

RESEARCH ARTICLES

ECONOMICS AND TECHNOLOGICAL GAP RATIOS OF AGROFORESTRY PRODUCTION IN RURAL AREAS OF KADUNA STATE, NIGERIA: IMPLICATION FOR ENVIRONMENTAL RESOURCE MANAGEMENT

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ABSTRACT

This study evaluated the economics and technological gap ratios (TGRs) of agroforestry production in rural areas of Kaduna State, Nigeria: Implication for environmental resource management. A multi-stage sampling technique was used. A total sample size of 120 respondents comprising of 62 (51.67%) male agroforestry farmers and 58 (48.33%) female agroforestry farmers were selected. Primary data were collected with the aid of a well-structured and a well-designed

questionnaire. Data were analyzed using the following tools: descriptive statistics, stochastic production efficiency frontier model, stochastic meta-efficiency frontier model, and principal component model. The farm size, labour input, chemical input, fertilizer input, and agroforestry tree density contributes positively to output of male, female agroforestry farmers as well as pooled data respectively. The average agroforestry farmers achieve 83.1% (male), 64.7% (female) and 72.8% (pooled) of their frontier output given their present technologies. In other words, agroforestry farms are losing 16.9%, 35.3% and 27.2% of their maximum potentials output to inefficiencies. The mean technical efficiency relative to meta-frontier was estimated to be 74%, 47% and 59% for the male, female agroforestry farmers and the pooled data respectively. Based on the estimated technological gap ratios (TGRs) of 90%, 73% and 82% for the male, female agroforestry farmers and the pooled data respectively, the average male and female agroforestry farmers and the pooled data could be more technically efficient by increasing their output and closing the gaps of 10%, 27% and 18% respectively. The study recommended that farmers should be educated on the benefits of agroforestry production technologies.

Key words: Economics, technology gap ratios, agroforestry production, stochastic meta – efficiency frontier model, gender

INTRODUCTION

The Food and Agriculture Organization, FAO (2015) defined agroforestry as a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence. Agroforestry is a combination of forestry and agriculture; it is an intensive land management system that optimize the benefit from the biological interactions created when trees and or shrubs are combined deliberately with crop and/ or animals. Agroforestry is a proven model of integrated sustainable land use system which can enhance agricultural productivity and production in a low input and in an ecological and economically feasible way in the effort of enhancing food security sustainably (Mbow, 2015). Agroforestry has multiple economic and environmental benefit as it helps farmers adapt to rapidly changing weather patterns and combat climate change (IPCC, 2019a). Agroforestry reduces soil and water erosion, improves water management, and reduces crop yield variability, all of which contribute to adaptation (Ajayi et al., 2019). The growing of trees on the border of the crop land is a good source of income for smallholder farmers on one hand and on the other

hand plays an important role in increasing soil fertility, enhances biodiversity and cleans water that ultimately reduces global warming by carbon sequestrations (Ingwe et al., 2009). Agroforestry systems are both stable and sustainable, it has greater diversity than do monoculture practices and can distribute production over a long period, thus provide income that is more regular with increased cash flow stability. Integrating of trees into agricultural systems may result in more efficient use of sunlight, moisture and plant nutrients than is generally possible by monocropping of either agricultural or forestry crops (Amonum et al., 2009). Agroforestry production technology also have economic dimension since it helps maximize agricultural production by reducing soil erosion, water, and organic matter losses. The practice can increase microbial activities which can help nutrient recycling, thus increase the fertility of soil under agricultural production (Jose, 2009). Forests contribute to the resilience of agricultural systems in many ways. At landscape level, they contribute to water and temperature regulation and provide habitats for important species such as pollinators. Agroforestry production technologies have contributed a lot in the protection of watershed services and maximize the production systems. The role of agroforestry is important on current Sustainable Development Goals of the United Nations through climate change adaptation and mitigation. The trees also have a significant contribution in fixing nitrogen that can increase agricultural productivity. Agroforestry is an efficient adaptation strategy known for its capacity to increase resilience and reduce vulnerability of agricultural production systems to climate change effects (Palsaniya and Ghosh, 2016). Agroforestry practices are essential resources to combat climate because of their role in sequestering carbon and other greenhouse gases (AAC, 2014). The choice of tree species is the most important factors to be considered in agroforestry systems. The choice of tree species be made after careful consideration of their benefit for rural populace and adaptability for growth. Restoring degraded forests to healthy states, thereby re-establishing ecosystem functions, is a major strategy for increasing resilience., inundation and flood damage, saltwater intrusion and sea- level rise, and damage from coastal storms. The importance of forests as safety nets in times of natural disasters (e.g. floods and droughts) or civil unrest is well documented (Angelsen and Wunder, 2003). During these times, forests are often relied upon to provide food for the household or products to sell for survival. They also fill gaps in other times of difficulty. While heightened dependence on forest foods and products generally drops off when times return to normal, it is important to keep the safety net option open (i.e. not restricting access of vulnerable people to forests when needed for survival), particularly where relief services and social services are not adequately developed to meet emergency needs. Agroforestry is a combination of forestry and agriculture; it is an intensive land management

system that optimize the benefit from the biological interactions created when trees and or shrubs are combined deliberately with crop and/ or animals. The system is intentional, intensive, interactive, and integrated. Agroforestry, the integration of trees in agricultural activities has the capacity to increase soil fertility, reduce evaporation, increase nutrient recycling, reduce land degradation from erosion, and improvement of water quality. Agroforestry system contribute to the rural economy through poverty alleviation, employment generation, and environmental protection at a local, regional and national level (Alavalapati et al., 2004). Agroforestry production technology also have economic dimension since it helps maximize agricultural production by reducing soil erosion, water, and organic matter losses.

A technical efficient firm is the one that produces the maximum output for a given amount of inputs given the level of production technology available. Efficiency implies that firms produce the largest possible quantity of output from a given set of inputs. Efficiency of a firm comprises of two components, technical and allocative efficiency, but that a combination of the two components give a measure of total economic efficiency (overall efficiency). The firm's technical efficiency is the ability to produce maximum output from a minimum quantity of inputs (Obianefo et al., 2021). Stochastic meta-technical efficiency frontier model can be defined as an envelope of all individual production functions. The approach allows the estimation of technology gap ratios, the technological differences between male and female agroforestry farmers, the approach shows how far or how close the individual production technologies are to the best possible production technology (the stochastic meta-technical efficiency frontier model) (Missiame et al., 2021). The stochastic meta technical efficiency frontier relaxes the assumption that firms in an industry face one or the same production technology. It allows a likelihood ratio test (statistical test) to confirm whether there are any differences in technology (Missiame et al., 2021). Estimation procedure when technologies are not the same (technologies are dissimilar) which are prevalent in the situations where comparison of industries/farms from different groups or regions are involved, the stochastic meta-technical efficiency frontier (SMTEF) is more appropriate for such comparative analysis (Onumah et al. 2013). Nan and Basil (2015) reported that stochastic meta technical efficiency frontier is a procedure developed to determine whether there is any difference between technologies adopted among firms. The SMTEF model can be used to evaluate the production efficiency frontier from a non-parametric approach (may or may not rely on normal distribution, mean, variances or rely on assumptions about the populations). The SMTEF model provides the economists with effective

and efficient way to evaluate and compare firms' relative production performance (Huang et al., 2014).

Women account for more than half of the work force by participating in different farm activities, either directly or indirectly. In sub-Saharan Africa women are the backbone of the agricultural sector. Women accounted for 60% of agricultural production, 70% of agricultural labor, and 80% of food production (Alabi et al., 2021). The roles of women, the main actor in sub-Saharan African agriculture have not been recognized. Rural women run most of their farm activities themselves, provide most of the agricultural labour, constitutes majority of small-scale, smallholder farmers, are mostly the head of the households and manage their farms on a daily basis (Alabi et al., 2021).

MATERIALS AND METHODS

This study was conducted in Kaduna States, Nigeria. Kaduna State lies between Longitudes 06° 15' and 08° 50' East and Latitudes 09° 02' and 10° 36' North of the equator. The State has a total land area of 4.5 million hectares. The mean rainfall is about 1,482mm, the temperature of the State ranges from 35°C - 36°C, which can be as low as 10°C to 23°C during the harmattan period. The population of the State in 2021 stood at 8.9 million people. They are involved in agroforestry production. One hundred and twenty (120) respondents comprising of 62 (51.67%) male agroforestry farmers and 58 (48.33%) female agroforestry farmers were selected. Multi-stage sampling technique was employed. The sample frame of male and female agroforestry farmers was 73 and 67 respectively. Primary sources of data were used. Data were obtained through a well-designed and a well-structured questionnaire. This study employed the formula advanced by Yamane (1967) in the determination or estimation of the sample size. The formula is stated thus:

$$n = \frac{N}{1+N(e^2)} \dots\dots\dots(1)$$

Where,

n = Desired Sample Size

N = Sample Frame (Number)

e =Maximum Acceptable Margin of Error as Determined by the Researcher

Data were analyzed using the following tools:

Descriptive Statistics

This involves the use of frequency distributions, mean, percentages, and standard deviation to summarize the socio-economic characteristics of male and female agroforestry farmers and pooled data as specified in objective one (I).

This was used specifically to achieve objective one (I)

Stochastic Production Efficiency Frontier Model

According to Alabi et al. (2022) and Alulu et al. (2021), the stochastic production frontier model for male and female agroforestry farmers is stated thus:

$$\ln Y_{ik}^z = \beta_{ok}^z + \sum_{j=1}^5 \beta_{ik}^z \ln X_{ijk}^z + v_{ik}^z - u_{ik}^z \dots \dots \dots (7)$$

$$\ln Y_{ik} = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + v_{ik} - u_{ik} \dots \dots \dots (8)$$

Where,

Y_{ik} = Output of Agroforestry (Kg)

k = Male and Female Agroforestry Farmers

X_{ijk} = Vectors of Factor Inputs

β_{ik} = Vectors of Parameters

v_{ik} = Statistical Noise

u_{ik} = Error Term due to Technical Inefficiency

X_1 = Farm Size (Ha)

X_2 = Labour Input in Mandays

X_3 = Chemical Input in Litres

X_4 = Fertilizer Input in Kg

X_5 = Agroforestry Trees Density (Number of Trees on the Farm Land)

$$u_{ik} = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 \dots \dots \dots (9)$$

Where,

Z_1 = Age in year

Z_2 = Experience in Agroforestry (Years)

Z_3 = Years of Formal Education

α_0 = Constant Term

$\alpha_1 - \alpha_6$ = Parameters to be Estimated

u_{ik} = Error Term due to Technical Inefficiency

This was used specifically to achieve objectives two (ii) and four (iv)

Stochastic Meta-Technical Efficiency Frontier Model

Stochastic meta-technical efficiency frontier model according to Alulu et al. (2021) for pooled data for agroforestry farmers is given by:

$$\ln Y_i^{z*} = \beta_o^{z*} + \sum_{j=1}^5 \beta_j^{z*} \ln X_{ij}^{z*} + \varepsilon_{ij}^z, j = 1, 2, 3 \dots \dots \dots j \dots \dots \dots (10)$$

Y_i^{z*} = The Metafrontier Output

X_{ij}^{z*} = The Vector of Variable Inputs used in the agroforestry farms such as farm size (ha), labour input (mandays), chemical input (litres), fertilizer input(kg), agroforestry tree density (number of trees on the farm land)

- β_o^{z*} = The Constant
- β_j^{z*} = The Parameters to be Estimated
- ε_{ij}^z = The Error Term
- Asterisk (*) =The Meta-Frontier

The environmental-specific characteristics and economic-specific variables for the meta-technical analysis include climate change, and market access in kilometer. This was used specifically to achieve objectives three (iii) and four (iv)

Technological Gap Ratios (TGR_{ik}^z)

The ratio between the technology of the itch farm in the jet group and the best technology available for all group is called technological gap ratio (TGR_{ik}^z) and is defined as:

$$TE_{ik}^{z*} = TE_{ik}^z \times TGR_{ik}^z \dots \dots \dots (11)$$

Where,

- TE_{ik}^{z*} = Meta-Technical Efficiency
- TE_{ik}^z = Technical Efficiency of Individual Group
- TGR_{ik}^z = Technological Gap Ratio

Technological Gap Ratio (TGR) defined according to Missiame et al. (2021) and Obianefo et al. (2023) as the ratio of *jth* firm’s production frontier (Y_i^j) to the meta-frontier [$f^M(x_i^j \beta^j)$] as stated below:

$$TE_{ik}^{z*} = \frac{Y_i^j}{f^M(x_i^j \beta^j)} = TE_{ik}^z \times TGR_{ik}^z \dots \dots \dots (12)$$

Principal Component Analysis: The constraints facing agroforestry farmers and militating against agroforestry production practices were subjected to principal component analysis. This was used specifically to achieve objective five (v).

Log-Likelihood Ratio Test

The generalized likelihood-ratio (LR) test was used to validate the stated hypotheses. The model is specified as:

$$LR_c = -2[Ln(L(H_0) - Ln(L(H_a))] \dots \dots \dots (13)$$

If $LR_c > LR$ Tabulated, The Null Hpotheses (H_0) is Rejected

Where,

- LR_c = The Calculated Likelihood Ratio
- $L(H_0)$ = Likelihood Function for Stochastic Frontier Estimated by Pooling the Data
- $L(H_a)$ = The Sum of the Likelihood Function for the Two Groups (Male and Female) Stochastic Frontier Estimation

RESULTS AND DISCUSSION

Test of hypotheses for the analysis

The results of the hypotheses test of stochastic frontier assumptions are presented in Table 1. In the first hypothesis, the specification of the Cobb-Douglas production function for the data set of the group levels and also for the pooled data is rejected in favour of the alternative hypothesis which state that the stochastic frontier model is better than the ordinary least squares regression model or the Cobb-Douglas production function model. The Likelihood ratio (LR) statistics for male (27.14), female (21.85), and pooled data (36.75) were greater than LR critical value (20.15) each at 0.001 and 5 degrees of freedom respectively. This result is in line with similar findings of Kadua et al. (2022) who reported that the estimates stochastic frontier model is more consistent and accurate compared to the results in the Cobb-Douglas production function model. In the second null hypothesis or assumption that male agroforestry farms and female agroforestry production technologies are the same was also rejected. The LR statistics (42.65) was greater than the LR critical value (32.909) at 0.001 and 12 degrees of freedom, this confirmed the alternative hypothesis that the meta-technical efficiency frontier model is the appropriate estimation technique to use for this work. The specification of the meta-technical frontier model would not have been necessary if the agroforestry production technologies in the two farms (male and female) were the same. This result is in consonance with similar observations made by Asravor et al. (2015) and Onumah et al. (2013). The third hypothesis test confirmed that the inefficiency effects are present in all the models (i.e male, female frontiers, and the pooled data frontier). The LR statistics for male (28.51), female (23.17), and pooled data (34.42) were greater than LR critical value (20.515) at 0.001 and 5 degrees of freedom, this null-hypothesis is hereby rejected, this confirmed the existence of the inefficiency effects are existed in the models at every levels. This result is in line with findings of Ayinde et al. (2009). The fourth null hypothesis which state that the exogenous factors or variables included in the inefficiency model have no effects on agroforestry farmers' level of efficiency was rejected. This implies that the combined effects of the exogenous factors or variables hypothesized in the inefficiency model are statistically significant in explaining agroforestry farm efficiency. The LR statistics for male (31.26), for female agroforestry farmers (33.19), and pooled data (37.79) were greater than the LR critical (26.125) at 0.001 and 8 degree of freedom. This implies that the null hypothesis was rejected and the alternative hypothesis was accepted. This confirmed the influence of the exogenous factors on the variations of the agroforestry farmers' efficiency level.

Table 1. Results of the hypotheses test of stochastic frontier assumptions

S/N	Hypotheses	LR Statistics(λ)	LR Critical Value @ 0.001	DF	Decision
1	$H_0: \beta_{ik} = 0$				
	Male	27.14	20.515	5	Reject H_0
	Female	21.85	20.515	5	Reject H_0
	Pooled	36.75	20.515	5	Reject H_0
2	$H_0: f(X_i; \beta_M^2) = f(X_i; \beta_F^2)$ Pooled	42.65	32.909	12	Reject H_0
3	$H_0: \gamma = \delta_0 = \delta_1 = \delta_2 \dots = \delta_6 = 0$				
	Male	28.51	20.515	5	Reject H_0
	Female	23.17	20.515	5	Reject H_0
	Pooled	34.42	20.515	5	Reject H_0
4	$H_0: \delta_1 = \delta_2 \dots = \delta_6 = 0$				
	Male	31.26	26.125	8	Reject H_0
	Female	33.19	26.125	8	Reject H_0
	Pooled	37.79	26.125	8	Reject H_0

Source: Field Survey (2023)

Socio-economics and farm specific characteristics of agroforestry farmers

Table 2 presented the summary statistics of socio-economic and farm specific characteristics of agroforestry farmers. The mean age of 46 years (Male), and 44 years (Female) were indicated by the group specific variables and 45 years for pooled data. The mean experiences in agroforestry production technologies for male farmers were 12.7 years, for female farmers were 7.1 years and for pooled data were 6.4 years. These statistics demonstrate that the agroforestry farmers were young, agile, in their productive age, they are better experienced to handle farming challenges with strength and vigor, this will help them in adopting new agroforestry production technologies. In addition, age has an impact on the managerial capability of the respondents. This result is similar to the findings of Umar et al. (2020), and Obianefo et al. (2020). The household sizes were large with 9 people for male, 6 people for female agroforestry farmers, and 7 people for pooled data respectively. The large household sizes provide or is a good source of family labour for farm activities. On the average, the results indicated that male, female agroforestry farmers and pooled data spent 13, 10, and 11 years in formal learning institutions. This means that the agroforestry farmers had formal education and were literate but do not finish their secondary education. This result is similar with the findings of Bime et al. (2014) who reported that 58% of respondents had primary education. The mean yield and farm sizes were calculated as follows for male (1,951.31Kg/ha, 2.07ha), for female (1,631.7Kg/ha, 1.38ha) and for pooled data (1,852.4Kg/ha, 1.73ha) respectively. This shows that

the agroforestry farmers were smallholder farmers because they all had less than 5 hectares of farm land.

Table 2. summary statistics of socio-economic and farm specific characteristics of Agroforestry farmers

Variable	SI Unit	Male		Female		Pooled	
		Mean	SD	Mean	SD	Mean	SD
Age	Years	46	11.18	44	11.49	45	1.29
Household Size	Number	9	2.7	6	3.4	7	2.91
Experience in Agroforestry	Years	12.7	7.1	9.6	2.8	10.8	6.4
Formal Education	Years	13.84	5.18	10.91	6.0	11.41	4.56
Yield	Kg/ha	1,951.31	112.31	1631.7	146.31	1852.4	90.51
Farm Size	ha	2.07	0.97	1.38	0.74	1.73	0.98

Source: Field Survey (2023)

Parameter estimates for gender specific stochastic production frontier model

Table 3 presented the parameter estimates of the stochastic production frontier model for the male and female agroforestry farmers. The gamma values were 0.748 and 0.364 for the male and female agroforestry farmers. These statistics show that the male and female agroforestry farmers were 74.8% and 36.4% deviation from frontier output was coming out from the gender specific variables. The remaining 25.2% and 63.6% emanating from the random noise or disturbances. According to Obianefo et al. (2023), the gamma parameter in the stochastic production frontier model (SPFM) measures the inefficiency of production. Huang et al. (2014) reported that gamma value is used to measure how far output falls short of the achievable maximum. The male and female agroforestry farmers with higher gamma values are more efficient in delivering a quantity of output using the production technologies. Also, the cause of the inefficiency is attributed to their managerial characteristics, and not the obsolete production technologies. The sigma and Log -likelihood ratios were for male (0.069, - 24.816) and for female agroforestry farmers (0.038, -8.648) respectively. In the technical efficiency (TE) component, the results show that, farm size, chemical input, fertilizer input, and agroforestry tree densities are the significant factors that influence agroforestry production for male farmers at ($P < 0.01$). The fertilizer input, and agroforestry tree densities are the significant factors that influence agroforestry production for female farmers at ($P < 0.05$). The coefficients of fertilizers were positive and statistically significant for male (0.421) and female (0.291) agroforestry farmers respectively. This finding suggests that a 1% increase in the use of fertilizer input with other factors held constant will lead to 42.1% and 29.1% increase in output of male and female agroforestry farmers respectively. Therefore, there is need for agroforestry

farmers to be encouraged to apply fertilizer input to agroforestry farms to increase output in a way that is environmentally sustainable.

The estimates of gender-specific variables are presented at the bottom of Table 3. A gender-specific variable with a positive coefficient signifies that the variable has a negative effect on technical efficiency. In contrast, those variables with negative coefficients signifies that the respective variables have a positive effect on technical efficiency. The results show that experience in agroforestry at ($P < 0.01$) and years of formal education at ($P < 0.05$) were the significant factors influencing output of male agroforestry farmers. Also, experience in agroforestry and years of formal education are the factors significantly influencing output of female agroforestry farmers at ($P < 0.05$).

Table 3. Parameter estimates for gender specific stochastic frontier models

Variables	Male			Female		
	Estimate	Std. Error	Z	Estimate	Std. Error	Z
Farm Size	0.671***	0.1859	3.61	0.087	0.1474	0.59
Labour Input	0.189	0.372	0.51	0.142	0.1183	1.20
Chemical Input	0.116***	0.025	4.64	0.451	0.4214	1.07
Fertilizer Input	0.421***	0.136	3.09	0.291**	0.098	2.95
Agroforestry Tree Density	0.461***	0.130	3.55	0.492**	0.2102	2.34
Constant	8.205***	1.412	5.81	7.271**	2.587	2.81
Gender-Specific Variables						
Age	-0.030	0.05	-0.60	-0.030	0.1298	-0.231
Experience in Agroforestry	-0.202***	0.055	-3.68	-0.021**	0.0091	2.31
Years of Formal Education	-0.126**	0.052	-2.44	-0.316**	0.1183	2.67
Constant	-5.326	4.76	-1.12	-4.417	3.371	-1.31
Model Statistics						
Log-Likelihood	-24.816			-8.648		
Sigma	0.069			0.038		
Gamma	0.748			0.364		

Source: Field Survey (2023), ***-Significant at 1% probability level,
 **-Significant at 5% probability level, *-Significant at 10% probability level.

The coefficients of years of formal education are negative for male (-0.126) and female (-0.316) agroforestry farmers. A 1% increase in years of formal education and keeping other factors constant will lead to 12.6% decrease in technical inefficiency among male agroforestry farmers. Also, a 1% increase in years of formal education and keeping other factors constant will lead to 31.6% decrease in technical inefficiency among female agroforestry farmers.

Parameter estimates of the stochastic meta-frontier model (smfm)

The results of the stochastic meta-frontier analysis of pooled data for agroforestry production are presented in Table 4. In the diagnostic statistics, the study revealed that the gamma value was 0.648, this implies that the meta-frontier model experienced a 64.8% deviation from the maximum or expected optimal. This deviation from optimum output is associated with environmental and economic specific variables. The gamma value is a measure of variation in total output of agroforestry due to inefficiencies in the usage and combination of input variables. Therefore, to have a gamma value of 0.648 means that 64.8% of the variations in output of agroforestry farmers are due to inefficiency in farm level practices and input usage. This implies that the stochastic factors beyond the control of the agroforestry farmers contributes 35.2% of the variations in output.

Table 4. Parameter estimates of the stochastic meta-frontier model

Variable	Estimates	Std. Error	Z
Farm Size	0.245***	0.028	8.75
Labour Input	0.162***	0.0531	3.05
Chemical Input	0.004	0.009	0.44
Fertilizer Input	0.163***	0.059	3.78
Agroforestry Tree Density	0.481***	0.153	3.15
Constant	7.428***	2.141	3.47
Environmental/Economic Specific Variables			
Climate Change	0.721**	0.263	2.74
Market Access	-0.631	0.198	- 3.19
Constant	-18.064	7.002	- 2.58
Model Statistics (Diagnostic Statistics)			
Log-Likelihood	-158.340		
Sigma	0.027		
Gamma	0.648		

Source: Field Survey (2023), *-Significant at 1% probability level**

**-. Significant at 5% probability level, *-Significant at 10% probability level

According to Binam et al. (2008) the stochastic factors include unfavorable weather conditions, policy constraints, diseases and pest infestations, measurement errors, endowment constraints. The Log-likelihood function and the sigma values were -158.340 and 0.027 respectively. The results of the stochastic meta-frontier model (SMFM) show that the significant factors influencing output of agroforestry farmers were farm size ($P < 0.01$), labour input ($P < 0.01$), fertilizer input ($P < 0.01$), and agroforestry tree density ($P < 0.01$). All the variables included in the model had positive coefficients. A 1% increase in fertilizer input will lead to 16.3% increase in output of agroforestry farmers. Also, a 1% increase in farm size will lead to 24.5% increase in output of agroforestry farmers. This result is

consistent with the findings of Kodua et al. (2022). In the inefficiency components, variables with negative coefficients have a positive effect on the meta-technical efficiency (MTE). The inefficiency observed in the agroforestry production can be attributed to environmental and economic-specific variables. The significant environmental specific variable was climate change ($P < 0.05$). Climate change has positive coefficient (-0.721), this means a 1% change in climate will result to 72.1% increase in meta technical inefficiency. Climate change can be in the form of drought, flood, strong wind, sand dunes, high temperatures, high rainfall etc. This result is in line with findings of Ng'ombe (2017).

Estimates of technical efficiency (TE) and technological gap ratios (TGRs)

Table 5 presented the results of TE, TGR and meta-technical efficiency (MTE) for male, female agroforestry farmers and pooled data respectively. Technical efficiency gains convey directly into improvements in farmers benefit and farm household incomes. The results show that the mean technical efficiencies of stochastic frontier models are 0.831, 0.647 and 0.728 for male, female agroforestry farmers and pooled data respectively. This implies that on the average agroforestry farmers achieve 83.1% (male), 64.7% (female) and 72.8% (pooled data) of their frontier output given their present technologies and input use available to them. In other words, agroforestry farms are losing 16.9%, 35.3% and 27.2% of their maximum potential output to inefficiencies in agronomic farm practices and input use. Therefore, if agroforestry farmers have to achieve 100% of their frontier output, they should focus to close the gap between their current performance levels and the maximum potential performance of their agroforestry farms by minimizing the effects of some inefficiency factors. The best performing agroforestry farmers on the other hand achieves 99% and 93% of the frontier output for male and female groups, respectively. On the other hand, the least performing agroforestry farmers achieves 21% and 11% of their potential frontier outputs for male and female groups, respectively. The technological gap ratio measures the gap between male, female agroforestry and the technological that is available for the whole agroforestry industry given the vector of inputs.

This is in line with findings of Gero et al. (2020) and Nguyen et al. (2019). This means that if agroforestry farmers were technically efficient in relation to the stochastic frontier at the farm level, the agroforestry farmers could still increase output by closing a gap between their current performance and the best farm practice for the industry. The closer the value is to 1, the gap become smaller between the individual frontier and meta-frontier.

Table 5. Technical efficiency scores (TE) and technological gap ratios (TGRs)

Variable	Mean	Minimum	Maximum	Standard Deviation
Technological Gap Ratios (TGRs)				
Male	0.900	0.34	0.99	0.14
Female	0.730	0.21	0.98	0.15
Pooled	0.821	0.23	0.96	0.17
Technical Efficiency (TE) (Group Frontier)				
Male	0.831	0.21	0.99	0.27
Female	0.647	0.11	0.93	0.23
Pooled	0.728	0.14	0.97	0.22
Technical Efficiency (MTE) (Meta-Frontier)				
Male	0.748	0.12	0.96	0.21
Female	0.473	0.04	0.89	0.20
Pooled	0.598	0.06	0.92	0.21

Source: Field Survey (2023)

As further shown in Table 5, the technological gap ratios (TGRs) are 0.90, 0.730, 0.821 are calculated for male, female agroforestry farmers and pooled data respectively. This implies that if the average male and female agroforestry farmers and the pooled data were to be technically efficient (i.e on their group frontier) they would still increase their output by closing a gap of 10%, 27%, and 18% respectively, if they were to employ the most efficient meta-technology for the entire agroforestry farming sector. This implies that the gap between the current agroforestry technologies and the meta-frontier is smaller in the male agroforestry farms than in the female agroforestry farms. However, the gap in technology ranges from a minimum of 0.14 to 0.99 for the male agroforestry farms and 0.21 to 0.98 for the female agroforestry farms. The mean technical efficiency scores for male agroforestry farms and female agroforestry farms relative to the meta-frontier efficiency scores are 0.748 and 0.473 respectively. The values of the technical efficiency scores relative to the meta-frontier means that male agroforestry farms are more efficient than female agroforestry farms. This maybe attributable to the correct and timely use of agroforestry technologies by male farmers. Furthermore, the technical efficiency (TE) scores relative to the individual group stochastic frontiers were greater than that of those relative to the meta-frontier. The difference between the two (2) efficiency scores shows the order of bias efficiencies obtained when using the group frontier relative to the technology available for the entire industry. Kodua et al. (2022) reported the

position that using the estimates from the individual group frontiers for male agroforestry farms and female agroforestry farms for comparison of technical efficiencies may be misleading.

Types of agroforestry production technologies among rural farmers

Table 6 presented the various types of agroforestry production technologies among the rural farmers. The results show that the agroforestry production technologies were the retaining of forest trees on farmland had the highest frequency ($f = 76$) with 17% of the total percentage score, this is followed by windbreak with ($f = 71$) having 15.88% of the total percentage score. According to Amonum et al. (2009) who described windbreak as agroforestry system where double rows of forestry trees are planted around the boundary of a food crop farm especially on the windward side. The major advantage is that windbreak reduce erosion and also at the same time produce forest alongside food crops. The home gardens came third with 11.63% of total percentage score ($f = 69$). In home garden agroforestry systems, multipurpose shrubs and trees are grown in association with agricultural crops and raised with livestock in homesteads. The frequency and percentages of other agroforestry production technologies practiced among rural farmers include alley cropping ($f = 52$, 11.63%), shelterbelt ($f = 50$, 11.19%), taungya farming ($f = 47$, 10.52%), aqua forestry ($f = 42$, 9.40%), and border planting ($f = 40$, 8.95). Annual or perennial crops are grown between the rows of trees which provides short term income before the trees bear nuts and fruits or are harvested for timber. Some shrubs and trees species commonly found in agroforestry systems are *Parkia biglobosa*, *Adansonia digitata*, *Vitellaria paradoxa*, *Tamarindus indica*, *Tectonia grandis*, *Elaeis guineensis*, *Citrus sinensis*, *Mangifera indica* L., *Azadirachta indica*, *Moringa oleifera*, *Vernonia amygdalina*, *Carica papaya*, *Jatropha curcas* L., *Eucalyptus camaldulensis*, *Acacia Senegal* etc.

Constraints faced by agroforestry farmers

The constraints faced by agroforestry farmers was subjected to principal component analysis and presented in Table 7. In the analysis, the constraints with Eigen-values greater than one were retained by the model, while the constraints with Eigen – values less than one were discarded. From the results, lack of credit facilities was ranked 1st based on the perception of the agroforestry farmers with Eigen value of 5.9537, and this explains 31.28% of all constraints retained by the model. Lack of fertilizer input was ranked 2nd based on the perception of the agroforestry farmers with Eigen-value of 3.2672, and this explains 50.02% of all constraints retained by the model.

Table 6. Agroforestry Production Technologies among Rural Farmers

Agroforestry Production Technologies	*Frequency	Percentage
Retaining Forestry Trees on Farmland	76	17.00
Home Garden	69	15.43
Alley Cropping	52	11.63
Shelter Belt	50	11.19
Taungya Farming	47	10.52
Wind Break	71	15.88
Aqua Forestry	42	09.40
Border Planting	40	08.95
Total	447	100.00

Source: Field Survey (2023)

*Multiple Responses

Other constraints retained by the model include lack of agroforestry tree seedling (ranked 3rd, Eigen value = 2.5724), lack of chemical input (ranked 4th, Eigen value = 1.3469), and lack of extension contact (ranked 5th, Eigen value = 1.2540). All the constraints retained by the model jointly explained 74.66% of all constraints included in the analysis. The Chi square of 874.25 and KMO of 0.7928 was significant at ($P < 0.01$), this confirmed the justification of using the principal component model for the analysis.

Table 7. Constraints faced by farm level agroforestry farmers

Constraints	Eigen-Value	Difference	Proportion	Cumulative	Rank
Lack of Credit Facilities	5.9537	2.6865	0.3128	0.3128	1 st
Lack of Fertilizer Input	3.2672	0.6948	0.1874	0.5002	2 nd
Lack of Agroforestry Tree Seedlings	2.5724	1.2255	0.1237	0.6239	3 rd
Lack of Chemical Input	1.3469	0.09287	0.0576	0.6815	4 th
Lack of Extension Contact	1.2540	0.42068	0.0651	0.7466	5 th
Bartlett Test of Sphericity	874.25***				
Chi Square	0.7928				
KMO	1.0000				
Rho					

Source: Field Survey (2023)

CONCLUSION AND RECOMMENDATIONS

The meta-frontier analysis was used to evaluate the efficiency levels of the male agroforestry and female agroforestry farms in Kaduna State, Nigeria. A cross-section data was employed with a total of 120 farms comprising of 62 male agroforestry farms and 58 female agroforestry farms. The results show that the agroforestry farmers were young, active, productive in their middle-age. All the input variables considered in the stochastic frontier and meta-frontier models have

positive effect on agroforestry production for both male and female farmers. Estimated technological gap ratios (TGRs) and technical efficiency with respect to meta-frontier model demonstrates that male agroforestry farmers are nearer to the best practice technology compared to their counterparts who are female agroforestry farmers. This also means that male agroforestry farmers are more technically efficient compared to the female agroforestry farmers. The study has shown that farm specific and gender specific factors together influence the technical efficiency of agroforestry farms under the group frontier. Also, farm specific and economic together with environmental factors influence the technical efficiency in the meta-frontier model, even though some variables are statistically not significant. The results show that in the stochastic frontier model, the fertilizer input, agroforestry tree density will increase output of male and female agroforestry farmers. Also, experience in agroforestry and years of formal education will increase technical efficiency (TE) of agroforestry production among male and female farmers. Also, in the meta-frontier model, farm size, labour input, fertilizer input, agroforestry tree density will increase the output of agroforestry farmers for the industry. Also, impact of climate change had adverse effect on technical efficiency of meta-frontier analysis of agroforestry farmers for the industry. The major agroforestry production technologies observed among rural farmers include: home gardens, alley cropping, shelter belt, wind break, taungya farming, aqua forestry, retaining forest trees on farmland and border planting. The major constraints facing agroforestry farmers include: lack of credit facilities, lack of fertilizer, lack of agroforestry tree seedlings, lack of chemical input, and lack of extension contact. The study recommended the following:

- (i) The use and practice of agroforestry production technologies among rural should be intensely encouraged and management skills pertaining to the use of such technologies should be improved to increase efficiency and productivity by reaping the full benefits it offers
- (ii) Education and training of agroforestry farmers should be intensified by relevant stakeholders including extension officers, research institutes and ministry of agriculture, such training and education should focus on agroforestry technologies, rightful application of fertilizers, and agrochemicals in terms of appropriate quantities, product and time of application.
- (iii) Knowledge management and information sharing on existing agroforestry production technologies among farmers should be promoted.
- (iv) Credit facilities should be made available for agroforestry farmers at low interest rate, devoid of cumbersome administrative procedure.

- (v) Agroforestry tree seedling should be given to farmers free for environmental resource management. Also, fertilizer input and chemical input should be provided for farmers at subsidized rate at appropriate time.
- (vi) Feeder roads should be constructed or rehabilitated for easy access of agroforestry farms.

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