasticity	*t*-ratio
Constant	3.207***	20.87
Natural log of plot size	-0.014	-0.29
Natural log of total manure used(ton)	0.179***	3.95
Natural log of quantity of seed use(kg)	0.591***	12.88
Natural log of total labor (man-days)	0.410***	8.77
Returns to Scale	1.167	

*** Significant at 1% probability level.

respectively, increase in pigeonpea output. Input elasticity results also revealed that technical change has been labor and seed-using and that technological progress for smallholder pigeonpea production mainly depends on seed and labor inputs. Plot size had a negative but insignificant effect on productivity which also supported the earlier conclusion that the type of technical change has been land-saving; perhaps the current level of land use is at the stage of diminishing returns to input. The returns-to-scale for the production function, computed as the sum of the elasticities of all inputs, was 1.167, suggesting that pigeonpea producers were experiencing increasing returns to scale, meaning that a given percentage increase in all inputs simultaneously could result in a higher proportionate increase in output.

CONCLUSION AND RECOMMENDATIONS

Using a translog frontier production analysis for the smallholder pigeonpea production in Northern Tanzania, results showed that inputs including plot size, labor, interaction between plot size and quantity of seed, and the interaction between seed use and time positively and significantly affected pigeonpea productivity. The study also found that the technical change has been in favor of labor and seed-using but in disfavor of land-using. The result implied that technological progress for smallholder pigeonpea production mainly depends on factors such as improvements in human capital and quality of seed. It is also found that there was technological improvement in smallholder pigeonpea production systems over the period of 2008 to 2010. Moreover, findings revealed that output of pigeonpea could respond positively and significantly for the change in the quantity of manure, seed and labor inputs. Furthermore, returns-to-scale for the pigeonpea production function showed that farmers were experiencing increasing returns to scale.

Findings of this study support a continuing emphasis to be given for human capital development of farmers through extension and training and technological improvements in pigeonpea seed. Moreover, farmers should also be encouraged to apply more manure, seed and labor so as to increase pigeonpea production under the existing plot size.

ACKNOWLEDGEMENTS

The authors would like to thank the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) for providing the data set to undertake this study. They are also most grateful to the anonymous reviewers of the paper for their valuable comments that helped in improving the paper.

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