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Effects of livelihood diversification strategies on income security status of women farmers in Niger state, Nigeria

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ABSTRACT

The study analysed the livelihood diversification strategies and its effects on food security status among women farmers in Niger State, Nigeria. A multistage sampling technique was used for this study. A total of 242 registered women farmers were randomly selected as respondents, data were analysed using inferential statistics such as (Simpson Index of Diversity, Foster-Greer-Thorbecke (FGT) and Probit regression model). Results obtained show that majority (67.8%) of the women farmers had moderate livelihood diversification, while 26.4% had low extent of diversification, that is, they depended on less than two sources of income. The results obtained also showed that 52.0% of the respondents were income insecure, while 48% were income secured. However, factors such as, age, level of education, family labour, access to government support, income from crop diversification, income from off-farm diversification and income from on-farm diversification were significant effects of livelihood diversification on income security of the women farmers households. The result conclude that majority of rural women households had moderate extent of livelihood diversification while only few had low extent of diversification with low income security status due to the economic situation of the nation. It was recommended that farm households should diversify their sources of livelihood into non-farm so as to increase their earnings to bridge the poverty gap.

KEY WORDS: *Livelihood*; *Income*; *Women*; Security; Diversification

1. Introduction

Agriculture is an essential sub sector of the economy of developing countries of the world. It contributes significantly to Gross Domestic Product (GDP) and employs large proportion of labour force (Habib *et al.*, 2023). According to World Bank (2018), the sub sector accounted for 4% of global gross domestic product (GDP) in developing countries. Babatunde (2013) stated that, in Nigeria, farming as a sole source of income has failed to generate adequate income for farm households to meet their needs. This can be attributed to the subsistence nature of their farming practices, decline in farm size, low level of produce turnout which characterize agricultural sub sector in developing countries (Asiga, 2013). Todaro and Smith (2015) opined that for growth and development of rural areas to take place, people, including women's living conditions must be elevated through incomes, consumption of adequate and right type of food, access to

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healthcare, education and freedom to choose from a variety of economic activities.

The role of women in agricultural development and agro-allied industries cannot be over emphasized. Their involvement in agriculture varies from country to country. Irrespective of these variations, women are actively involved in various agricultural activities. To this end, women represent a substantial share of the total agricultural labour force, as individual food producers or as agricultural workers, and that about two-third of the female labour force in developing economies is engaged in agriculture and related work (Uzokwe *et al.,* 2017). Rural women are actively engaged in various agricultural activities, including planting, weeding, harvesting, and tending to livestock. Their labour is fundamental to crop cultivation, ensuring a steady food supply for communities and nations (Uzokwe *et al.,* 2017). Despite their significant contributions to agriculture and rural development, rural women are often faced with resource constraints, limited access to productive resources, unequal access to extension services and agricultural training. Amid these challenges, poverty persists as a multifaceted issue in rural areas across the world, with rural women bearing a disproportionate burden. In Nigeria, as in many parts of the world, rural women face multifaceted obstacles that hinder their economic empowerment and overall well-being.

Recognizing these challenges, rural women often turn to livelihood diversification strategies as a means to improve their economic well-being and break free from the cycle of poverty. Livelihood diversification entails engaging in a range of income-generating activities beyond traditional agriculture. According to Uzokwe *et al.* (2017) these activities may include setting up small-scale businesses, participating in non-farm enterprises, exploring opportunities for off-farm employment, and collaborating in community-based initiatives. Diversification has two phases, which is either a shift away from agricultural activities or an increasing mix of income activities. The choice is often influenced by livelihood options available within the rural community (Uzokwe *et al.,* 2017). In Nigeria, rural women diversify their livelihoods by engaging in non-farm activities such as small business ventures, trading, and services (United States Agency for International Development [USAID], 2019). Rural women may start small-scale businesses, by selling food items or goods, provide services such as hair dressing, tailoring, or engage in petty trading in local markets. These activities can provide additional sources of income, which can help them become more self-sufficient and improve their overall well-being.

One of the primary reasons why rural women farmers engage in livelihood diversification is financial fluctuations (International Fund for Agricultural Development (IFAD), 2018). Agriculture, especially in developing countries, can be unpredictable and subject to various risks such as weather events, disease outbreaks, and market price fluctuations. Diversifying their income sources will provide women farmers with a more stable financial portfolio, reducing the effect of these risks and assisting them to better manage their finances. Akinwale (2011) classifies reasons of livelihood diversification into pull (favourable conditions which draw farm households into diversification) and push factors (harsh conditions that force households into diversification). Also, Women farmers often have limited access to production resources, which makes their ability to generate sufficient income from agriculture short changed. Diversifying livelihoods can help women farmers overcome these challenges and increase their income security (USAID, 2019).

Previous studies (Ojikutu, 2018; Shrestha *et al*., 2019; Dia *et al*., 2022) have examined the challenges faced by rural farmers and the broader poverty status of rural communities, shedding light on the impact on food security status among crop farmers in Nigeria. However, these studies have not delved into the specific effects of livelihood diversification strategies on the poverty status of rural women farmers. While Sali (2013) conducted similar studies, focusing solely on women rice processors, there remains a significant gap in empirical evidence regarding the effects of livelihood diversification strategies on the poverty status of women actively engaged in agricultural production in the study area. This identified knowledge gap form the basis for the study. Thus, this study aimed to examine the women farmer's livelihood diversification strategies, estimate the income security status of women farmers in the study area and assess the effect of livelihood diversification strategies on women farmers' income security status.

2. Material and Methods

This study was conducted in Niger State, Nigeria. The State was created in 1976. It is located in Guinea Savannah Region and lies between Latitude 8° 20′ and 11°30′ North and Longitudes 38° 30′ and 8° 20′ East of the equator (Dia *et al.*, 2022). The State covers an estimated land area of 74,244sq km of 7,424 million hectares covering

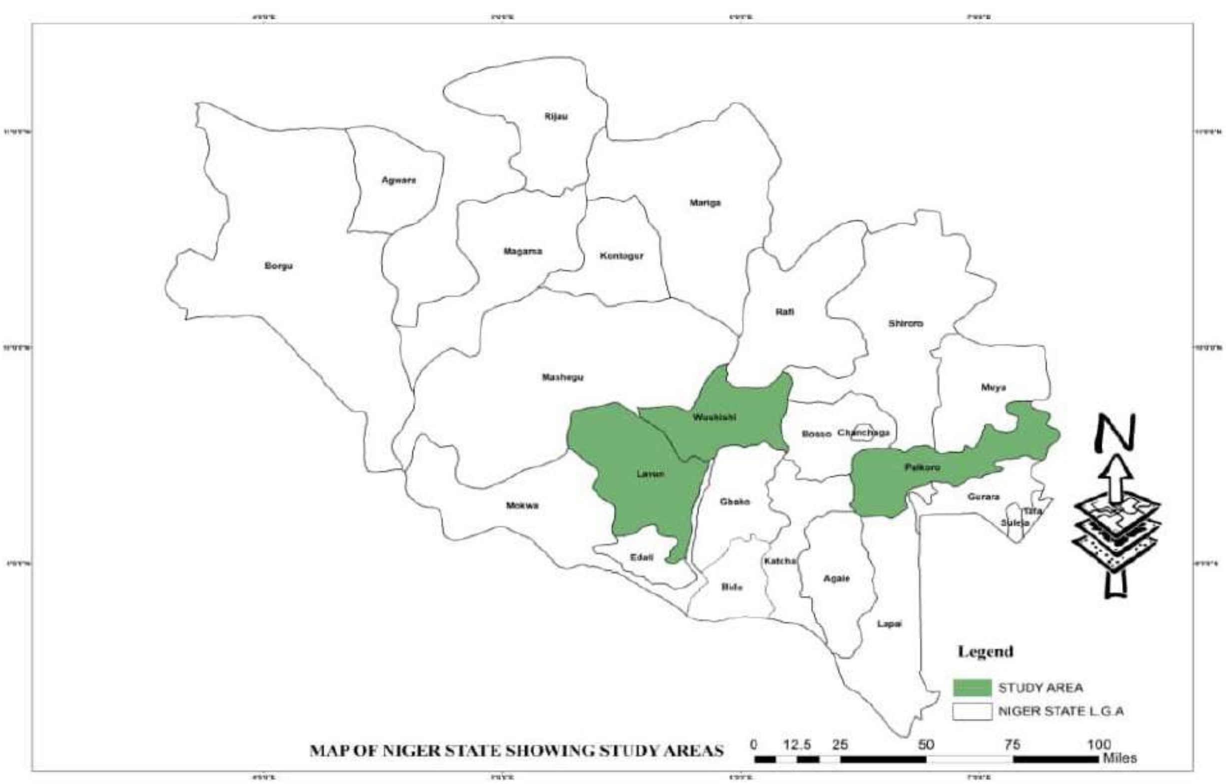

Fig. 1: Map of Niger State showing the selected LGAs

8% of the land area of the country. As at 2006 census the state has human population of about 3,950,249 people with Male population of 2,032,725 and female population of 1,917,524 (National Population Commission (NPC), 2006). The projected population as at 2021 using 3.2% growth rate was 6,139,477 with male population of 3,159,261 and female population of 2,980,216 (National Bureau of Statistics (NBS), 2021). An overview of the study area is shown in Fig. 1.

Three stage sampling technique was used in this study to select the respondents. In the first stage, one (1) Local Government Area (LGA) was randomly selected from each zone namely: Lavun LGA from zone I, Paikoro LGA from zone II and Wushishi LGA from zone III. In the second stage, three (3) villages were randomly selected from each of the three selected LGAs. The list of registered women farmers from each of the village selected was obtained from Niger State Agricultural and Mechanization Development Authority (NAMDA) as sample frame (that is 1832 women farmers). The sample outlay of the respondents in the study area is given in Table 1. The third stage involved selection of 242 respondents using the Taro Yammane sample size determination formula as used by Schuler and Boender (2012).

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

Where
n = Sample size required
N = Sampling frame
1 = constant
e^2 = level of precision (6%)

Simpson Index of Diversity was used to analyse the women farmers's livelihood diversification strategies, Foster Greer and Thorbek (FGT) index was used to evaluate income security status of women farmers and binary probit regression model was used to estimate the effects of livelihood diversification strategies on women farmers' income security status.

Table 1: Sample outlay of the respondents in the study area

LGAs/Zone	Villages	Sample Frame	Sample Size
Lavun I	Batati	289	38
	Kutigi	367	48
	Busu/Kuchi	68	9
Paikoro II	Kafinkoro	218	29
	Nikuchi	124	16
	Paiko	52	7
Wushishi III	Kodo	194	26
	Lokogoma	202	27
	Zungeru	318	42
Total	9	1832	242

Source: Niger State Agricultural Mechanization and Development Authority

2.1 Simpson index of diversity

The Simpson Index of Diversity as used by De Haan and Zoomers (2017) and is expressed as in equation (2):

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right) \text{ ------------------------------(2)}$$

Where:
n = number of livelihood diversification strategies employed by the rural woman
N = total number of livelihood diversification strategies available

The values of *SID* ranges between zero (0) and one (1). The index 1 represents high diversification, while 0 implies low diversification.

2.2 Foster-Greer-Thorbecke (FGT)

The mathematical formulation of income security status as derived from Foster, Greer and Thorbecke as used by De Haan and Zoomers (2017) is estimated as in equation (3) to (7):

$$P_{ai} = \frac{1}{n}\sum_{i-1}^{q}\left[{(z-y)}/{z}\right]^{a} \text{---------------------(3)}$$

Where;

a=0, $P_o = \frac{1}{n}\sum_{i-1}^{q}\left[{(z-y)}/{z}\right]^{0} = \frac{q}{n}$ → Income security incidence --(4)

a=1, $P_1 = \frac{1}{n}\sum_{i-1}^{q}\left[{(z-y)}/{z}\right]^{1}$ → Income security depth ---(5)

a=2, $P_2 = \frac{1}{n}\sum_{i-1}^{q}\left[{(z-y)}/{z}\right]^{2}$ → Income security severity --(6)

Where;
a = degree of income security
n = number of households in a group
q = the number of income insecure households
y = y the per capita income (PCI) of the ith household
z = income security line
Total per-capita income TPCI = Summation of PCI
Mean TPCI = TPCI/ Total number of households
Income security line PL = x MTPC

2.3 Binary Probit regression model

The Probit regression model is express explicitly as in equation (7):

$$Z = \beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_n X_n + U \text{ -----------------(7)}$$

Where;
X_1………..X_n are the explanatory variables.
Z= Income security status (Income secured = 1, 0 if otherwise).
X_1 = Age of the respondents (in years)
X_2 = Household size (numbers)
X_3 = Education (years)
X_4 = Access to local markets (access = 1, 0 if otherwise)
X_5= Farm size (Ha)
X_6 = Family occupation (Faming=1, otherwise=0)
X_7 = Extension contact (number)
X_8=Access to credit facility (amount received in ₦)
X_9 = Income from crop diversification (₦)
X_{10} = Income from Livestock diversification (₦)
X_{11} = Income from off-farm diversification (such as inputs supply and processing) (₦)
X_{12} = Income from Non-farm diversification (such as Handcrafts and white-collar job) (₦)
X_{13}= Access to Government support and palliative (value in ₦)
U= error term

3. Results and Discussion

3.1 Livelihood diversification strategies among the rural households

Simpson index was used to determine the livelihood diversification of women farmers in the study area. The value of Simpson index ranges between 0 and 1. Simpson index of 0 implies not diversify, while 1 means perfect diversification. The closer the value is to unity, the greater the degree of diversification. Results in Table 2 presents' the different livelihood activities in the study area. The participation was calculated by dividing the number of respondents that are engaged in a particular livelihood activity with the total number of respondents, and then multiply by 100. The results revealed that on-farm livelihood activities in the study area are land leasing, agro-processing, seed collection, input supply and farm labour. While off-farm livelihood activities are marketing, photo/video coverage, food vendor, soap making/selling, shoe making, private consultant, hair plaiting, tailoring and civil service amongst others.

Table 2: Livelihood diversification strategies

Variables	Yes (%)	No (%)
Farm activities		
Arable crop farming	231(95.5)	11(4.5)
Tree crop farming	59(24.4)	183(75.6)
Livestock farming	131(54.1)	111(45.9)
Vegetables farming	131(54.1)	111(45.9)
Fish farming	38(15.7)	204(84.3)
Poultry farming	153(63.2)	89(36.8)
On-farm activities		
Land leasing	96(39.7)	146(60.3)
Agro-processing	191(78.9)	51(21.1)
Seed collection	38(15.7)	204(84.3)
Input supplier	56(23.1)	186(76.9)
Farm labour	179(74.0)	63(26.0)
Off-farm activities		
Marketing	167(69.0)	75(31.0)
Photo/video coverage	10(4.1)	232(95.9)
Food vendor	161(66.5)	81(33.5)
Soap making/selling	197(81.4)	45(18.6)
Shoe making	61(25.2)	181(74.8)
Extension services	59(24.4)	183(75.6)
Hair plaiting	211(87.2)	31(12.8)
Tailoring	165(68.2)	77(31.8)
Civil servant	36(14.9)	206(85.1)

Source: Field survey, 2024

Based on farm activities, the result shows that arable crop farming (95.5%), livestock and vegetable farming (54.1%) and poultry farming (63.2%) have higher livelihood diversification among the women farmers in the study area. Agro-processing (78.9%) and farm labour (74.0%) are the on-farm livelihood activities with high diversification. Moreover, with regards to the off-farm activities, marketing, food vendor, soap making/selling, hair plaiting and tailoring had high level of participation amongst the rural crop farmers.

This implies that apart from farming, majority of the farm households are engaged in non-farm activities so as to increase their total earning. This is consistent with the findings of Afridi (2017) who found out that farming was the primary occupation of most households in the study area and that they also engaged mostly in non-farm activities such as petty trading, matting, tailoring, barbing, telecommunication services, and construction work as a means of livelihood diversification.

3.2 Extent of livelihood diversification

Results in Table 3, presents the extent of livelihood diversification of rural farming households in the study area. The measure of livelihood diversification, which takes into account the variations in the livelihood activities, was estimated using the Simpson diversification index. The higher the number of activities, the higher the value of Simpson diversification index. Results in Table 3 shows that all women farmers diversify their livelihood. Majority of farming households (67.8%) had moderate extent of livelihood diversification, while 26.4% had low extent of diversification. This is in line with findings of Afridi (2017) which shows that rural farming households do not rely only on farm incomes to sustain their livelihoods, but they also diversify their income sources into the non-farm sector driven by various motives.

Table 3: Simpson diversification class

Class Livelihood diversification	Simpson index	Frequency	Percentage
Low livelihood diversification	0.25-0.50	64	26.4
Moderate livelihood diversification	0.51-0.75	164	67.8
High livelihood diversification	0.76-1.00	14	5.8
Total	1.00	242	100

Source: Field survey, 2024

3.3 The income security status of the rural households

An income secure household is that whose per capita monthly earnings are at least two- third of the mean per capita monthly earnings on food expenditure. On the other hand, an income insecure household is that whose per capita monthly earnings are less than two-third of the mean monthly per capita earnings on food expenditure. Table 4 shows that the mean per capita earnings per month was estimated to be ₦35,522 and this value was used as income security index. That is, any respondent whose per capita monthly mean earnings is less than ₦35,522.0 (income security index) was regarded as being income insecure.

Table 4: Income security status of the rural households

Variable	Frequency	Percentage
Income secure	117	48
Income insecure	125	52
Total	242	100
Income security line / month	₦35,522	
Income security line / day	₦1,184.07	
Income security incidence	0.484	
Income security gap	0.137	
Severity of income insecurity	0.062	

Source: Field survey, 2024.

The distribution of the respondents by income security status in Table 4 reveals that majority (52.0%) of the respondents were income insecure, while 48% were income secure. This might be as a result of relatively low level of livelihood diversification among the women farmers in the study area. This corresponds with UN who stated that majority of the Nigeria live below $1 per day. This finding is in disagreement with Fakayode and Yusuf (2015) who found that 66.39% of the household were income secure while the remaining 33.61% were income insecure.

3.4 Effects of livelihood diversification on income security of the rural households

Probit regression model was used to examine the effects of livelihood diversification on income security of the women farmer's households in the study area. Thus, the result from Table 5 shows the Pseudo R^2 of (0.4159), implying that about (42%) of variations that occur in the income security of women farmers' were explained by the independent variables included in the models. while the remaining (58%) were due to error in measurement of some variables. The Prob chi-square is significant at 1% level of probability. This implies the model is fit for the objectives.

The coefficient of age of the respondents was found to be negative and significant at 10% level of probability. This implies that increase in the

Table 5: Probit regression on effects of livelihood diversification on income security status

Variables	Coefficient	Standard error	Z-value	p>|T|
Age	-0.0269	0.0149	-1.80*	0.072
Household size	0.00003	0.0003	0.09	0.931
Level of education	0.2008	0.0627	3.20***	0.001
Marital status	0.0612	0.0805	0.76	0.447
Farm size	-0.0467	0.0731	-0.64	0.523
Access to extension agent	-0.1719	0.2166	-0.79	0.428
Family labour	-0.5840	0.1978	-2.95***	0.003
Income from livestock diversification	0.0795	0.0604	1.32	0.188
Access to government support	0.0342	0.0170	2.01**	0.045
Income from crop diversification	0.0777	0.0155	5.01***	0.000
Access to local market	0.2814	0.1750	1.61	0.108
Income from off-farm diversification	0.7094	0.2169	3.27***	0.001
Income from on-farm diversification	0.1602	0.0485	3.30***	0.001
Constant	-2.2176	0.8849	-2.51***	0.012
Number	242			
LR $chi^2(13)$	91.03			
Prob > chi^2	0.0000***			
Pseudo R^2	0.4159			

Source: field survey, 2024

age of the farmers lead to decrease in the likelihood of income security of the farmers. As it may affect the tendency of diversification in various livelihood activities thereby reducing the earning capacity of the women farmers in the study area. This is in consonance with the findings of Shrestha *et al.* (2019) who reported that age of farmers has a positive influence on their income security status.

The finding also reveals that the coefficient of level of education of the women farmers is positive and significant at 1% level of probability. This implies that as the respondent's educational attainment increases, the level of the farmers' income security and livelihood diversification also increases. This might be as a result that education is a function of exposure of the respondents, which also enable the farmers easily understand the use and benefit of diversifying in various livelihood activities in the study area. This agrees with Uzokwe *et al.* (2017) who reported that level of education influences farmers decision to adopt a given technology or innovations. More so, the coefficient of family labour is negatively significant at 1% level of probability. This implies that the use of family labour limit the level of livelihood diversification thereby reducing the income security of the women farmers among the farming households in the study area.

The finding also reveals that the coefficient of access to government support is positive and significant at 5% level of probability. This implies that an increase in farmers' access to government support will lead to increase in the likelihood of the farmers' livelihood diversification and income security of women farmers in the study area. This agrees with Wepnes (2019) which showed that increase in farmers' access to government support alleviate the food security status of the rural households in the study area.

The finding reveals that the coefficient of income from crop diversification of the women farmers is positive and significant at 1% level of probability. This implies that as the respondents income increases the likelihood of the farmers' income security will also increases. This might be as a result level of status attained, which make the farmers to focus on one field of livelihood sustenance. This agrees with Uzokwe *et al.* (2017) which showed that increase in farmers income lead to proportionate increase in livelihood activities of the farming households in the study area. The finding also reveals that the coefficient of income from on-farm and off-farm diversification is positive and significant at 1% level of probability respectively. This implies that an increase in the additional sources of income of the women farmers from on-farm and off-farm sources will lead to increase in the likelihood of the farmers' income security status among the farming households in the study area. This agrees with Omondi (2018) who reported that increase in farmers income from various sources increase the farmers food security status among the farming households in the study area.

4. Conclusion

The study concluded that majority of women farmers had moderate extent of livelihood diversification while only few had low extent of diversification. It was also concluded that majority of the respondents were income insecure. However, age, level of education, family labour, access to government support, income from crop diversification, income from off-farm diversification and income from on-farm diversification were significant effects of livelihood diversification on income security of the women farmers households. Based on the findings of the study, the following recommendations have been advanced:

i. Farmers should explore opportunities to diversify their income sources beyond traditional agricultural activities. This could include engaging in off-farm activities such as small-scale businesses, livestock rearing, or agro-processing ventures.

ii. The State Government should invest in education and training programmes tailored towards improving the needs of women farmers, focusing on building skills relevant to diversified livelihoods. These programs could cover areas such as entrepreneurship, vocational training, agricultural practices, and financial literacy to empower women farmers to engage in diverse economic activities effectively.

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Estimation of soil water and the physical conditions of soils under different management practices on acid soils of Akwa Ibom state, Nigeria

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ABSTRACT

The study was carried out in Akwa Ibom State University, to estimate soil water and physical conditions of soil under different management practices on acid soils (coastal plain sands). The management practices were three land use types (fallow plot, grassland and cultivated). Soil and undistributed core samples were collected in three locations in each of the three land use types, bulked for physical and chemical analyses. Soil physical properties (total silt, silt, clay, bulk density, saturated hydraulic conductivity, and total porosity), chemical properties (organic matter, available phosphorus, calcium, magnesium, sodium, potassium, exchangeable acidity, effective cation exchange capacity, base saturation) and soil water characteristics were calculated. The data generated were fitted into 5×3 factorial experiment, Randomized Complete Block Design. The data were subjected into descriptive statistics and land uses were evaluated using Pearson Correlation analysis. For physical properties, the result revealed that sand was the dominant particle size fraction for all land management practices followed by clay and then silt. For chemical properties, the results revealed that base saturation recorded highest mean value at Grassland plot (49.86) and lowest at fallow plot (48.82). For soil water characteristics, Gravimetric Moisture Content (GMC) had highest mean value at cultivated plot (147.59) and lowest at fallow plot (86.19) respectively. The result of management practices shows that there were some relationships between some soil properties and soil water characteristics. Field water capacity correlated positively with permanent wilting point (1.000), correlation result also revealed that total sand correlated negatively with silt (-0.955) and organic matter (-0.777). The knowledge of management of soil water will guide on the proper management practice of soil water for effective productivity.

KEY WORDS: *Soil water characteristic*; *Physical chemical properties*; *Management practices*; *Acid soils*

1. Introduction

Non availability of soil water is a major obstacle in agricultural production, especially during dry spell and dry season in the area. Since soil is the main source of water taken by the roots of the plants, therefore the management of water in dry spell and dry season in the area is very crucial (Asgarzadeh, 2010). Kirkham (2005) viewed that scarcity or lack of moisture in the soil is not due to lack of the seasonal rainfall and the rain is not distributed well, it is also as the result of mis-

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management of irrigation processes. Poor soil structure leads to significant water losses in agricultural fields as well as limited water absorption capacity and field crop absorption capacity. Water is essential for plant growth and crop production. Kumar (2010) pointed out that water serves as the solvent and carrier of food nutrients, secured good tilt at right stage of moisture content, helps to achieve good structural formation, improve metabolic activities of micro-organisms, essential for the process of photosynthesis, water maintains the turgidity of plants, it also protects plants from adverse conditions like; drought, frost etc. often an excess deficit of water in the soil is a major problem in crop production and soil formation.

It is limiting factor in seed germination and plant growth. Physical soil quality is a recently widespread term known and is the ability of a particular type of soil to operate within the boundaries of the natural ecosystem to maintain plant productivity, maintain water and air quality and support human health (Essien *et al*., 2025; Essien *et al*., 2024). Mismanagement and improper land management practice as a result of the expansion of agricultural land at the expense of forest and pasture land can cause physical degradation of soils, such as lowering soil porousness and rising their bulk density values (Landon, 1998; Sam *et al*., 2025; Essien *et al.*, 2024; Mark *et al*., 2024), which leads to deterioration in the physical quality of the soil to a lousy level (Cherub *et al.*, 2016; Simeon and Essien, 2023; Essien *et al*., 2023). Several factors influence availability of soil water such as porosity, soil texture and structure, organic matter content compaction and biological activities. These greatly influence water infiltration, permeability and water holding capacity. Climate, soil depth, soil characteristics (texture, hydraulic conductivity and salinization level). Topographic characteristics (example; slope and crop properties), (Gwak and Kim, 2016; Essien and Ogban, 2018).

Numerous studies have investigated the availability of soil water and the physical conditions, for example, Smith and Doe, (2018); Zhang *et al.*, (2020); Lal (2000). The study of Ibanga *et al*. (2023) ; Akpan *et al*. (2024) ; Akata *et al.* (2024a) ; Akata *et al*. (2024b) ; Ben *et al*. (2024) demonstrated that higher organic matter content led to improved soil porosity and increased water holding capacity. There is no clear information or little understanding about available soil water and the physical conditions of soil under different management practices in acid soils of Akwa Ibom State that can help in, making better soil management decisions. Therefore the study aim at investigating available soil water and the physical conditions on slope under different management practices.

2. Material and Methods

2.1 Site description

The research was conducted on acid soils of Akwa Ibom state, South Nigeria. Akwa Ibom lies between Latitude 4°30' N and 5° 30' N and Longitude 7° 30' E and 8° 20' E. The location of the study area was indicated by the use of GPS. The climate of Akwa Ibom State is characterized by two seasons, namely, the wet or rainy season and dry season. The dry season starts in November and continues up to the first quarter of the following year. The wind become dry and dusty resulting in the Harmattan haze due to the influence of tropical continental air mass and the North East wind. Rainfall in the state is dependent on the location of inter Tropical Zone of Convergent. It last for about 10-11 months near the coast and about 9-10 months northwest. Annual rainfall varies from more than 3000mm along the coast to 2500 mm in the mid-section and about 2,250 mm in the northern fringe (Petters *et al.*, 1989).

The geographical material from which soils of the study areas was developed is coastal plain sands. Akwa Ibom State lies entirely on the coastal plain of Southeastern Nigeria where sediments are supplied by the Cross River, Qua Ibo River and Gulf of Guinea. Generally, the landscape of the state comprises a low-lying plain and riverine area. No position of the landscape exceeds 175m above the sea level. The physiographic of the state is subdivided into six contrasting land forms, namely; mangrove swamps and floodplains with recent alluvial sediments, beach ridge sands, level to undulating sandy plains which occupies a greater portion off the surface area of Akwa Ibom state, sandstone hills, beach ridges with steep-sided valleys and obot mme steep-side isolated hill or upland areas. Akwa Ibom State falls within the broad vegetation community of lowland rainforest and mangrove forest. This vegetation as a result of devastation by man and has degraded into mosaic-farmland, riparian forest and oil forest.

The dominant species for the oil palm forest, riparian forest, mosaic-farmland, the coastal swamp and mangrove include; oil palm (*Elaeis guineensis*), raffia palm (*Raphia hookeri*), mango (*Mangifera*) Avocado (*Persea americana*), Kola (*Kola nitida*). Cultivated crops in the area include maize (*Zea mays*), Yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), fluted pumpkin (*Telfairia occidentalis*), pumpkin (*Cucrbita* spp.) amongst others. The major food crops grown are: cassava (*Manihot esculentum*), Yam (*Discorea* spp), cocoyam (*Colosia* spp.) and maize (*Zea mays*). The state could be divided into two ago-ecological zones namely the riverine south and the upland north. Palm is the major economic tree actively cultivated in Akwa Ibom State, either as plantation or in much smaller units. The common fallow length is 3-5 years.

Akwa Ibom State is drained by two major rivers Qua Ibo and Cross River. The major rivers divided the state between two system trends, northwest in southeast demarcating two sub-equal drainage basins to the east and west. (Petters *et al.*, 1989).

2.2 Field methods

Soil samples were collected in three (3) land use management practices (fallow plot, grassland and cultivated) in three (3) locations (Oruk Anam, Etinan and Essien Udim Local Government Area), also three random soil samples were collected in three location. A total number of twenty seven (27) samples were collected and another set of undisturbed core samples were collected for the determination of bulk density and hydraulic conductivity.

2.3 Laboratory analysis

The bulk samples were air-dried and passed through a 2mm sieve for the following analysis:

Physical Properties

Particles size Analysis: The particles size distribution was determined by the hydrometer method according to the procedure cited in Grossman and Renish (2002). Bulk density was determined using core sampler as described by (Grossman and Renish, 2002). Soil samples were oven dried at 105° C to a constant weight and bulk density calculated using the equation below;

$$\ell b = \frac{Ms}{Vt}$$

Where;

ℓb= bulk density (Mgm^{-3})
Ms = mass of oven dry soil (mg)
Vt = Total volume of soil (m^{-3})

The total volume of soil was calculated from internal dimension of the cylinder.

Total porosity: Total porosity was calculated from particle size and bulk density relationship as described by Grossman and Renish (2002);

$$f = 1 - \left[\frac{\ell b}{\ell s}\right]$$

Where;

f = Total porosity (m^3m^{-3})
ℓb = bulk density ($Mg\ m^{-3}$)
ℓs = particle density ($Mg\ m^{-3}$)

Saturated hydraulic conductivity: Saturated hydraulic conductivity (Ksat) was determined using the constant head parameter method (Dane and Topp, 2002). The core sample was placed in a basin of water and allowed to be saturated by capillary. The saturated core sample was then placed in a funnel and a cylinder head was held to core cylinder with a masking tape. The water passing through the soil column was collected into a measuring cylinder and the saturated hydraulic conductivity was calculated using the equation.

$$\text{Ksat} = \frac{QL}{\Delta h A t}$$

Where;
Ksat = saturated hydraulic conductivity ($cmhr^{-1}$)
Q = Discharge rate ($cm^3\ min^{-1}$)
L = Length of soil column (cm)
Δh = change in hydraulic head (cm)
A = Cross sectional area through which the flow takes place (cm^2)
t = time (minutes)

Field water content (FWC): Field water content was determined using the approximate method described by Dane and Topp (2002). The determination was done with the core cylinders based on the fact that "the content of water, on a mass or volume basis" remaining in a soil two (2) or three (3) days after having been wet and after free drainage is negligible (Six *et al.*, 2000). Field water Content (FWC) was calculated using the equation;

$$FWC = \frac{M(s+c)i - M(s+c)f}{Ms}$$

Where;

FWC = field water content
M(s+c)i = initial mass of saturated soil + core
M(s+c)f = final mass of oven dried soil + core

Available Water Content (AWC): Available soil water was determined using the approximate method described by Dane and Topp (2002). The determination was done using the core cylinder. Available soil water was calculated using the equation;

$$\text{AWC} = \text{M(s+c)}f \div \text{M's}$$

Where;
AWC = Available Water Capacity
M(s+c)i = initial mass of saturated soil + core

M(s+c)*f* = final mass of oven dried soil + core

Chemical properties

Soil pH was determined using a glass electrode pH metal and in KCl to 1:2.5 soil water ratio (Udo *et al*., 2009). Organic carbon was measured by Walkly and Black wet digestion method (Udo *et al*., 2009). Organic matter was calculated by multiplying organic carbon by Van Bemmelen factor of 1.724. Total Nitrogen was determined by micro-kjeldhal digestion method and distillation method described by (Udo *et al*., 2009). Exchangeable cations was determined by the method described by (Grossman and Renish, 2002). The amount of potassium (K) and sodium (Na) were determined using flame photometer with appropriate filters while magnesium (Mg) and calcium (Ca) was determined by atomic adsorption spectrometer (AAS).

Basic saturation was determined as a sum of exchangeable basic cations divided by ECEC and multiplied by 100% (Udo *et al*., 2009). Available phosphorus was determined by Bray P-1 extracted and P in the extract was determined using Murphy and Riley Methods as described by (Udo *et al*., 2009). Exchangeable acidity was determined by titration using KCL extraction method (Peech *et al*., 1962). Effective cation exchange capacity was obtained by summation of the exchangeable bases and exchangeable acidity (Udo *et al*., 2009). Electrical conductivity was determined in a 1:2.5 soil/water ratio conductivity bridge (Udo *et al*., 2009).

3. Results and Discussion

3.1 Effect of Management Practices on Soil Properties

Physical properties

The Figure 1 – 6 shows the trend of soil physical properties affected by management practices in the study area. The result of total sand (Fig. 1) indicated that cultivated plot recorded mean value of 926 ± 13.33 g kg^{-1} (CV = 1.44%), grass land had a mean value of 938 ± 12.40 g kg^{-1} (CV = 1.32 %), fallow land recorded a mean value of 884 ± 36.61 g kg^{-1} (CV = 16.61%).

The result of silt content (Fig. 2) shown that cultivated land recorded mean value of 33 ± 15 g kg^{-1} (CV = 46%), grass land had a mean value of 17 ± 10 g kg^{-1} (CV = 62.53%), while fallow had mean value of 32 ± 13.18 g kg^{-1} (CV = 40.63%).

The result of clay content shown in Fig. 3, indicated that cultivated land recorded mean value of 41 ± 10 g kg^{-1} (CV = 25%), grass land had a mean value of 48 ± 7.94 g kg^{-1} (CV = 16.54%), fallow land recorded mean value of 74 ± 31.75 g kg^{-1} (CV = 43.16%). The primary soil particles were irregularly distributed. This was also found by Essien *et al* (2023). However, particle size was dominated by sand fraction for all land management practices (The result of bulk density is shown in Fig. 4. The result indicated that bulk density in cultivated land had a mean value of 1.63 ± 0.28 Mgm^{-3} (CV = 17.18 %), grass land recorded mean value of 1.57 ± 0.03 Mgm^{-3} (CV = 1.91 %), while fallow land had a mean value of 1.62 ± 0.34 Mgm^{-3} (CV = 20.99 %).

Ksat was high in grassland follow in cultivated land and follow by fallow plot (Fig. 5), this may be due to high sand content in cultivated plot and grassland, which characterized by larger pore space, also the low Ksat may be probably because of the high water table at the fallow plot.

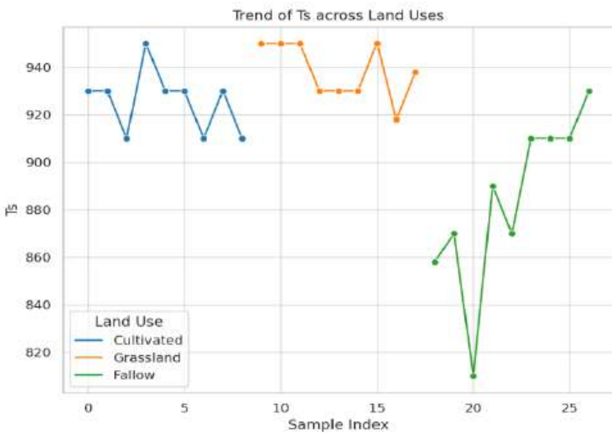

Fig. 1: Trend of total sand across land uses system

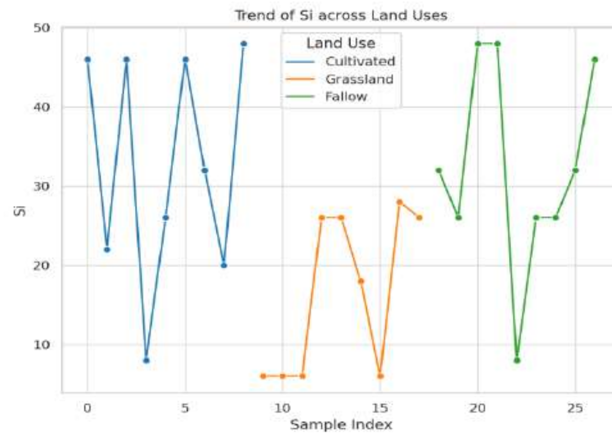

Fig. 2: Trend of silt across land uses system

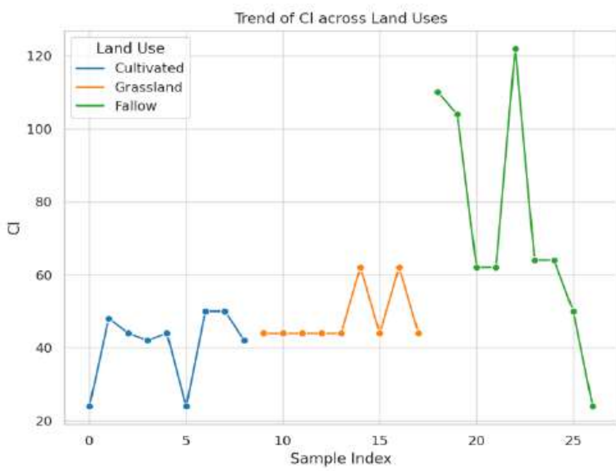

Fig. 3: Trend of clay across land uses system

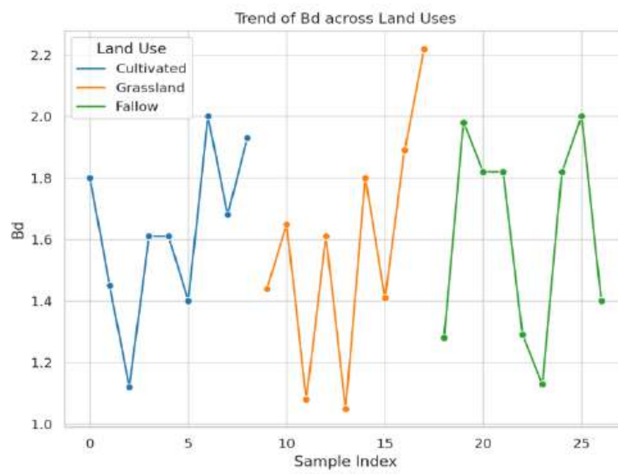

Fig. 4: Trend of bulk density across land uses system

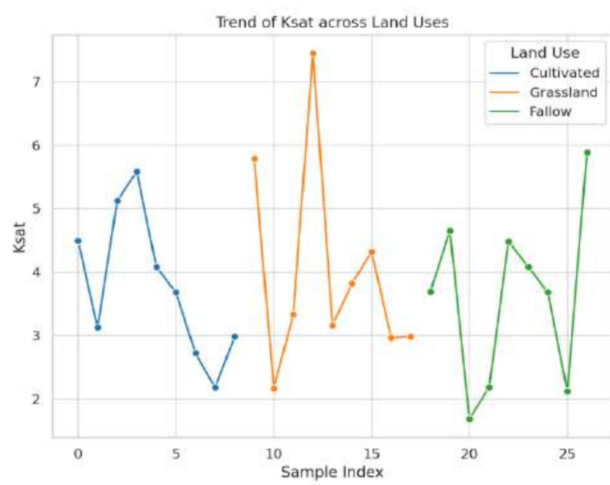

Fig. 5: Trend of saturated hydraulic conductivity across land uses system

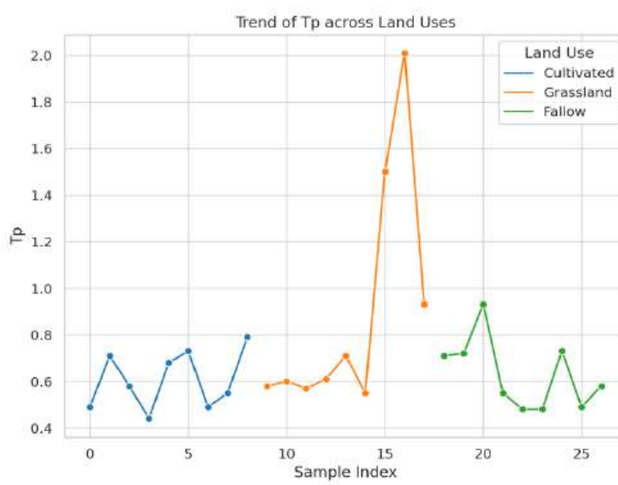

Fig. 6: Trend of total porosity across land uses system

Chemical properties

Table 1 present some chemical properties of soils affected by management practices. In cultivated land pH mean value was 5.8 ± 0.49 (CV = 8.43%), Organic matter revealed that the mean value in cultivated land showed 3.4 ± 0.65% (CV = 19.06), AV.P recorded mean value of 4.87 ± 2.94 mg kg^{-1} (CV = 60.37%), Essien *et al*. (2025). Ca had mean value of 2.98 ± 3.06 Cmol kg^{-1} (CV = 102.68%), Mg had mean value of 1.06 ± 0.38 Cmol kg^{-1} (CV = 35.45 Cmol kg^{-1}), Na recorded mean value of 0.29 ± 0.11 Cmol kg^{-1} (CV = 37.93%), K had 0.26 ± 0.31 Cmol kg^{-1} (CV = 119.23%), EA recorded mean value of 4.24 ± 1.82 Cmol kg^{-1} (CV = 42.92%), ECEC had mean value of 8.83 ± 2.84 Cmol kg^{-1} (CV = 32.16%) and Bsat recorded mean value of 49.76 ± 17.64% (CV = 35.455%).

At the grassland plot the result revealed that pH recorded mean value of 5.7 ± 0.98 (CV = 17.13%), OM had a mean value of 3.79 ± 1.51% (CV = 39.84%). AV. P had a mean value of 5.88 ± 2.56 mg kg^{-1} (CV = 43.54%), Ca recorded mean value of 1.99 ± 0.94 Cmol kg^{-1} (CV = 94.00%), Mg recorded mean value of 1.12 ± 0.54 cmol kg^{-1} (CV = 48.21%), Na had mean value of 0.33 ± 0.11 Cmol kg^{-1} (CV = 33.33%), K had a mean value of 0.18 ± 0.24 Cmol kg^{-1} (CV = 133.33%), EA had a mean value of 4.12 ± 2.07 Cmol kg^{-1} (CV = 50.24%), ECEC recorded mean value of 7.54 ± 1.54 Cmol kg^{-1} (CV = 20.42), and Bsat recorded mean value of 49.86 ± 16.805 (CV = 33.69%).

The result of the fallow plot revealed that pH recorded mean value of 6.1 ± 0.20 (CV = 3.27%), OM had mean value of 3.3 ± 0.69% (CV = 21.10%), AV.P had mean value of 4.96 ± 3.97 mg kg^{-1} (CV = 80.40%), Ca had mean value of 3.38 ± 3.01 Cmol kg^{-1} (CV = 89.05%), Mg recorded a mean value of 1.20 ± 0.56 Cmol kg^{-1} (CV = 46.67%), Na had mean value of 0.25 ± 0.13 Cmol kg^{-1} (CV = 52.00%), K had mean value of 0.10 ± 0.04 Cmol kg^{-1} (CV = 40.00%), EA had mean value of 4.83 ± 1.74 Cmol kg^{-1} (CV = 36.02%), ECEC recorded mean value of 9.77 ± 4.17 Cmol kg^{-1} (CV = 42.68%) and Bsat recorded mean value of 48.82 ± 15.33% (CV = 32.40%).

Table 1: Soil chemical properties affected by management practices in the study area (exchangeable bases)

Land Use Type	pH (H_2O)	OM (%)	Av.P (mg kg^{-1})	Ca	Mg	Na	K	EA	ECEC	Bsat (%)
				(cmol kg^{-1})						
Cultivated Land	5.80	3.40	4.87	2.98	1.06	0.29	0.26	4.24	8.83	49.76
Std (±)	0.49	0.65	2.94	3.06	0.38	0.11	0.31	1.82	2.84	17.64
CV (%)	8.43	19.06	60.37	102.68	35.45	37.93	119.23	42.92	32.16	35.45
Grass Land	5.70	3.80	5.88	1.99	1.12	0.33	0.18	4.12	7.54	49.86
Std (±)	0.98	1.51	2.56	0.94	0.54	0.11	0.24	2.07	1.54	16.80
CV (%)	17.13	39.84	43.54	94.00	48.21	33.33	133.33	50.24	20.42	33.69
Fallow Land	6.13	3.30	4.96	3.38	1.20	0.25	0.10	4.83	9.77	48.82
Std (±)	0.20	0.69	3.97	3.01	0.56	0.13	0.04	1.74	4.17	15.33
CV (%)	3.27	21.10	80.04	89.05	46.67	52.00	40.00	36.02	42.68	31.40

OM - Organic Matter, AV.P - available phosphorus, Ca - Calcium, Mg - Magnesium, Na - Sodium, K - Potassium, EA - Exchangeable acidity, ECEC - Effective Cation Exchangeable Capacity, Bsat- Base Saturation.

3.2 Relationship between some soil properties and soil water characteristics under cultivated land management practices

Land uses were evaluated using pearson moment correlation coefficient. Correlation analysis between some soil properties and soil water characteristics under cultivated land use management (Table 2).

Showed that total sand was negatively correlation with silt (-0.0678), the negative relationship between total sand silt may be due to the fact that silt seal up pore space, which affects penetration of fluid down the soil profile. Total porosity correlation negatively pH. Field water capacity correlated positively with permanent wilting point (1.000) and available water capacity (1.000), and permanent wilting point correlated with available water capacity (Fig. 6). The positive relationship between field water capacity permanent wilting point and available water, provide water to resuscitate plant that was about to wilt.

3.3 Relationship between some soil properties and soil water characteristics under grassland soil management practice.

Correlation analysis between some soil properties and soil water characteristics under grassland soil management practice (Table 3) shows that total sand correlated negatively with silt (-0.955) and organic matter (-0.777). Silt correlated positively with organic matter. The positive relationship between Organic matter and Silt, provide binding materials for soil aggregation, may be effective also in bringing about strong inter-particle forces and stability in the tropic soils (Ogban and Essien, 2016). Field water capacity correlated positively with permanent wilting point (1.000) and available water capacity (1.000). Permanent wilting point correlated with available water capacity. The positively relationship may be for provision of water during wilting process in plant.

3.4 Relationship between some soil properties and soil water characteristics under fallow land management practice

Correlation analysis between some soil properties and soil water characteristics under forest soil management practice (Table 4) revealed that total

Table 2: Correlation matrix of some soil properties with soil water characteristics under cultivated management practice

	TS	Si	Cl	Bd	Ksat	Tp	pH	OM	FWC	PWP	AWC	GMC
TS	1.000											
Si	-0.678*	1.000										
Cl	-0.228	-0.544	1.000									
Bd	-0.156	-0.017	0.100	1.000								
Ksat	0.380	-0.036	-0.359	-0.473	1.000							
Tp	-0.311	0.404	-0.079	-0.118	-0.360	1.000						
pH	-0.030	-0.402	0.481	0.332	0.070	-0.762*	1.000					
OM	-0.109	0.279	-0.303	0.591	-0.025	0.332	-0.177	1.000				
FWC	0.390	0.139	-0.646	-0.023	0.101	-0.175	0.014	-0.110	1.000			
PWP	0.390	0.139	-0.646	-0.023	0.101	-0.175	0.014	-0.110	1.000**	1.000		
AWC	0.391	0.140	-0.648	-0.202	0.103	-0.176	0.013	-0.110	1.000**	1.000**	1.000	
GMC	-0.242	-0.019	0.241	0.285	-0.382	0.131	-0.045	0.423	-0.574	-0.574	-0.575	1.000

Table 3: Correlation Matrix of some soil properties with Soil Water Characteristics under Grassland

	TS	Si	Cl	Bd	Ksat	Tp	pH	OM	FWC	PWP	AWC	GMC
TS	1.000											
Si	-0.955**	1.000										
Cl	-0.620	0.361	1.000									
Bd	-0.481	0.418	0.410	1.000								
Ksat	0.029	0.051	-0.208	-0.113	1.000							
Tp	-0.379	0.261	0.418	0.303	-0.248	1.000						
pH	0.215	-0.043	-0.650	-0.359	0.173	0.127	1.000					
OM	-0.777*	0.764*	0.379	0.060	-0.089	0.618	0.139	1.000				
FWC	0.514	-0.509	-0.268	-0.214	-0.557	-0.185	0.001	-0.525	1.000			
PWP	0.512	-0.509	-0.264	-0.215	-0.560	-0.186	0.000	-0.522	1.000**	1.000		
AWC	0.515	-0.510	-0.272	-0.212	-0.555	-0.185	0.002	-0.527	1.000**	1.000**	1.000	
GMC	-0.333	0.387	0.088	0.373	-0.103	0.109	-0.515	0.251	-0.148	-0.152	-0.145	1.000

sand correlated negatively with Total porosity (-0.694), (P 0.01). The negative relationship maybe due to high porosity as characteristics of sand particles that conducts rapid flow of water and has low water retention capacity.

Silt correlated negatively with clay, the negative relationship between silt and clay may be pointed out to the fact that with silt and clay particles the soil pores will be sealed up and hampered percolation of water. Water also may be hold so tight in clay surface and cannot be release for absorption by plant Bulk density correlated negatively with pH (-0.742) (p< 0.01). Organic matter correlated positively with Field water capacity (0.728) (P < 0.01), permanent wilting point (0.728) (P < 0.01) and available water capacity (0.728) (P < 0.01). The positive relationship may be that organic matter plays important role in soil water content, by maintaining a high proportion of macro pores and stabilizes soil structure, which enhances high conductivity of the soil. Field water capacity correlated positively with permanent wilting point

Table 4: Correlation matrix of some soil properties with soil water characteristics under fallow plot

	TS	Si	Cl	Bd	Ksat	Tp	pH	OM	FWC	PWP	AWC	GMC
TS	1.000											
Si	-0.087	1.000										
Cl	-0.501	-0.685*	1.000									
Bd	-0.131	0.305	-0.203	1.000								
Ksat	0.457	-0.359	0.094	-0.510	1.000							
Tp	-0.694*	0.382	0.054	0.363	-0.273	1.000						
pH	-0.001	0.135	0.013	-0.742*	0.228	-0.390	1.000					
OM	0.231	-0.509	0.412	0.268	0.286	-0.070	-0.641	1.000				
FWC	0.198	-0.297	0.238	0.074	0.311	0.249	-0.556	0.728*	1.000			
PWP	0.198	-0.297	0.238	0.074	0.311	0.249	-0.555	0.728*	1.000**	1.000		
AWC	0.198	-0.297	0.238	0.074	0.311	0.249	-0.556	0.728*	1.000**	1.000**	1.000	
GMC	0.168	-0.400	-0.009	0.076	0.165	-0.463	-0.062	0.114	-0.434	-0.434	-0.434	1.000

(1.000) ($P < 0.05$) and available water capacity (1.000) ($P < 0.5$). Permanent wilting point correlated with available water capacity (1.000) ($P < 0.5$). The positive relationship shows that field water capacity available water capacity and permanent wilting point are inter- related and that with field water capacity, available water capacity can be increase and in turns will be reduction in wilting coefficient.

4. Conclusion

Estimation of soil water will help to know the water level (condition) and the knowledge will help to guide on the effective management practices that will enhance water in the soil for efficient crop and development of crop. Soil management practices influence the physical conditions of a soil in several ways. It improves soil properties, soil aggregation and texture, soil bulk density, soil porosity and soil hydraulic conductivity, which are indicators of soil health.

5. Reference

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Assessment of pesticide residues level in surface and groundwater from Melleri irrigation farmlands in Gombe state, Nigeria

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ABSTRACT

This study determined pesticide residues levels in surface and groundwater from irrigation farmlands in the Kwami Local Government Area of Gombe State, Nigeria. Pesticide residues were analyzed using a gas chromatograph equipped with a 63Ni electron capture detector (SHIMADZU GC-2010). The mean concentration of aldrin in the surface water samples ranged from 0.0001 to 0.0013 mg kg^{-1} and 0.0024 to 0.0041 mg kg^{-1} in groundwater, whereas atrazine was below the detectable limit in all the studied samples. Chlorpyrifos ranged from 0.00 to 0.015 mg kg^{-1} in both samples, cyhalothrin was below the detectable limit, dichlorvos ranged from 0.00 to 0.031 mg kg^{-1}, while endosulfan ranged from 0.0034 to 0.086 mg kg^{-1} in the soil samples. The levels of cyhalothrin ranged from 0.00 to 0.0094 mg kg^{-1} in groundwater and 0.0013 to 0.0032 mg kg^{-1} in surface water, whereas those of endrin, heptachlor, imidacloprid, lambda-cyhalothrin, and Lindane were below the detectable limit. The levels of these pesticide residues may accumulate in food crops through the uptake of water. However, monitoring and stringent regulations should be imposed on the use of pesticides in soil and foodstuff for public health protection.

KEY WORDS: *Soil Groundwater*; *Pesticide residues*; *Surface water*; *Levels*

1. Introduction

The widespread use of pesticides for agricultural and non-agricultural purposes has resulted in the presence of residues in surface and ground water resources (András *et al*., 2015). Contamination occurs not only due to the current use of agrochemicals but also due to the leaching of persistent ingredients from soil. Pesticide contamination of surface water in a particular region depends on several factors, such as the proximity of crop fields to surface water, characteristics of surrounding fields (soil, grassland, slope, and distance to water bodies), and climate conditions (temperature, humidity, wind, and precipitation) (Judith, 2022). Consequently, pesticide residues are being reported as common organic contaminants worldwide in surface waters and other environmental matrices (András *et al*., 2015). The physicochemical properties of pesticide compounds, particularly their solubility in water and organic solvents, characterized by their octanol-water partition coefficients, determine

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theirleaching characteristic of into surface and ground waters (Pérez-Lucas *et al*., 2019).

Groundwater, like any other water resource, is not only of public health and economic value; it also has an important ecological function (Sulaiman *et al*., 2016). The contamination of groundwater resources by pesticides has raised environmental concern (Pérez-Lucas *et al*., 2019). The problem has become more prominent in countries where groundwater aquifers constitute the main drinking water resources for rural and adjacent urban areas (Carrard *et al*., 2019). Pesticide residues reach the aquatic environment through direct runoff, leaching, careless disposal of empty containers, equipment washings, etc. (El-Saeid *et al*., 2011). Widespread use of pesticides could lead to extensive pollution of the environment and constitute a potential and/or deliberate risk to human health because some of pesticides are classified as a probable human carcinogen (Mohamed and Ahmed, 2020).

Surface water in agricultural areas can be contaminated by pesticide residues with possible adverse effects on the ecosystem (Lundqvist *et al.*, 2019). Surface water contamination may have eco-toxicological effects on aquatic flora and fauna as well as for human health if used for public consumption (Bashir *et al*., 2020). Environmental monitoring of pesticide residues in water is generally based on chemical analysis of the pesticides and known metabolites or degradation products thereof (Lundqvist *et al.*, 2019). Leaching is a form of environmental pollution in which chemicals drain away from the treated region to non-targeted environments (Pérez-Lucas *et al*., 2018). In this way, surface waters have the potential of becoming contaminated when irrigation water that has passed over pesticide-treated plants and/or the environment drains or leaches into the surface waters (Syafrudin *et al*., 2021). Another source of pollution is drift, which occurs if a pesticide sprays targets, having been deflected by the wind or resulting from the error of missing the intended target, thereby landing on a non-targeted farm area (Damalas and Eleftherohorinos, 2011). In view of this, the present study aimed to determine pesticide residues levels in water samples collected from different farmlands in Malleri, Kwani local government area of Gombe state, Nigeria.

2. Material and Methods

2.1 Area of the study

The Malleri is a village in the Kwami local government area, and Kwami LGA is one of the eleven Local Governments of Gombe State. It is located about 6 kilometers in the northeastern part of Gombe town and lies on the latitude 10°29'35"N and longitude 11°12'36"E (Fig. 1). The area falls within the northern Guinea savanna zone of the Kwami Local Government Area of Gombe State. Kwami has a total area of 1,787 km² (690 sq mi). It has a population of 195,298 (2006, Census). The area receives an average annual rainfall of approximately 800 mm, which is sufficient for a single farming season. The annual rainfall pattern is erratic at the beginning of the rainy season, starting in April, and intensifying as the season advances, rising from 600 to 1000 mm. The maximum temperature could rise as high as 41°C and the minimum as low as 16°C. The temperatures were usually high, with an average of 34°C.

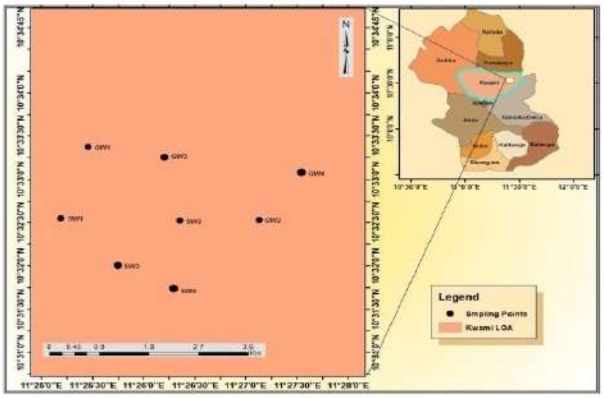

Fig. 1: Map of the study area

2.2 Sampling techniques

The water samples were collected using the grab sampling method. Samples were collected in 1-L amber-colored glass bottles. Sampling bottles were rinsed with water and carefully filled to overflow without trapping air bubbles in the sealed bottles. The samples were transported in a cool box containing ice packs. The containers were prepared by washing with detergent, rinsing with tap water, ultrapure water (Millipore), and air-drying. After transportation to the laboratory, samples were stored at 4°C, and extraction was performed within 48 h.

2.3 Chemicals and Reagents

The solvents used for the extraction were obtained from Merck (HPLC grade for chromatography). Individual pesticide stock standard solutions were prepared by exact high-purity substances in 10 mL volumetric flasks and filled with an appropriate solvent such as acetone and n-hexane. All stock standard solutions were stored in a deep freezer protected from light at 20°C. An intermediate and working standard of suitable concentration was made from the stock as and when required.

2.4 Sample Extractions and Analysis

Water samples were filtered using Whatman No. 1 filter paper to remove debris. 800 mL of water sample was transferred into a 1-L glass-separating funnel. Then, 80 g of NaCl was added to produce a salt-out effect. The mixture is thoroughly mixed by inverting the flask three to four times. The sample was extracted three times with 160 mL of dichloromethane (80:40:40) and shaken for 3-4 min each time with periodic venting. The combined organic phase is dried by passing it through anhydrous Na_2SO_4. The organic phase is concentrated to 3-5 mL in a vacuum rotary evaporator (Heidolph) and further dried under a gentle stream of nitrogen in a Turbovap (Caliper Science) low-volume concentrator. The sample was reconstituted in 1 mL of n-hexane, and 1 µL of the aliquot was analyzed by GC-MS (Gas Chromatography-Mass Spectroscopy).

2.5 Sample Analysis

The pesticide residues were analyzed using gas chromatograph equipped with a 63Ni electron capture detector (SHIMADZU GC-2010), and the presence of pesticides was confirmed using a Varian Saturn 2200 GC-MS. The determination of pesticide residue had been performed following the U.S. Environmental Protection Agency (USEPA) Method 8081 B and a self-modified laboratory method using GC-SHIMADZU with an electron capture detector. A Varian Saturn 2200 gas chromatograph mass spectrometer was used to confirmthe pesticide analysis. The injection port temperature was set to 250°C, and a liner with a plug of glass wool was installed. An amount of 1 µL of the concentrated extracts was injected in split mode (1:5). Helium was used as the carrier gas at a flow rate of 0.94 mL/min. The pesticides will be separated with a 50.10 min oven temperature program as follows: initial temperature 40°C (hold 2 min), increase at 25°C min1 to 130°C (hold 0 min), increase at 12°C min1 to 180°C (hold 0 min), and finally increase at 3°C min1 to 280°C (hold 7 min). The mass spectrometer is operated in the electron impact (70 eV) selected ion monitoring (SIM) mode. The temperature of the injector and interface was 200°C and 250°C, respectively (Summaiya *et al.*, 2014).

2.5 Data Analysis

The data obtained will be subjected to simple descriptive statistics (mean and standard deviation) using SPSS software version 25 for Windows. The mean values obtained in this study were compared with WHO standards.

3. Results and Discussion

3.1 Percentage of pesticide in surface and ground water samples

The percentage of pesticide residues is presented in Fig. 2. Aldrin, chlorpyrifos, cypermethrin, and endosulfan were detected in the water samples. The percentage of Aldrin in the water samples was in the range of 15.96%, 33.33%, and 23.16%, and 17.11%, 31.43%, and 2.70 in locations 1, 2, 3, and 4 for surface and ground water, respectively, while the percentage of chlorpyrifos in the water samples was 25.35% and 27.63%, and 32.20% and 32.43 in locations 1 and 3 for surface and ground water, respectively, and below the detectable limit in location 2. The percentage levels of cypermethrin in the water samples were 19.44% and 31.43% and 8.47% and 27.03% at locations 2 and 3 for surface and groundwater, respectively, and were below the detectable limit at GW1. The levels of dichlorvos in the water samples were in the order of 14.55% and 13.169% in location 1 for surface and groundwater, respectively, and below the detectable in locations 2 and 3, while the percentage levels of endosulfan in the water samples were in the range of 44.13%, 47.22%, and 36.16%, and 42.11%, 37.14%, and 37.84 in both locations 1, 2, and 3 for surface and groundwater, respectively.

3.2 Levels of pesticide in ground and surface water samples

Table 1a and 1b presents pesticide levels in surface and groundwater samples from Melleri irrigation farmlands. The concentrations of altrazine, dieldrin, dimethoate, endosulfan, endrin, heptachlor, imidacloprid, lindane, naphthalene, 1-methyl, p,p'-DDT, paraquat dichloride, phenanthrene, pyrazophos, and quintozene in the samples were below the detectable limit. Aldrin concentrations in the samples ranged from 0.0013-0.0034 mg L^{-1}, 0.0011-0.0024 mg L^{-1}, and 0.0001-0.0041 mg L^{-1} at locations 1, 2, 3, and 4, respectively, while the concentrations of chlorpyrifos in the samples ranged from 0.0021-0.0054 mg L^{-1} and 0.0012-0.0057 mg L^{-1} at locations 1, 3 and 4, respectively, and were below the detectable limit at location 2 in both surface and ground water samples. The dichlorvos concentration ranged from 0.0031 to 0.03 mg L^{-1} at location 1 in both ground and surface water and was below the detectable limit at locations 2 and 3 for both surface and ground water samples. The endosulfan concentrations in the samples ranged from 0.0032-0.0094 mg L^{-1}, 0.0013-0.0034 mg L^{-1}, 0.0014-0.0064 mg L^{-1}, and 0.0014-0.0065mg L^{-1} at locations 1, 2, 3, and 4 respectively for surface and groundwater.

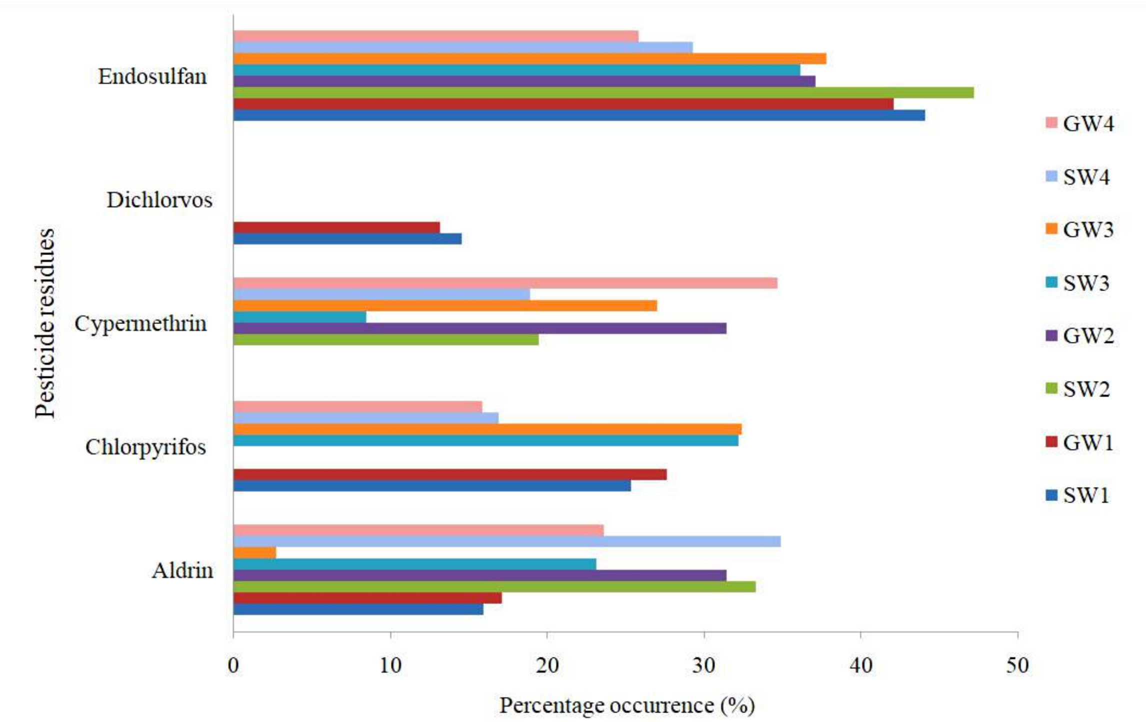

Fig. 2: Percentage (%) of pesticide residues in surface and groundwater samples

The level of aldrin obtained in this study was below (0.015 mg L^{-1}) that reported in a water sample from Southwestern Kenya (Nyaundi *et al*., 2019). Adeleye *et al*. (2019) reported the detection of aldrin (0.509 mg L^{-1}) in surface and ground water (0.391 mg L^{-1}) above the values obtained in this study. Ibrahim *et al*. (2019) also reported that the level of aldrin detected was higher than that obtained in this study.

Chlorpyrifos is a well-known broad-spectrum organophosphate pesticide commonly used in rural agricultural farmlands in Nigeria, and it is produced in different brands (Ononamadu *et al*., 2017). Ononamadu *et al*. (2017) reported that the content of chlorpyrifos was 0.0020-0.027 mg L^{-1}, which was below the value of 0.0057 mg L^{-1} obtained in this study. The chlorpyrifos concentration detected in this study was below the European Union maximum residue level (EU MRL).

Dichlorvos, an organophosphate, is a predominant pesticide used for domestic insect control in developing countries. Acute and prolonged exposure may lead to death and genotoxic, neurological, reproductive, carcinogenic, immunological, hepatic, renal, respiratory, metabolic, dermal, and other systemic effects. Its toxicity is due to its ability to inhibit acetylcholine esterase at the cholinergic junctions of the nervous system (Okoroiwu and AIwara, 2018). The results of this were similar to those reported by Yao *et al*. (2023). The detected dichlorvos levels exceeded the MRL recommended by the European Union. This could be due to unawareness and misuse of

Table 1a: Levels of pesticide residues in surface water (mg L^{-1}) samples

Pesticide	SW1	SW2	SW3	SW4
Aldrin	0.0013±0.03	0.0011±0.03	0.0001±0.03	0.0012±0.02
Altrazine	BDL	BDL	BDL	BDL
Chlorpyrifos	0.0021±0.01	BDL	0.0012±0.02	0.0014±0.02
Cyhalothrin	BDL	BDL	BDL	BDL
Cypermethrin	BDL	0.0011±0.01	0.0010±0.01	0.0010±0.02
Dichlorvos	0. 0010±0.03	BDL	BDL	BDL
Dieldrin	BDL	BDL	BDL	BDL
Dimethoate	BDL	BDL	BDL	BDL
Endosulfan	0.0032±0.03	0.0013±0.03	0.0014±0.03	0.0014±0.02
Endrin	BDL	BDL	BDL	BDL
Heptachlor	BDL	BDL	BDL	BDL
Imidacloprid	BDL	BDL	BDL	BDL
lambda.-Cyhalothrin	BDL	BDL	BDL	BDL
Lindane	BDL	BDL	BDL	BDL
Naphthalene, 1-methyl	BDL	BDL	BDL	BDL

Note: BDL= Below Detectable Limit

pesticides use in Nigeria (Sulaiman *et al*., 2021).

The level of endosulfan obtained in this study was below (0.043 mg L^{-1}) that reported in a water sample from Southwestern Kenya (Nyaundi *et al*., 2019). Ibrahim *et al*. (2019) also reported that the endosulfan content was higher than that obtained in this study.

4. Conclusion

The present study was conducted to determine pesticide residues levels in surface and groundwater cultivated with vegetables in Maleri,

Table 1b: Levels of pesticide residues in Ground water (mg L^{-1}) samples

Pesticide	GW1	GW2	GW3	GW4
Aldrin	0.0034 ±0.01	0.0024±0.01	0.0041±0.01	0.0032±0.01
Altrazine	BDL	BDL	BDL	BDL
Chlorpyrifos	0.0054±0.11	BDL	0.0057±0.11	0.0055±0.11
Cyhalothrin	BDL	BDL	BDL	BDL
Cypermethrin	BDL	0.0014±0.02	0.0015±0.12	0.0014±0.12
Dichlorvos	0.0031±0.12	BDL	BDL	BDL
Dieldrin	BDL	BDL	BDL	BDL
Dimethoate	BDL	BDL	BDL	BDL
Endosulfan	0.0094 ±0.01	0.0034±0.01	0.0064±0.01	0.0065±0.01
Endrin	BDL	BDL	BDL	BDL
Heptachlor	BDL	BDL	BDL	BDL
Imidacloprid	BDL	BDL	BDL	BDL
lambda.-Cyhalothrin	BDL	BDL	BDL	BDL
Lindane	BDL	BDL	BDL	BDL
Naphthalene, 1-methyl	BDL	BDL	BDL	BDL

Note: BDL= Below Detectable Limit

irrigation farmlands, Kwami Local Government Area of Gombe State, Nigeria. The water samples collected and analyzed in this study contained considerable amounts of Aldrin, Chlorpyrifos, Cypermethrin, Dichlorvos, and Endosulfan at different concentrations. In addition to aldrin, chlorpyrifos, cypermethrin, dichlorvos, and endosulfan in the sample, altrazine, cyhalothrin, dieldrin, dimethoate, endosulfan, endrin, heptachlor, imidacloprid, and lambda-cyhalothrin, lindane, naphthalene, 1-methyl, p,p'-DDT, paraquat dichloride, phenanthrene, pyrazophos, and quintozene were below the detectable limit in the studied samples. However, the need for regular monitoring of pesticide residues should be encouraged, because an increase in misuse of pesticides in agricultural produce is still ongoing in Nigeria.

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Barrier to the adoption of climate-smart agricultural practices by small-scale farmers in Kebbi state, Nigeria

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ABSTRACT

The study examined the barriers smallholder farmers in Nigeria's Kebbi State faced while attempting to implement climate-smart farming methods. To choose 120 respondents for the study, a three-stage sampling technique was employed. A well-structured questionnaire schedule was used to collect the data, and frequency and percentage were used for analysis. Access to farmer-based insurance was cited by nearly half of the respondents (31.3%) as a very high economic barrier. Infertile soil (58.0%) and the prevalence of weeds, pests, and diseases (67.3%) were cited by a significant portion of respondents as major environmental limitations. Disputes between farmers and herders (62.0%) and tribal disputes (51.3%) were examples of socio-cultural restrictions. Institutional restrictions included limited access to extension services (57.3%) and minimal government assistance for agricultural inputs (53.3%). Therefore, it is advised that budgetary support be provided and public-private partnerships be strengthened to leverage funding for the implementation of climate-smart activities.

KEY WORDS: *Climate-Smart Agriculture*; *Small-scale farmers*; *Kebbi state*; *Nigeria*

1. Introduction

There are factors affecting the development and sustainability of agriculture which include social, economic and environmental factors (Toliatkashani *et al.*, 2019). Climate is an environmental component that has a significant impact on agriculture; it impacts the sorts of crops that can be cultivated as well as the length of each crop's growth season. Unfortunately, the world's climate is currently changing, hurting agriculture in a variety of ways. These include variations in average temperatures, rainfall, other climate extremes, insect and disease infestation, changes in atmospheric carbon, ground-level ozone concentration, and changes in the nutritional value of some crops (Abdulrahman *et al*., 2021).

These changes have a greater impact on smallholder farmers and developing nations. To

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ensure food security in the face of climate change, a systematic approach to sustainable agricultural growth must be developed that does not deplete the soil's natural state (Ukhurebor *et al*., 2021). Climate-smart agriculture methods are one example of such an intervention. It is a novel method of guiding the necessary adjustments to agricultural systems, especially to address the issues of food security and climate change, rather than a new agricultural system. A method for changing and refocusing agricultural development in light of the new realities of climate change is known as climate-smart agriculture (CSA) (Food and Agricultural Organization, 2022).

Climate change can affect all humans because of the severe threats it poses to the environment and agricultural harvests around the world. The climate influences the distribution and number of organisms. Enhancing carbon dioxide (CO_2) accumulation has a wide range of possible consequences on plants, as well as indirect dangers to herbivores and other food chain members. Extreme weather conditions such as heavy rainstorms, high wind pressures, and high temperatures have a significant impact on agricultural activity. Climate and agriculture are inextricably linked universal processes, and hence climate variations affect agricultural activity. A large climate change risk is due to a temperature rise (global warming) which is predicted to pose major threats to the environment disturbing agriculture, with higher CO_2 quantities, increase in atmospheric average temperature, large glacial overflow, varied rainfall sequence and the interrelation of all the above factors (Ekpa *et al.*, 2021).

The severe and negative consequences on small-scale farmers' access, availability, and sufficiency of food were confirmed by Mburu *et al.* (2014) in their study on the effects of climate variability and change on food security. Nearly 80% of small-scale farmers who rely on agriculture for their livelihood will experience increased food insecurity, slower economic growth, and poverty as a result of the interplay of multiple factors, including temporal and spatial climate variability, seasonal pattern changes, degraded soil, and uncertain future climate scenarios (Ani *et al*., 2022). The general objective of the study was to ascertain constraints to the use of climate-smart agricultural practices among smallholder farmers in Kebbi State, Nigeria. Specifically, the research

1. Assessed farmers' level of awareness of climate-smart agricultural practices
2. Examined the constraints to the use of climate-smart agriculture practices among small-scale farmers

2. Material and Methods

The study was carried out in Kebbi State, Nigeria. The State lies in the northwest Sudan Savannah region between latitudes 10° 051 and 13° 271N of the equator and between longitudes 3° 351 and 6° 031E of the Greenwich. The State has a population of 3,351,831 (NPC, 2006) according to the 2006 census. Projecting this population to the year 2022 at 3% growth rate reveals the population as 4,351,067. Over two-thirds of the population is engaged in agricultural production, mainly arable crops alongside cash crops with livestock production.The population of this study comprised selected small-scale farmers in Kebbi State.

A randomized selection was used to select 120 small-scale farmers from three local governments in the state. One local government area was randomly selected from each of the three senatorial districts of Kebbi State. These include Argungu, Bunza and Zuru Local Government Areas from Kebbi North, Central and South respectively. Two rural communities were selected from each of the local government areas and small-scale farmers were selected from each community randomly. A well-structured questionnaire was used to collect data from the small-scale farmers. Descriptive statistics were used to describe the socioeconomic characteristics of respondents.

3. Results and Discussion

3.1 Awareness of Climate-Smart Agricultural Practices

Table 1 highlights the awareness levels of various climate-smart agricultural (CSA) practices among farmers. The highest awareness percentage (75.3%) is observed for agroforestry and fodder trees. Agroforestry integrates trees into farming systems providing benefits like improved soil fertility, enhanced biodiversity, and sustainable livelihoods. High awareness in this area indicates the potential for significant environmental and economic impacts if properly implemented. Odebode (2021), confirms the growing recognition of agroforestry's role in mitigating climate change and improving farm productivity. Improved fodder production also shows substantial awareness (74.0%). This practice enhances livestock nutrition and reduces dependency on overgrazing, which often leads to land degradation. The emphasis on improved fodder production aligns with the increasing focus on sustainable livestock management (Abdullahi and Ibrahim, 2020).

Weather prediction has an awareness rate of (70.7%), reflecting farmers' reliance on accurate forecasts for planting and harvesting decisions. The importance of this practice is underlined by Ayanlade *et al*. (2022), who emphasize the role of localized weather prediction tools in enhancing resilience to climate variability in Nigeria. Moderate awareness levels are seen in tree planting (64.0%) and climate change campaigns (60.7%), suggesting that these practices are gaining traction but require more targeted outreach programs. Soil water conservation and better livestock management, with awareness levels of (46.0%) and (27.3%), respectively, indicate gaps that need to be addressed. Eze *et al.* (2019) emphasize the importance of educating farmers on water conservation techniques and sustainable livestock practices to ensure CSA's broader adoption.

Table 1: Awareness of climate-smart agricultural practices

Awareness of climate-smart agricultural practices	Aware %	Not Aware %
Weather prediction	70.7	29.3
Soil water conservation	46.0	54.0
Improved fodder productions	74.0	26.0
Agroforestry and fodder trees	75.3	24.7
Better livestock management	27.3	72.7
Awareness campaigns on climate change	60.7	39.3
Establishment of tree planting	64.0	36.0

Source: Field survey 2024

3.2 Constraints to the Use of Climate-Smart Agricultural Practices

Table 2 outlines the constraints to adopting CSA practices, with a focus on economic, environmental, socio-cultural, and institutional factors. The most significant constraint is the experience of weeds and pests, with a very high constraint percentage of (67.3%). This issue is a critical challenge in Nigerian agriculture, as noted by Okpala *et al*. (2023). The prevalence of weeds and pests reduces crop yields and raises production costs, discouraging the adoption of CSA practices.

Farmers/herders' conflicts are another major barrier, with (62.0%) of respondents identifying them as a very high constraint. These conflicts often arise over land use, undermining agricultural productivity and rural stability. According to Adisa and Adekunle (2021) highlight the urgent need for conflict resolution mechanisms to address these recurring issues and facilitate sustainable farming. Infertile soil (58.0%) and limited access to extension services (57.3%) also rank high as constraints. Infertile soils hinder productivity making it challenging for farmers to adopt CSA practices that require healthy soil conditions. Meanwhile, limited access to extension services restricts farmers' knowledge and technical support, a gap frequently cited in Nigerian agricultural studies (Oladele *et al*., 2020).

Institutional constraints like inadequate government support with farm inputs (53.3%) and the land tenure system (50.7%) further complicate

Table 2: Constraints to the use of climate-smart agricultural practices

Economic constraints	Very high constraint %	Low constraint %	Not a constraint %
There is demand for farm produce	49.3	11.3	38.0
Access to farmer-based insurance companies	31.3	40.0	28.7
Access to labour	39.3	29.3	29.3
Access to sustainable agriculture technologies	41.3	32.7	26.0
Poor pricing of agricultural produce	31.3	24.7	44.0
Environmental issues			
Experience of bush/forest fires	42.0	25.3	32.7
Infertile soil	58.0	30.0	12.0
Drought occurrence	55.3	44.7	-
Pests and diseases	67.3	19.3	13.3
Socio-cultural constraints			
Taboos and values of community	39.3	25.3	35.3
Occurrence of tribal conflicts	51.3	18.7	30.0
Encroachment of farmlands	30.0	56.0	14.0
Land tenure system	50.7	44.0	5.3
Farmers/herders' conflicts	62.0	18.0	20.0
Institutional constraints			
Government support with farm inputs	53.3	24.0	22.7
Access to extension services	57.3	30.7	12.0
Availability of Climate Smart Agriculture funds by the government	40.7	46.7	12.7
Access to roads and markets	49.3	32.0	18.7
Government Policy on Climate Smart Agriculture	38.0	36.7	25.3

CSA adoption. Access to inputs such as fertilizers and seeds is critical for implementing CSA practices, but inefficiencies in distribution remain a persistent problem. Similarly, the land tenure system in Nigeria often limits farmers' ability to make long-term investments in sustainable agricultural practices. Drought occurrence (55.3%) also poses significant challenges, as unpredictable rainfall patterns exacerbate water scarcity. This issue is particularly relevant in Nigeria's semi-arid regions, where climate change has intensified drought conditions, according to Ajibade *et al*. (2022).

Finally, socio-cultural constraints like community taboos (39.3%) and institutional challenges such as government policy on CSA (38.0%) highlight the need for awareness campaigns and policy reforms. Addressing these constraints will require collaboration between stakeholders, including government bodies, research institutions, and local communities.

4. Conclusion

The analysis of awareness and constraints related to CSA practices underscores both opportunities and challenges in achieving sustainable agriculture in Nigeria. High awareness of practices like agroforestry and fodder production suggests a foundation for further development, while constraints such as weeds, pests, and institutional barriers highlight areas requiring urgent attention. To maximize the potential of CSA practices, policymakers and stakeholders should prioritize investment in extension services, conflict resolution, and policy support, as suggested by recent Nigerian studies.

The farmers' level of knowledge contributes to the efficient and effective usage of climate-smart agriculture, and challenges encountered by the smallholder farmers affect the level of climate-smart agriculture usage. The concept of agriculture extension should be strengthened to promote easier and faster assimilation of CSA. The government should revisit the concept and prioritize their focus to facilitate general acceptance and easy adoption of CSA practices with their up-scaling at all levels including financial and intuitional support. The socio-cultural factors should be properly integrated into CSA blueprints.

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Bridging the gap between healthcare service and agricultural productivity: pathway for rural development in Nigeria

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ABSTRACT

Agriculture remains a fundamental pillar of Nigeria's economy, with rural households heavily reliant on farming for sustenance and income. However, poor health outcomes and limited access to healthcare services significantly hinder agricultural productivity. This study investigates the synergy between access to healthcare services and agricultural productivity among farming households in Nigeria. A multistage sampling technique was adopted to select 720 farming households in Southwest, Nigeria. Using a two-stage least squares (2SLS) regression model, the study examines how access to healthcare services influences farm productivity, employing distance to healthcare facilities as an instrumental variable. The findings reveal that farmers who utilize healthcare services exhibit higher productivity levels than those who do not. Specifically, the treatment group (households accessing healthcare services) reported a significantly higher value of farm produce sales (₦141,775.90) compared to the control group (₦102,430.11). Notable, major determinants of agricultural productivity include farm size, farming experience, cooperative membership, and access to health extension services, while distance to healthcare facilities negatively impacts healthcare utilization. The study highlights that frequent health-related incapacitation leads to labour loss and reduced efficiency, reinforcing the importance of an integrated approach to health and agriculture. Policy interventions such as mobile health clinics, community-based health insurance, and agricultural-health synergies could mitigate the adverse effects of poor health on agricultural output. Bridging the healthcare-agriculture divide is imperative for sustainable economic growth, improved food security, and poverty reduction in Nigeria.

KEY WORDS: *Productivity*; *Healthcare access*; *Health-capital transition; Rural development*

1. Introduction

In sub-Saharan Africa, agriculture is the predominant economic activity, with more than half of the population engaged directly or indirectly (FAO, 2021; Omotoso *et al*., 2023). It employs more than 60% of the economically active labour force and contributes nearly 40% to total productivity in the Nigerian economy (Omotoso & Omotayo, 2024b; Outhwaite *et al*., 2022). Consequently, growth in agricultural productivity is essential for improving welfare, especially among rural households and achieving sustainable economic growth for poverty reduction (Outhwaite *et al*., 2022). It is noted that no country has been able to sustain a rapid

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transition out of hunger and poverty without raising productivity in its agricultural sector (Ali & Awade, 2019; Mirzabaev *et al*., 2023). Notably, agricultural productivity in Nigeria is dependent on physical strength and stamina, and therefore, health shocks are more likely to directly and indirectly affect workers' productivity (Outhwaite *et al*., 2022).

Directly, ill health affects physical strength and work days/hours available for farm work while indirectly, ill health involving high medical expenditures tends to deprive farming households of resources to invest in experimentation on improved practices and the adoption of new technology (Gebrehiwot, 2015; WHO, 2023). Notably, poor health reduces farmers' ability to innovate, experiment, and operationalize changes in agricultural systems (Omotoso & Omotayo, 2024c; Outhwaite *et al*., 2022). Serious health conditions resulting in catastrophic expenditures may also result in the depletion of productive assets such as the sale of draught animals and the sale of cultivable land (Outhwaite *et al*., 2022). The consequences of these actions include a reduction in farm sizes, cultivation of less-intensive crops, and reduction in livestock numbers resulting in poor livelihoods (WHO, 2021). The intersection of healthcare services, agricultural productivity, and rural development is critical to fostering sustainable economic growth and improving the well-being of rural populations (Bazzana *et al*., 2022).

In Nigeria, majority of rural households depend on agriculture for their livelihoods, yet they face significant health challenges that hinder productivity (Fadare *et al*., 2023; Gebrehiwot, 2015). Poor access to quality healthcare services, high disease prevalence, and inadequate health infrastructure reduce the labour efficiency of farmers, ultimately affecting agricultural output and rural development (Outhwaite *et al*., 2022; WHO, 2019). The health-capital transition, which refers to the shift in economic productivity due to improved health conditions, is essential for breaking the cycle of poverty and underdevelopment in rural areas where agriculture remains the backbone of the economy, contributing significantly to employment and food security (Combary & Traore, 2021; Liu *et al*., 2024). However, poor health conditions among farmers, including malnutrition, waterborne diseases, and occupational hazards, lead to reduced labour productivity and lower farm yields (Liu *et al*., 2024; Sabasi & Shumway, 2018). Without proper healthcare services, rural communities struggle with high morbidity rates, limiting their ability to engage in productive agricultural activities (Allen *et al*., 2014; FAO, 2021).

Despite extensive research on the individual aspects of healthcare services, agricultural productivity, and rural development, there remains a significant gap in understanding how these three domains intersect to drive economic transformation in Nigeria. Existing studies (Combary & Traore, 2021; Fink & Masiye, 2015) have primarily focused on the health-productivity nexus, emphasizing how poor health conditions reduce labour efficiency in agriculture. However, there is limited empirical evidence on how integrated healthcare and agricultural policies can create a sustainable health-capital transition in rural communities. Additionally, most studies (Mirzabaev *et al*., 2023; Sabasi & Shumway, 2018) on agriculture and rural development tend to overlook the critical role of healthcare services in enhancing farmers' productivity and resilience. The link between rural health interventions and agricultural performance remains underexplored, particularly in the Nigerian context, where rural communities face both poor healthcare access and low agricultural yields.

Furthermore, there is a lack of comprehensive studies that analyze policy frameworks addressing the simultaneous improvement of healthcare infrastructure and agricultural productivity in Nigeria. While various government initiatives aim to boost agricultural development, there is little integration of healthcare policies that address the well-being of the farming population. Bridging the gap between healthcare and agricultural productivity requires a holistic approach that integrates health interventions, agricultural innovations, and rural development policies. Investments in rural health facilities, mobile health services, and agricultural extension programs can enhance farmers' well-being and improve their economic resilience. Additionally, strengthening health education, nutrition programs, and access to affordable healthcare services will ensure that rural populations remain healthy enough to sustain agricultural production.

Synergy between access to healthcare service and agriculture productivity

The interdependence between healthcare access and agricultural productivity is a crucial but often overlooked aspect of rural development. Agriculture remains the backbone of Nigeria's economy, employing a significant portion of the rural population (Allen & Ulimwengu, 2015; Mirzabaev *et al*., 2023). However, agricultural productivity is highly dependent on the health status of farming communities, thus the ability of farmers to engage in physically demanding agricultural activities is directly influenced by their access to quality healthcare services (Combary & Traore, 2021; Gebrehiwot, 2015). Poor health conditions lead to reduced labour availability, lower efficiency, and ultimately, decreased agricultural output (FAO, 2021; WHO, 2021). A well-functioning healthcare system, therefore, enhances agricultural productivity by ensuring that farmers remain physically fit, reducing the burden of disease, and minimizing work disruptions due to illness (Allen & Ulimwengu, 2015; Fink & Masiye, 2015).

Interestingly, healthcare access in rural Nigeria is often constrained by inadequate infrastructure, long distances to health facilities, and financial barriers (Otekunrin *et al*., 2021; Oyekale, 2017). These challenges contribute to high rates of preventable diseases such as malaria, respiratory infections, and waterborne illnesses, which significantly reduce agricultural labour efficiency (Balogun, 2021). Studies (Allen & Ulimwengu, 2015; Fink & Masiye, 2015) have shown that health shocks, including chronic illnesses and malnutrition, lead to substantial losses in farm productivity. Additionally, (Kehinde *et al*., 2021; Liu *et al*., 2024) found that malaria prevalence and poor healthcare access among rural farmers in Northern Nigeria resulted in lower technical efficiency and reduced agricultural output. Similarly, (Kehinde *et al*., 2021; Oloruntoba *et al*., 2021) revealed that a single day of illness and inadequacy of healthcare access among agricultural workers in Southwest, Nigeria led to a full day or more of labour loss. These findings underscore the need for improved healthcare accessibility to sustain agricultural livelihoods.

Conversely, well-nourished farmers are less susceptible to diseases and can sustain higher levels of productivity (Oloruntoba *et al*., 2021). However, the absence of comprehensive healthcare interventions in rural areas exacerbates the vulnerability of farming households to health-related shocks (Bazzana *et al*., 2022; Chaud *et al.*, 2021). Governments and policymakers have yet to fully integrate healthcare considerations into agricultural policies, resulting in fragmented development efforts (Daud *et al*., 2018; Mirzabaev *et al*., 2023).

To enhance the synergy between healthcare access and agricultural productivity, a multi-sectoral approach is needed. Policy interventions should include expanding rural healthcare infrastructure, subsidizing health insurance for farmers, and integrating health services into agricultural extension programs. By addressing healthcare challenges within the agricultural sector, Nigeria can achieve sustainable rural development, improved food security, and enhanced economic growth.

2. Material and Methods

2.1 Study area

The study was carried out in rural Southwest Nigeria, encompassing the states of Osun, Ogun, Ekiti, Ondo, Lagos, and Oyo. Agriculture is the primary livelihood activity in the geopolitical zone, with commercial production of maize, cassava, yam, oil palm, cocoa, and timber. The predominant households in this area depend mostly on subsistence farming, supplemented by income from trading, hunting, foraging, and handicrafts (Omotoso & Omotayo, 2024a). Consequently, rural households descended into a more acute poverty classification, compelling them to depend on savings and assistance from friends and relatives. The natural vegetation of the geopolitical zone consists of tropical rainforest in the south and guinea savannah in the north, with soil conducive to subsistence cultivation.

2.2 Sampling Procedures and Data Analysis

The study utilized primary data collected through an interview schedule. The study population is composed of rural farm households in the zone who primarily engage in subsistence farming. Additionally, 480 agricultural households across six (6) states in Southwestern, Nigeria were conducted using a multistage sampling procedure. The initial phase involved the deliberate selection of Ekiti, Ogun, and Oyo from the states that comprised the southwest geopolitical zone of Nigeria. The three states were selected due to their prominence in small-scale agricultural cultivation and their status as the food hub of the geopolitical zone. The second stage entails the selection of three zones from each state, resulting in a total of nine zones. In the third stage, a total of 2 blocks were randomly selected from nine zones in the area (18 blocks). In the fourth stage, four cells from each of the 18 blocks (a total of 72 cells) were randomly selected. The final stage entails the random selection of 10 rural farming households from each of the cells.

Consequently, a sample size of 720 rural farming households was employed in the study. Data about socio-economic characteristics, usage of health services, labour utilization patterns, and output value were gathered from the sampled households. The data were analyzed using descriptive statistics such as means, and standard deviation, two-sample t-test, and IV regression model. Ethical norms were rigorously followed. Before data collection, informed verbal consent was secured from each study participant, who were granted the complete right to withdraw from the interview at any point they felt uncomfortable. Moreover, secrecy was maintained by excluding the respondents' names from the data collection instrument, utilizing a unique identifying number as a code instead.

2.3 Model specification

Two stage least square (2SLS) selectivity model

Every impact assessment's primary focus is on treating non-compliers and removing selection bias (Bazzana *et al*., 2022). To address this, an instrumental variable model was used in the study. We can address the issue of treatment endogeneity and remove selection bias by using the conventional instrumental variables approach (Fink & Masiye, 2015). After controlling for observable characteristics, the technique implies the existence of at least one instrumental variable that explains the treatment but has no direct impact on the outcome. In order to account for any selection bias, we first calculated the following in light of the likely link between the decision to use health facilities and the observed or unobserved characteristics:

$$T = \alpha_0 + \alpha_i Z_i + \delta X_i + \mu_i \text{ ----------------------------(1)}$$

Where;
Z_i = represents the instrumental variable,
α_0,α_i and δ_i are parameter estimated

Following (Combary, 2016; Omotoso & Omotayo, 2024b), assessing the impacts of access to healthcare service on farm productivity, the second stage of the model is expressed as:

$$Y_{pt} = \beta_0 + \beta_i T_i + \gamma X_i + \delta_i \text{----------------------------(2)}$$

Where
Y_{pt} = Agricultural productivity
T_i = represents the treatment variable taking the value of 1 for treated household and 0 otherwise
X_i = vector of control variables

Noteworthy, the treatment variable differentiates between households that use healthcare services when sick (yes = 1) and those that do not (no = 0), allowing for a comparative analysis of the impact of access to healthcare service on productivity. Following (Bazzana *et al*., 2022; Combary & Traore, 2021), to address potential endogeneity, distance to healthcare facilities is used as an instrumental variable, as it influences healthcare service access and utilization but does not directly determine farm productivity.

3. Results and Discussion

3.1 Description of variable used in the analysis

The findings from Table 1 underscore the significance of healthcare access in shaping the agricultural productivity and socioeconomic well-being of farming households. The treatment group - comprising households that accessed healthcare facilities - exhibited significantly higher agricultural productivity (₦141,775.90) compared to the control group (₦102,430.11), with a mean difference of ₦39,345.79 ($p<0.001$). This suggests that improved health conditions, facilitated by healthcare access, enhance the efficiency and productivity of farm labour. Healthier farmers are more capable of performing labour-intensive activities, thereby improving yields and farm income (Combary, 2016; Daud *et al*., 2018). The observed difference aligns with prior studies (Allen & Ulimwengu, 2015; Combary & Traore, 2021), which emphasize the role of health in ensuring a stable and productive agricultural workforce.

Consistently, farm size also varied significantly between the two groups, with the treatment group

Table 1: Variable description and descriptive statistic of treatment and control group (n=720)

Variables	Description	Treatment group (n=292)		Control group (n=428)		Difference	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Test of diff.
Productivity	Value of sale of farm produce (₦)	141775.90	53092.11	102430.11	62003.72	39345.79	0.001***
Farm size	Area cultivated (hectares)	7.16	3.08	5.74	2.99	1.42	0.035**
Age	Age of the HH in years	48.17	23.84	51.62	31.07	-3.45	0.002***
Sex	Gender of HH (1=male, 0=otherwise)	0.682	0.241	0.661	0.302	0.021	0.103
Marital status	Marital status of HH (1=married, 0=otherwise)	0.705	0.511	0.600	0.337	0.105	0.216
Off income	Off-farm income (1=yes, 0=otherwise)	0.578	0.225	0.616	0.377	-0.038	0.021**
Experience	Farming experience (years)	16.89	8.44	9.02	3.85	7.87	0.012***
Cooperative	Membership of cooperative society (1=yes, 0=otherwise)	0.725	0.302	0.890	0.418	-0.165	0.000**
Hh size	Number of household members	8.61	3.17	10.01	4.96	-1.4	0.027**
Health	Contact with health extension works (1=yes, 0=otherwise)	0.821	0.461	0.402	0.228	0.419	0.003***
Water	Access to potable water (1=yes, 0=otherwise)	0.501	0.272	0.337	0.186	0.164	0.061*
Incapacitation	Incapacitation due to illness, injury (days)	50.74	37.01	72.15	24.22	-21.41	0.000***
Distance	Distance to healthcare facilities (Km)	6.11	2.95	14.47	6.92	-8.36	0.000***

***, ** and * means $p < 0.01$, $p < 0.05$ and $p < 0.1$

cultivating an average of 7.16 hectares compared to 5.74 hectares in the control group. Admittedly, larger farm sizes often require greater physical labour, which may be more effectively managed by healthier households with fewer incapacitating illnesses. Additionally, the treatment group had longer farming experience (16.89 years) than the control group (9.02 years), implying that households that prioritize health may have better agricultural knowledge and resilience against productivity shocks. Access to healthcare services was also associated with a higher likelihood of engagement with agricultural extension health services, cooperative membership and access to potable water suggesting broader positive spillover effects (Balogun, 2021).

Conversely, the control group reported a significantly greater average distance to healthcare facilities, reinforcing the role of physical accessibility in determining healthcare service accessibility. The control group also experienced higher days of incapacitation due to illness (50.74 days) compared to the treatment group which might indicate underreporting of illness or reliance on traditional healing methods rather than formal healthcare.

Furthermore, off-farm income engagement was slightly higher in the control group, possibly reflecting a coping strategy for households unable to maintain full agricultural labour due to untreated health issues (Oloruntoba *et al*., 2021). These results emphasize the critical interplay between health and labour efficiency in agricultural systems. Investing in healthcare infrastructure in rural farming communities could thus serve as a viable strategy for improving agricultural productivity and sustainable rural development.

3.2 Healthcare access and agricultural productivity – Two stage least squares estimation

The results presented in Table 2 from Two-Stage Least Squares (2SLS) regression estimate highlight the determinants of healthcare access among farming households and the impact of healthcare access on agricultural productivity. The first stage of the regression estimates the likelihood of accessing healthcare services, while the second stage examines how healthcare access influences productivity. The findings from 2SLS regression provide compelling evidence on the link between healthcare access and agricultural productivity.

Stage 1 – Determinants of access to healthcare services

The first-stage 2SLS regression identifies key factors influencing access to healthcare services among farming households. The significant and negative effect of distance to healthcare facilities ($\beta = -0.3391$, $p < 0.01$) corroborates previous studies (Allen & Ulimwengu, 2015; Combary, 2016) that have highlighted distance as a major barrier to healthcare utilization in rural settings. Long distances increase travel costs and reduce the likelihood of timely medical attention, leading to worsening health conditions (Combary & Traore, 2021).

Furthermore, the positive effect of access to health extension workers ($\beta = 0.0261$, $p < 0.01$) on healthcare access is consistent with (Oyekale, 2017; Rufai *et al*., 2021), who emphasized the role of community-based health interventions in improving healthcare utilization. The role of incapacitation due to illness ($\beta = 0.1741$, $p < 0.01$) is also notable, suggesting that severe health challenges push households to seek medical attention. Interestingly, age (β = -0.0223, $p < 0.01$) negatively affects healthcare access, a result that supports previous studies (Otekunrin, 2022; Rutledge *et al*., 2023) indicating that older individuals, particularly in rural areas, may face mobility and financial constraints when seeking medical care.

Stage 2 – Effect of healthcare service access on agricultural productivity

The second-stage regression establishes a significant positive relationship between healthcare access (β = 0.1554, $p < 0.01$) and agricultural productivity, reinforcing the argument that health is a critical determinant of labour efficiency and farm productivity. Farmers who utilize healthcare services are more productive, as they experience fewer workdays lost to illness and maintain higher energy levels to perform physically demanding agricultural activities (Rutledge *et al*., 2023; WHO, 2021). This finding aligns with studies by (Liu *et al*., 2024; Oloruntoba *et al*., 2021), who reported that health investments significantly enhance labor productivity and agricultural output.

Moreover, incapacitation due to illness (β = -0.3015, $p < 0.01$) significantly reduces

Table 2: Instrumental variable – Two stage least square regression estimate (n=720)

Variable	Stage 1 (Access to healthcare services)		Stage 1 (Productivity)	
	Coefficient	Robust SE	Coefficient	Robust SE
Farm size	0.0031**	0.0015	0.1074***	0.0043
Age	-0.0223***	0.0011	0.1244**	0.0622
Sex	0.0512	0.1062	-0.1893	0.7819
Marital status	0.1142	0.0997	0.4526	0.6210
Off income	0.2041	0.2133	0.0156***	0.0027
Experience	0.0041	0.0511	0.2302***	0.0931
Cooperative	0.2915	0.4114	0.1045*	0.0510
Hh size	0.1127	0.2041	0.1099*	0.0600
Health extension	0.0261***	0.0017	0.0024**	0.0010
Water	0.2291	0.7410	0.1185	0.1399
Incapacitation	0.1741***	0.0053	0.3015***	0.0061
Distance	-0.3391***	0.0110	-	-
Healthcare	-	-	0.1554***	0.0094
Constant	0.0013***	0.0001	0.2890	0.0442
Diagnostic statistics				
Wald chi^2	48.15***		-	
Prob> chi^2	0.0001***		-	
R-square	0.6512		0.7114	
Adj R-square			0.6809	

***, ** and * means $p < 0.01$, $p < 0.05$ and $p < 0.1$

productivity, highlighting the negative economic consequences of poor health in rural areas. This finding resonates with (Otekunrin, 2022; WHO, 2021), who demonstrated that malaria prevalence among farmers in Northern Nigeria led to reduced farm output and technical efficiency. The impact of health-related labor losses was also documented by (Omotoso & Omotayo, 2024b; Otekunrin, 2022), who found that each day of illness among agricultural workers resulted in more than a day of lost labour. Other productivity-enhancing factors identified include farm size ($\beta = 0.1074$, $p < 0.01$) and farming experience ($\beta = 0.2302$, $p < 0.01$), both of which have been widely acknowledged in agricultural economic literature as critical determinants of farm efficiency (Kehinde *et al.*, 2021; Liu *et al.*, 2024).

The positive role of cooperative membership ($\beta = 0.1045$, $p < 0.1$) and household size ($\beta = 0.1099$, $p < 0.1$) suggests that access to social capital and a larger labour pool improve farm productivity. Noteworthy, significant evidence supporting the positive impact of healthcare access on agricultural productivity suggests the need for rural health policy interventions that reduce barriers to healthcare utilization. The findings reinforce the bidirectional relationship between health and agriculture. Strengthening healthcare access not only enhances individual well-being but also serves as a key driver of rural economic development, supporting Nigeria's broader goals of food security and poverty reduction (Allen *et al.*, 2014; Allen & Ulimwengu, 2015; Daud *et al.*, 2018)

4. Conclusion

Access to healthcare services is essential for maintaining a healthy workforce, yet many rural farmers face challenges such as long distances to healthcare facilities, high costs, and inadequate medical infrastructure. This study examines the impact of access to healthcare services on agricultural productivity among farming households in Nigeria. Using the Instrumental Variable Two-Stage Least Squares (2SLS) regression approach, the findings reveal that households with better healthcare access exhibit higher agricultural productivity compared to those that do not seek medical care. Distance to healthcare facilities is a major determinant of healthcare utilization, negatively impacting farm productivity due to increased health-related incapacitation.

The results underscore the critical role of healthcare in enhancing agricultural labor efficiency, reinforcing the argument that poor health is a major constraint to rural development and food security. Key factors influencing healthcare access include proximity to health facilities, health extension services, farm size, and off-farm income. Productivity is significantly driven by farm size, farming experience, cooperative membership, and household size, emphasizing the need for economic and social resources to enhance agricultural outcomes. Health-related incapacitation negatively affects productivity, highlighting the economic burden of untreated illnesses on farming households.

The study recommends expanding rural healthcare infrastructure, strengthening health extension services, and implementing affordable health insurance schemes for farmers. Integrating health interventions into agricultural policies is essential for achieving sustainable food security and rural development.

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6. Data availability

The data underlying this article will be shared on reasonable request from the corresponding author.

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Performance evaluation of Soybean (*Glycine max* l.) varieties in Buno Bedele and Ilu Ababor zones of South Western Oromia, Ethiopia

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ABSTRACT

Soybean is becoming economical important oil crop in Ethiopia. Evaluating the adaptability of released soybean varieties in diverse agro ecology is important for efficient use of nationally released varieties in their area of adaptation and thereby increases production and productivity of soybean in the country. The experiment was conducted to identify, and recommend adaptable, high yielding, Insect pest and disease resistant released variety for Soybean producing areas of Buno Bedele and Ilu Ababor zones in south west Oromia. Seven Soybean varieties were evaluated in RCBD with three replication in Buno Bedele zone (Dabo Hana and Bedele districts) and Ilu Abba Bora zone (Darimu district) for two consecutive years (2021 and 2022 main cropping seasons). The combined analysis of variance revealed significant differences ($P< 0.05$) among varieties in grain yield, days to 50% flowering, days to 95% maturity, plant height and pod per plant. However, significant differences were not observed in number of seed per pod. Katta (3.14 tha^{-1}) and Didesa (2.95 ha^{-1}) varieties were high yielder than the rest while Jalale (1.85 ha^{-1}) variety is the lowest yielder. In general, Katta and Didesa varieties were identified as the best varieties for yielding ability, stability and recommended in the area and with similar agro-ecologies.

KEY WORDS: *Soybean*; *Adaptability*; *varieties*; *Glycine max*

1. Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the most important pulse crops and it belongs to the family (*Leguminosae*) and is a self-pollinated crop with a chromosome number of 2n=40 (Singh *et al*., 2007). It was originated in Asia (Hymowitz, 2004). Soybean is cultivated all over the world, as a major source of oil (18%) and protein (40%). It used for cooking oil, soy milk, soy flour, and it is a good source of unsaturated fatty acids, minerals (Ca and P) and vitamins A, B, C and D (Mekonnen and Kaleb, 2014). Soybean is one of the fastest growing crops in the World and occupies an important position among grain legumes for its economic benefits (Hungria and Mendes, 2015).

Soybean is one of the most valuable crops in the world, due to its multiple uses as a source of livestock and aquaculture feed, protein and oil for the human diet and biofuel. Beside, producing valuable grain, soybean fixes between 44 and 300 kg N ha^{-1} (Hung, 2014) which makes a significant N contribution to inter-cropped and rotated cereal crops. Crosswell *et al.* (1992) estimated the

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improvement of maize crop following soybean crop at between 0.5 and 3.5 tons ha^{-1} or 30-350% relative to maize-maize sequences. Soya bean is also an important source of edible vegetable oil and protein for both humans and animals; and it improves soil fertility by fixing atmospheric nitrogen (Worku *et al*., 2011).

It has long been understood that low and declining soil fertility is an important barrier to intensifying agriculture and biological nitrogen fixation in soybeans is economically and ecologically beneficial in Africa. It also stimulates the local food and oil processing industries, the livestock and poultry feed industries, and increase the region's share of the global market through import substitution and export (Raimi *et al.*, 2017).

Ethiopia is endowed with favorable climatic and soil conditions for production in South and Western Ethiopia. Soybean grows in altitudes ranging from 1250 to 2200 masl, but performs well between 1300 to 1800 masl (Asfaw *et al.*, 2006). The crop is grown over wider agro-ecologies with mean annual rainfall of 500 to 1500 mm. Nevertheless, critical moisture requirement stages are at germination and grain filling. Temperature ranging from 20 to 25°C, and prefers a soil pH of 5.5 (Zerihun *et al.*, 2015). The introduction of soybean crop to Ethiopia dated back to 1950s with the objective of supplementing the diet of Ethiopians especially during long periods of partial fasting (Asrat, 1965). In the International trade market, soybean ranks number one among the major oil crops with an average protein contents of 40% on dry matter basis. It has the highest protein contents of all field crops and is second only to groundnut in terms of oil content (20%) among the food legumes. (Dugje *et al.*, 2009) reported that soybean is more protein rich than any of common vegetable or legume food sources in Africa.

The yields of soybean in most parts of Africa can increase from 0.5 to 2.5 tons ha^{-1} if the recommended packages are followed during their production. (Van *et al*., 2018). In most cases when soybean yields exceed 1.2 ton ha^{-1}, farmers are likely to make profits but at less than 0.7 tons/ ha farmers may not be able to recoup the cost of production. As soybean market value is good, application of little fertilizer like 20 kg P ha^{-1}, starter nitrogen and inoculants is often profitable even with conservative yield increment of 0.5 tons ha^{-1}. Important measures for boosting soybean yields include; adoption of high grain yielding varieties, soil fertility management, pest/disease control, observing the most appropriate planting time. It is an ideal crop for nutrition, food security, sustainable crop production and suitable in livestock integration systems (Herrero *et al*., 2010). Production and the usage of improved seeds is one of the most efficient ways of raising crop production. Even though, soya bean is very important oil crop in our country, its distribution through the country was limited to a certain areas. And also many improved soybean varieties were released from research institutions but not well reached to the farmers. Therefore, the objective of this study was to evaluate improved soybean varieties and recommend the best variety(ies) for the study area and similar agro ecology.

2. Material and Methods

2.1 Description of the study area

The experiment was conducted at Dabo Hana and Bedele districts in Buno Bedele Zone and Darimu district in Ilu Aba Bora Zone during 2021-2022 main cropping seasons.

Bedele district of Buno Bedele Zone, South-west Oromia Regional state during 2021 and 2022 main cropping seasons. It is bordered by the Sigmo district, District of Jimma Zone on the south western, Chora district in the north-west, Jimma Arjo district. District in the northern, and by Gechi district in the east. It is found at 480 km away from the capital city, Addis Ababato the Southwest. The area receives mean annual rainfall of 1200-1800 mm and it has an altitude between 1300 and 2200 meters above sea level (Bbzahldo, 2018). Geographically, the district falls between 36° 0' 0" up to 28° 80' 0" N latitude and 20° 79' E longitude. The districthas 45% arable land or cultivable land (57% was under annual crops), 4.7% pasture land, 35%, and 12% is considered swampy and degraded or otherwise unusable land respectively (Fig. 1, 2 and 3).

Dabo Hana district is located in Oromia National Regional State, western Ethiopia, in 08° 30' 28.7" to 08° 41' 34.6" N and 036° 26' 19.2" to 036° 30' 41.1" E with altitude ranging from 1791 to 1990 m.a.s.l, The district had a uni-modal rainfall pattern with average annual rain fall of 1945 mm. The rainy season covers April to October and the maximum rainfall is received in the months of June, July and August. The minimum and maximum annual air temperatures are 12.9 and 25.8°C respectively, the predominant soil type in Southwest and Western Ethiopia in general and the study area in particular, is Nitisols according to the soil classification system (FAO, 2001). Darimu district is one of the districts of Ilu Abba Bora Zone of south western Oromia Regional State, located 668 Km away from AA to the south western. The altitude ranges from 862 to 1874 m.a.s.l.. The study area has mean mininum and mean maximum temperature of 11.6 and 25.5°C, with annual rain fall of 2077 mm (NASA, 2023) Nitisol, Acrisol and Cambisol were dominant soil.

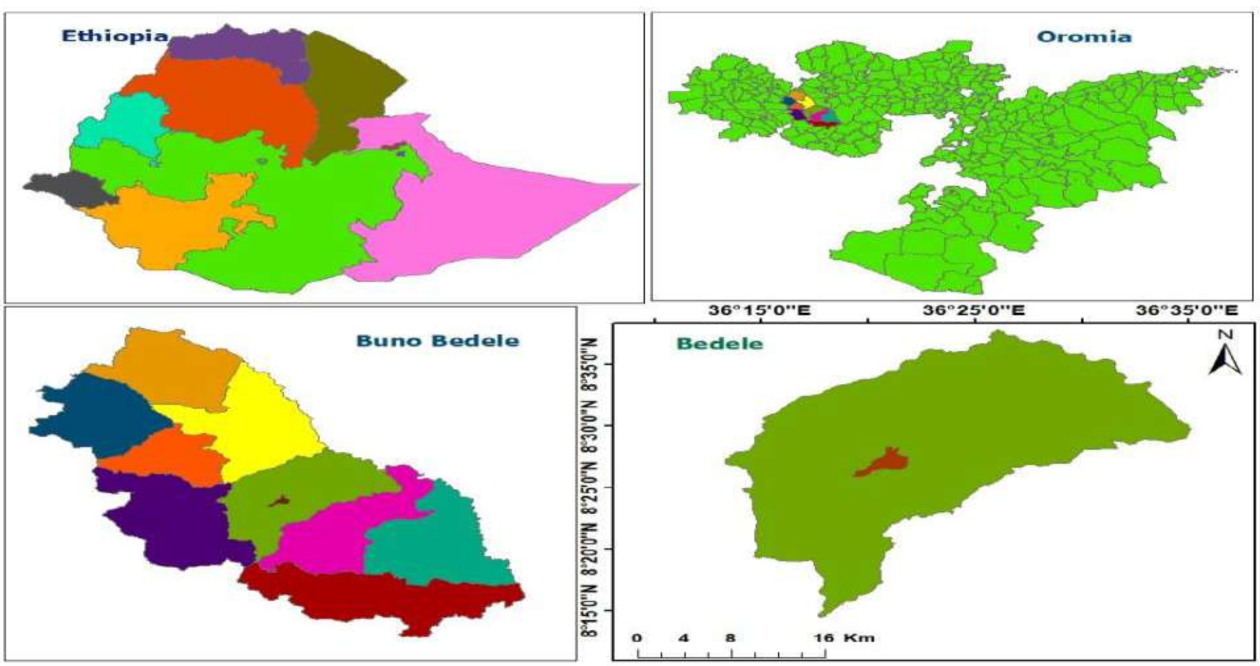

Fig. 1: Map of study area Bedele district

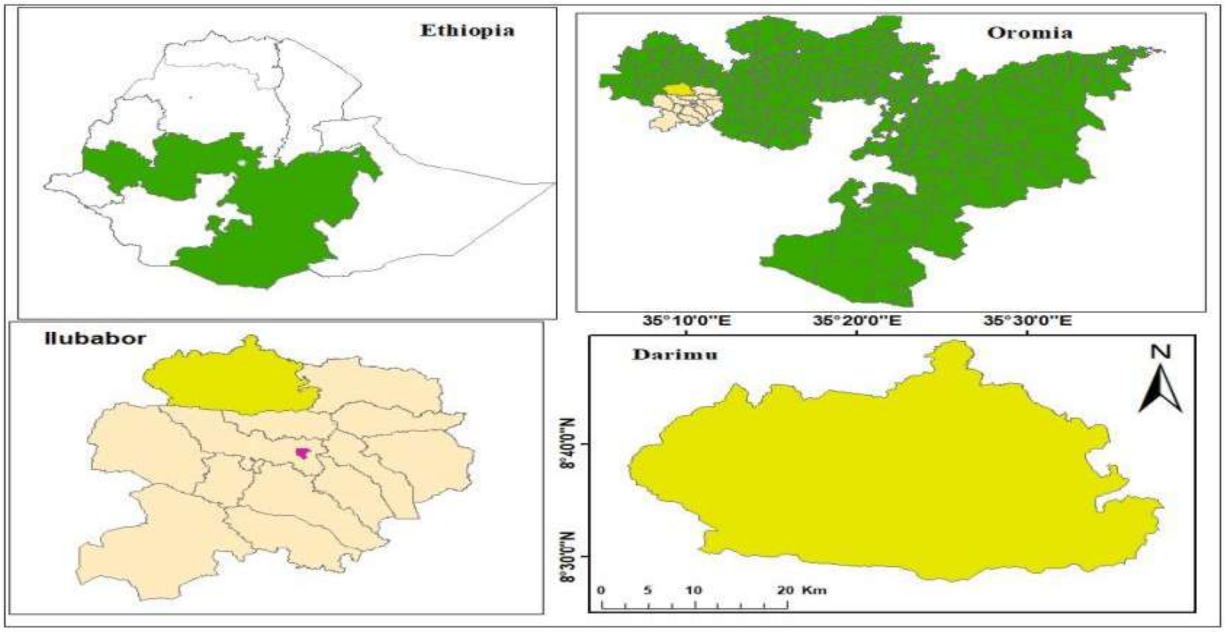

Fig. 2: Map of study Area (Darimu district)

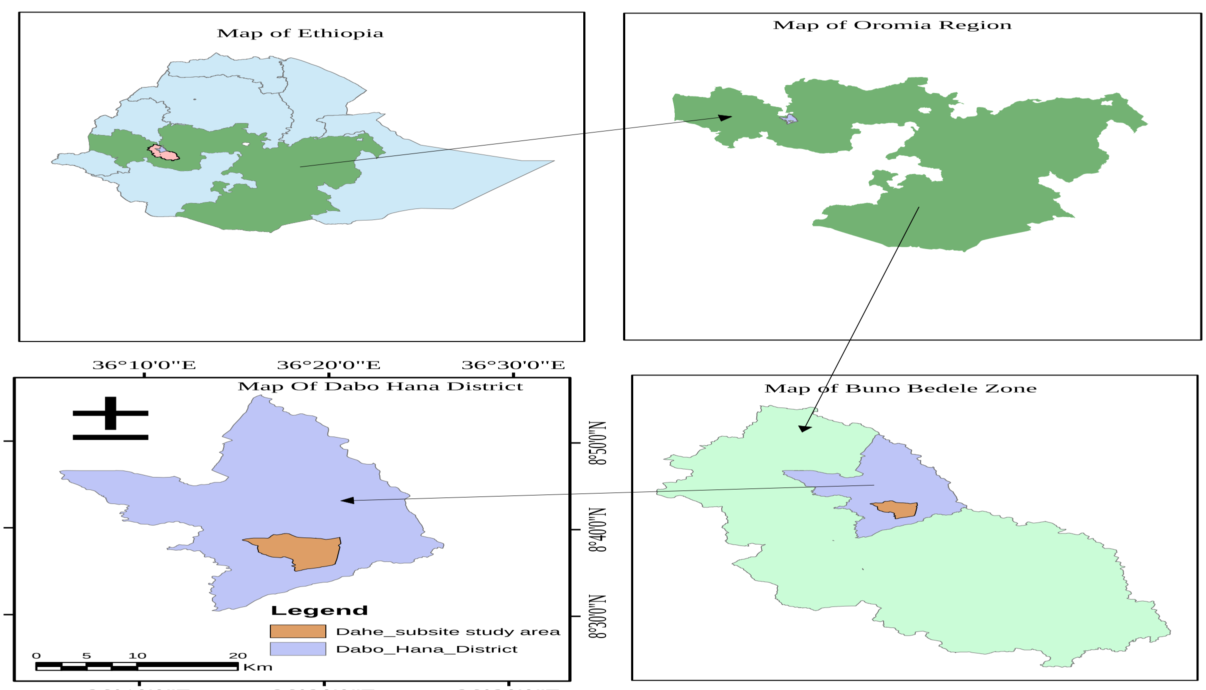

Fig. 3: Map of study Area (Dabo Hana district)

2.2 Experimental materials and design

The study was comprised of seven (7) improved soybean varieties (Table 1) organized in a randomized completed block design with three replications. The size of plots used for this experiment was 2.4m × 3m (7.2 m^2). The spacing between rows and plants was 40cm and 10cm respectively.

2.3 Data collection

Days to 50% seedling emergence: Days to emergence was recorded as number of days from planting to the time when 50% of the seedlings in plots emerged from the soil through visual observation.

Days to 50% flowering: this was determined by counting the number of days from planting to the time when first flowers appeared in 50% of the plants in a plot by counting the number of plants.

Days to physiological maturity: it was determined as the number of days from planting to the time when 90% of the plants started senescence of leaves (browning of the foliage) and pods started to turn black.

Plant height (cm): it was measured at physiological maturity from the base to the tip of a plant for randomly pre-tagged ten plants in harvestable rows using meter tape and averaged on a plant basis.

Number of pods per plant: it was recorded based on five pre-tagged plants in each net plot area at harvest and the average was taken as number of pods per plant

Number of seeds per pod: the total number of seeds in the pods of five plants was counted and divided by the total number of pods to find the number of seeds per pod.

Grain yield (kg ha^{-1}): Plants harvested from the four central rows and for aboveground dry biomass were threshed to determine grain yield, and the grain yield was adjusted to the moisture content of 10%.

$$\text{Adjusted Grain Yield} = \frac{(100\text{-MC}) \times \text{Unadjusted Yield}}{100 - 10}$$

Where MC- is the moisture content of Soybean seeds at the time of measurement and 10 is the standard moisture content of Soybean in percent. Finally, yield per plot was converted to per hectare basis and the average yield was reported in qt ha^{-1}.

Table 1: List of genotypes used for the experiment with their characteristics

Varieties	Year of release	Altitude (masl)	Maturity group	Center of release
Boshe	2008	1200-1900	Medium	BARC
Cheri	2003	1300-1850	Medium	BARC
Clark 63k	1981	100-1700	Medium	BARC
Cocker-240	1981	700-1700	Medium	BARC
Didesa	2008	1200-1900	Medium	BARC
Jalale	2003	1300-1850	Medium	BARC
Katta	2011	1200-1900	Medium	BARC

Note: masl=meter above sea level, BARC = Bako Agricultural Research Center

3. Results and Discussion

3.1 Analysis of variance

The combined analysis of variance for grain yield was presented in Table 2. The combined analysis of variance exhibited highly significant difference between tested Soybean varieties for grain yield. This indicated the presence of considerable variation in the genetic materials for yield and there is a possibility to improve the investigated Soybean varieties with simple selection.

However, the interactions; (Var×Loc) and (Year×Loc×Var) showed non-significant differences indicating consistent performance of varieties across locations and similarly the interaction (Year×Var) had non-significant effect on the grain yield and indicate that season was not affected the response of varieties on the studied parameters like grain yield.

3.2 The mean agronomic traits of the soybean varieties

The combined mean value of the grain yield and yield-related characters of the seven soybean varieties is presented below in Table 4. The highest plant height was observed in Cheri (86.72 cm) whereas the lowest plant height was recorded from Clark 63k (56.59 cm). The pods per plant were ranged from 49.46 to 73.94. The highest number of pods per plant was gotten from Katta (73.94) followed by Didesa (71.44), while the lowest number of pods per plant was obtained from Cocker-240 (49.46).

The highest days to maturity was recorded from Katta (139.4) and Cheri (131.2) while the lowest was obtained from Clark (116.8), which means that early maturing than the others. Based on the combined data wide ranges of mean grain yield values between the minimum (1.85 t ha^{-1}) from Jalale and maximum (3.118 t ha^{-1} from Katta were observed (Table 3). Katta and Didesa had the highest grain yield of (3.138 t ha^{-1}) and (2.946 t ha^{-1}), respectively, while Jalale (1.851 t ha^{-1}) had the lowest grain yield. The lowest productivity and range compared to the current study was reported by Mesfin and Abush (2019), whose mean grain yield ranged from 1.43 t $ha^{-1}$to 2.97 t ha^{-1}.

4. Conclusion

Within the final 2 decades or more clark 63K were the prevailing soybean variety developed in Jimma, Buno Bedele and Illu Aba Bora zones of

Table 2: ANOVA of seven soybean varieties for grain yield in 2021-2022 cropping season

SOV	DF	SS	MSS	F-Value	Pr(<F)
Var	6	2069.0	344.84	7.0140	3.933e-06***
Loc	2	928.5	464.25	9.4428	0.000191***
Year	1	223.0	223.02	4.5362	0.035946*
Var×Loc	12	756.8	63.06	1.2827	0.242844
Year×Loc	2	193.5	193.49	3.9355	0.050357
Year×Var	6	291.9	48.65	0.9896	0.437318
Year×Loc×Var	12	486.1	81.01	1.6477	0.143387
Residuals	89	4375.6	49.16		

Note: SOV = Source of variation, Var = Variety, Loc = Location, ** = significant at 0.01 probability level, *** = significant at 0.001probability level

Table 3: Combined mean value of seven Soybean varieties for yield and yield related traits at Buno Bedele Zone (Dabo Hana and Bedele dstricts) and Ilu Aba Bora Zone (Darimu district)

Genotype	DTF (days)	DTM (days)	PLH (cm)	NP/PL	NS/P	GY(qt/ha^{-1})
Boshe	76.39^{d}	122.7^{bc}	60.81^{b}	51.57^{c}	2.67	22.65^{cd}
Cheri	85.33^{ab}	131.2^{ab}	86.72^{a}	71.36^{ab}	2.61	25.40^{bc}
Clark 63k	77.67^{cd}	116.8^{c}	56.59^{b}	55.43^{c}	2.54	22.93^{cd}
Cocker-240	78.17^{bcd}	126.4^{bc}	59.56^{b}	49.46^{c}	2.61	23.42^{cd}
Didessa	84.17^{abc}	120.8^{bc}	76.02^{a}	71.44^{ab}	2.67	29.46^{ab}
Jalale	76.67^{d}	125.9^{bc}	60.26^{b}	59.81^{bc}	2.59	18.51^{d}
Katta	86.33^{a}	139.4^{a}	85.54^{a}	73.94^{a}	2.67	31.38^{a}
GM	81	126.2	69.39	61.86	2.62	24.82
LSD (0.05)	7.45	12.71	14.39	13.36	0.36	5.20
CV%	14.0	15.3	31.4	29.72	20.7	31.7
P-value	*	*	*	**	NS	**

Note: DTF = Days to Flowering, DTM = Days to Maturity, PLH = Plant height (cm), NP/PL = Number of pod per Plant, NS/P=Number of seed per Pod, GM = Grand mean, LSD = Least significant different, CV = Coefficient of variation, NS= Non-significant, * = Significant at P<0.05 level, ** = Highly significant.

Table 4: Mean grain yield (t ha^{-1}) and diseases reaction of seven soybean genotypes tested over six environments in south-western Ethiopia during 2021-2022 cropping season

Genotype	Mean grain yield (t ha^{-1})					Mean	Disease data
	Dabo Hana		Bedele		Darimu		
	2021	2022	2021	2022	2022		
Boshe	1.056^{bc}	1.482^{c}	2.546^{a}	27.08	1.852^{cd}	2.265^{cd}	0
Cheri	2.032^{a}	2.418^{b}	2.941^{a}	26.44	2.315^{bcd}	2.540^{bc}	0
Clark 63k	0.875^{c}	1.477^{c}	2.24^{ab}	31.76	3.056^{abc}	2.293^{cd}	0
Cocker-240	1.315^{bc}	1.688b^{c}	2.576^{a}	25.14	2.315^{bcd}	2.342^{cd}	0
Didesa	2.032^{a}	2.229^{bc}	3.091^{a}	3.269	3.495^{ab}	2.946^{ab}	0
Jalale	0.713^{c}	1.729^{bc}	1.496^{b}	3.125	1.269^{d}	1.851^{d}	0
Katta	1.565^{ab}	3.750^{a}	3.080^{a}	2.986	3.935^{a}	3.138^{a}	0
GM	13.70	21.10	25.71	29.17	26.03	24.82	
LSD(0.05)	6.52	8.14	8.82	1.37	14.32	5.20	
CV %	27.20	21.79	29.20	27.70	30.9	31.7	
P-value	*	**	*	NS	*	**	

Note: GM= Grand mean, LSD = Least significant different, CV = Coefficient of variation, NS = Non-significant, *=significant at P<0.05 level, **=highly significant.

South western Ethiopia. Within the consider made for two year with discharged varieties, Katta (3.138 t ha^{-1}) and Didesa (2.95 t ha^{-1}) were found the two high yielding varieties based on 2 a long time mean.

In this manner, the two varieties Katta and Didesa were prescribed for further exhibit and advancement for the study region and regions with comparable agro-ecology within the Buno Bedele and Ilu Abba Bor zone of south-western Oromia. Encourage inquire about will be done utilizing more soybean varieties/genotypes, over more areas and a long time to come up with way better profoundly adjusted and steady genotypes.

5. Acknowledgement

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6. Conflicts of interest

Authors declare that there is no conflict of interest exists.

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Preliminary investigation of effects of rhodic lixisol soil and biochar types on Soybean inoculated with *Bradyrhizobium japonicum*: A field trial study

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ABSTRACT

In our previous study, biochars derived from poultry manure (PMB) and rice husk (RHB) where shown to be promising sources of nutrients to the soybean crops that were grown in the ferric acrisol soils. Furthermore *Bradyrhizobium japonicum* inoculated soybean seeds were concluded to be advantageous. However, no field study was found for the rhodic lixisol soil types. Here we report effects of such biochars on soybean crops grown in rhodic lixisol soils were examined in terms of root dry weight (unit), shoot dry weight (g plant^{-1}), total plant dry weight (g plant^{-1}), seed weight (g), grain yield (Mg ha^{-1}), number of nodules (nodule number plant^{-1}), nodule dry weight (g plant^{-1}) and harvest index (unit). Our results showed 4 kg Mg ha^{-1} PM had a superior effect on the grain yield of the soybeans coated with *B. japonicum*. In this study *B. japonicum* coated seeds produced both high numbers as well as dry weights of nodules in response to PM and biochars either alone or in combinations. The harvest index of the un-inoculated soybeans upon treatment with 5 kg Mg ha^{-1} RHB + 2 kg Mg ha^{-1} PMB was found to be the highest. We successfully conclude rhodic lixisol soils to be well suited for PM and RHB applications on both inoculated and un-inoculated soybean crops.

KEY WORDS: *Poultry manure biochar*; *Rice husk biochar*; *Soil microbes*; *Soybean crops*

1. Introduction

In Sub-Saharan Africa, the majority of tropical soils are naturally deficient in organic matter due to continuous nutrient mining by growing crops and the presence of kaolinitic clays, which are chemically inert and affect productivity (Adiaha, 2017; Vlek *et al.*, 1997). The current practices of soybean production in the forest-savannah transition agro-ecological zone, especially continuous crop farming without the return of crop residues and fertilizer prior to soybean cultivation, could progressively reduce yields. Limitations of existing practices include nutrient imbalances, reduced soil quality, and increased vulnerability to erosion (Rashmi *et al.*, 2020; Hartemink, 2002). Additionally, soybean seeds require substantial amounts of nitrogen (N), phosphorus (P), and potassium (K), as well as smaller amounts of sulfur (S) and some micronutrients. Although soybean requires

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considerably less P and S than N or K, all these nutrients are essential for plant development.

This study builds on our previous work (Elebiyo & Bachmann, 2024), where poultry manure (PM), poultry manure biochar (PMB), and rice husk biochar (RHB) were prepared, characterized, and applied to soybean seeds inoculated with *Bradyrhizobium japonicum.* However, no field study had previously addressed rhodic lixisol soil types. In the present investigation, rhodic lixisols were used, with the experimental site located in the forest-savannah transition agro-ecological zone. Rhodic Lixisol is a tropical soil classified under the Cutanic, Aric, and Clayic categories. It is one of the most strongly weathered soils, retaining remnant qualities in humid subtropical climates, with low nutrient reserves and low available nutrient levels. Drier regions of the tropics and subtropics are predominantly occupied by rhodic lixisols, covering over 435 million hectares, particularly in East and Sub-Saharan Africa. Literature has shown that biochar applications are especially effective in nutrient-poor and acidic soils (Elias *et al*., 2020; Elebiyo & Bachmann, 2024). All the methods used in this study followed the procedures described in Elebiyo and Bachmann (2024) without modifications unless stated otherwise.

This study hypothesized that biochar addition would enhance soil organic carbon, while short-term agronomic effects would depend on pre-existing organic carbon levels. It was expected that combining poultry manure or poultry manure biochar with rice husk biochar would outperform RHB alone due to better N, P, and K availability, improving soybean growth, nodulation, and yield. Understanding these interactions is essential for optimizing biochar use in sustainable agriculture and environmental management. This research investigated how different biochar combinations and *Bradyrhizobium* inoculation affect soybean growth and yield in tropical rhodic lixisols. The findings are anticipated to guide effective biochar application strategies in improving global food security.

2. Material and Methods

2.1 Raw materials

The raw materials used in the present study were poultry manure (PM) and rice husk (RH), previously collected from local rice millers and poultry farms (Elebiyo & Bachmann, 2024). These materials were then converted into biochars following the procedures described in Elebiyo and Bachmann (2024). The chemical profile of the resulting biochars has also been previously reported (Elebiyo & Bachmann, 2024).

2.2 Experimental site

This study was conducted at the College of Agriculture, Ejura's Research Farm in Ghana between May and August 2017. The site is situated at a latitude of 07°23′04″ N and longitude 01°21′32″ W, with an elevation of approximately 249 m above sea level (see Fig. 1). The experimental site lies in the forest-savannah transition agro-ecological zone. The criteria for site selection were consistent with those used in Elebiyo and Bachmann (2024).

2.3 Weather

Weather data were obtained from the Ghana Meteorological Agency (GMet). The region experiences a bimodal rainfall pattern, with the major rainy season from mid-March to July and a minor rainy season from September to November.

The average annual rainfall is approximately 1439 mm. Monthly average temperatures range between 21.2℃ and 31.2℃. Relative humidity during the major cropping season averages 86%, while it drops to about 55% during the minor season.

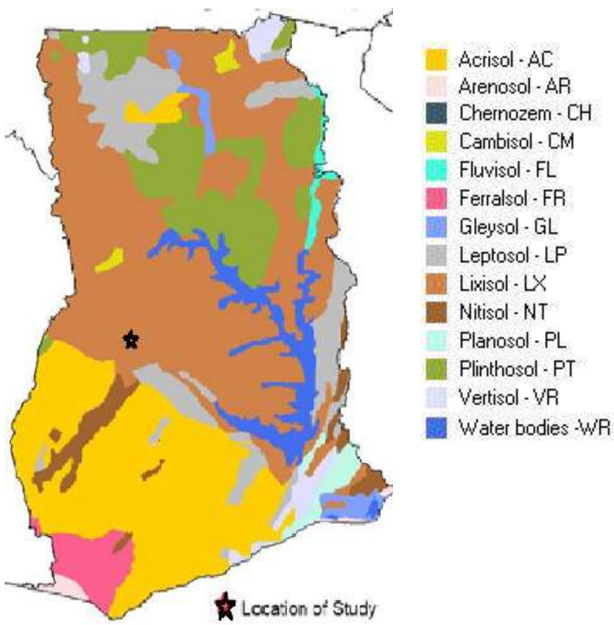

Fig. 1: Soil map of Ghana based Harmonised World Soil Map version 1.21. The dominant soil group at the study site is predicted to be Lixisol

2.4 Soil testing

Standard soil testing procedures were employed to determine key soil properties. Soil pH was analyzed using the method of McLean (1982), and electrical conductivity followed the standard protocol outlined by Rayment and Higginson (1992). Soil organic carbon (SOC) was estimated using the method of Nelson and Sommers (1982). Available phosphorus was assessed using the Bray and Kurtz (1945) method, and total nitrogen was measured according to Bremner and Mulvaney (1982). Exchangeable minerals including calcium, magnesium, and sodium were analyzed as per Brown and Lilleland (1946) and Moss (1961). Total exchangeable acidity (hydrogen and aluminum ions) was determined following the methods outlined by Page *et al*. (1982). Soil texture was determined using the hydrometer method described by Bouyoucos (1962).

2.5 Soil sampling and treatments

Soil sampling and treatment application were conducted following the methods described by Elebiyo and Bachmann (2024). Briefly, poultry manure biochar (PMB) was applied at rates of 2 and 4 Mg ha^{-1}, while rice husk biochar (RHB) was applied at 5 and 10 Mg ha^{-1}. Some RHB treatments were enriched with either dry PM or PMB. Control plots received no biochar amendments and were maintained with plain soil at 10 kg Mg ha^{-1}.

2.6. Soybean seed inoculation

Soybean seed inoculation followed the method described in Elebiyo and Bachmann (2024). Seeds were moistened using gum arabic and inoculated with *Bradyrhizobium japonicum* (SoyCap) at a rate of 10 g per kg of seeds. Each seed was estimated to carry between 10^4 and 10^6 viable rhizobial cells.

2.7 Soybean seed planting

Soybean seeds were planted on June 6, 2017, in the forest-savannah transition zone. Planting was done by placing three seeds per hole at a depth of 5–7 cm. Row spacing was maintained at 60 cm, and intra-row spacing at 10 cm.

2.8 Experimental design

The study employed a randomized complete block design (RCBD) as previously used in Elebiyo and Bachmann (2024). A total of 3 blocks were established, each consisting of 18 plots. In half of the plots, soybean seeds were not inoculated with *B. japonicum*, while the other half received inoculated seeds. In total, the experiment comprised 54 plots, covering a land area of 1295 m². Plots measured 5 m × 3 m, with 2 m spacing between blocks and 1 m between individual plots. The complete layout is summarized in Table 1.

2.9 Fertilizer

Triple superphosphate and potassium (K) were from muriate of potash. Fertilizers were applied to all soybean plots one week after planting using the band method. The application rate for phosphorus was 30 kg P per hectare (ha^{-1}) and potassium was also 30 kg K per hectare (ha^{-1}) respectively (Elebiyo & Bachmann, 2024).

2.10 Measurement of crop parameters

The soybean crops were analysed for dry biomass (shoot, root and total) weight, nodulation, grain yield and harvest index in accordance with methods described in Elebiyo and Bachmann (2024).

2.11 Statistical analysis

The data obtained for nodulation, growth, and yield parameters of soybean were subjected to statistical analysis using GENSTAT (2012 Edition). Analysis of variance (ANOVA) was performed to determine significant differences

Table 1: Soil treatments at experimental site of the forest-savannah transition agro-ecological zone. Values are on Mg ha^{-1} basis (Elebiyo & Bachmann, 2024).

Main plot number	Treatment	Main plot	Split plot		
		B. japonicum	PM	PMB	RHB
1	Plain soil	+	-	-	-
	Plain soil	-	-	-	-
2	10RHB	+	-	-	10
	10RHB	-	-	-	10
3	4PM	+	4	-	-
	4PM	-	4	-	-
4	4PMB	+	-	4	-
	4PMB	-	-	4	-
5	2PM+10RHB	+	2	-	10
	2PM+10RHB	-	2	-	10
6	2PMB+10RHB	+	-	2	10
	2PMB+10RHB	-	-	2	10
7	4PM+5RHB	+	4	-	5
	4PM+5RHB	-	4	-	5
8	2PMB+5RHB	+	-	2	5
	2PMB+5RHB	-	-	2	5
9	4PMB+5RHB	+	-	4	5
	4PMB+5RHB	-	-	4	5

PM - Poultry manure, PMB - Poultry manure biochar and RHB - Rice husk biochar between treatments after significant mean values were separated using the Duncan Multiple Range Test (DMRT) at the probability level of 5%.

3. Results and Discussion

3.1 Soil characteristics

The general characteristics of the soil at the experimental site were found to be similar to those of our previous study (Elebiyo & Bachmann, 2024). The soil type, however, was found to be rhodic lixisol (FAO/UNESCO Soil Map of the World Legend; Adu, 1992; Sys *et al*., 1993). The pH tests revealed that the chemical characteristics were very acidic (pH = 5.44). The pH is, however, found lower than that reported for ferric acrisol (Elebiyo & Bachmann, 2024). The SOC content was 0.39% and was found marginally appropriate for soybean cultivation; the SOC of a previous study was found to be moderate (Elebiyo & Bachmann, 2024) (Table 2). The characteristics of treated soil at the experimental site are shown in Table 3.

3.2. Growth of Soybeans with biochar-enriched soil and *B. japonicum* on a continuous cropping farm

In the present study, the outcomes of the root dry weight, shoot dry weight, and total plant dry weight of soybeans were not statistically different in their significance ($p < 0.05$) after applying 4 Mg ha^{-1} PM, 10 Mg ha^{-1} RHB and 4 Mg ha^{-1} PMB alone or in combination. Effects of *B. japonicum* coated seed on soybean root, shoot, or total plant dry weights were also found to be statistically similar in their significance ($P > 0.05$) after applying PM, RHB, and PMB alone or in combination. *B. japonicum*-coated seed had no significant ($P > 0.05$) effect on soybean root, shoot, or total plant dry weight (Fig. 2–4).

It is seen from Fig. 3 that 4 kg Mg ha^{-1} PM alone, and in combination with 5 kg Mg ha^{-1} RHB showed an increase in the dry shoot biomass. The findings were comparable to the un-inoculated soybean control samples. In fact, in this study 5 kg Mg ha^{-1} RHB combined with 4 kg Mg ha^{-1} PM showed the highest dry shoot weight relative to

Table 2: Soil physical and chemical properties prior to the experiment for soybean production in a rhodic lixisol of forest-savannah transition agro-ecological zone

Soil parameter	Unit	Rhodic Lixisol	Soil characteristics	Ferric Acrisol	Soil characteristics
pH (1:2.5 H_2O)		5.44	S3	5.64	S2
Electrical conductivity	(dS/m)	0.6	S1	0.6	S1
Organic carbon	(%)	0.39	S3	1.81	S2
Total nitrogen	(%)	0.01	NA	0.03	NA
Available phosphorus	(mg kg^{-1})	8.71	NA	9.4	NA
Calcium	(g kg^{-1})	2.34	NA	2.23	NA
Magnesium	(g kg^{-1})	0.22	NA	0.11	NA
Potassium	(g kg^{-1})	0.26	NA	0.13	NA

Suitability: S1 (high), S2 (moderate), S3 (marginal), N (unsuitable), NA: Not available

Table 3: Nutrient status of treated rhodic lixisol from the forest-savannah transition agro-ecological zone

Soil parameter	10 t RHB	4 t PM	4 t PMB	2 t PM + 10 t RHB	2 t PMB + 10 t RHB	4 t PM + 5 t RHB	4 t PMB + 5 t RHB	2 t PMB + 5 t RHB
Organic carbon	0.71	0.44	0.41	0.74	0.72	0.57	0.57	0.56
Total nitrogen	0.014	0.017	0.016	0.017	0.017	0.018	0.018	0.015
Available phosphorus	17.4	49.1	38.6	37.4	32.2	42.8	42.8	28
Calcium	2.34	2.54	2.42	2.44	2.38	2.42	2.42	2.38
Magnesium	0.226	0.235	0.231	0.233	0.232	0.234	0.234	0.229
Potassium	0.293	0.327	0.291	0.326	0.308	0.307	0.307	0.292

the control. The application of 4 kg Mg ha^{-1} PM, 10 kg Mg ha^{-1} RHB, 4 kg Mg ha^{-1} PMB, 10 kg Mg ha^{-1} RHB + 2 kg Mg ha^{-1} PM, and 5 kg Mg ha^{-1} RHB + 4 kg Mg ha^{-1} PM to the inoculated soybean seeds showed enhanced dry shoot biomass relative to the controls. The application of Mg ha^{-1} RHB + Mg ha^{-1} PMB in varying formulations on the contrary showed poor results, implying that more organic amendment is required.

From Fig. 4 it can be seen that inoculated soybeans treated with Mg ha^{-1} PM and Mg ha^{-1} RHB alone or in combination yielded high dry root biomass. In Fig. 5 it is obvious that PM and RHB are promising sources of nutrients to the inoculated soybean seeds.

5 kg Mg ha^{-1} RHB + 4 kg Mg ha^{-1} PM (18.02 g plant^{-1}) had the highest dry biomass weight, while 5 kg Mg ha^{-1} RMB + 2 kg Mg ha^{-1} PMB (10.02 g plant^{-1}) had the lowest influence. The findings indicate that PM released nutrients faster than PMB. Technically, PM has a shorter-term effect than PMB on agronomic practices. The findings indicate that the application rate was insufficient to address the nutrient shortfall in a timely manner at the research site, where nitrogen and phosphorus levels were low, organic matter was low, and the soil was acidic. The treatments with *B. japonicum* produced decent but not substantial results. PM is a more effective enhancer than PMB, which releases nutrients slowly. Our findings are congruent with those of Wu *et al*. (2022), who found that an optimum biochar application rate was effective in generating stable yields or yield increases under continuous cropping settings. It was also reported by Wu *et al*. (2022) that biochar applications increased the total root volumes relative to control samples. In the present study, the pH (7.88) of the PM-treated soils is close to the pH (7.39) of one of the biochar-treated soils in Wu *et al*. (2022), which showed about a 28.06% increase in total root volumes compared to control samples.

The study by Yusif *et al*. (2019) is of significance owing to the fact that acidic soils treated with 40 t ha^{-1} of biochar at 8 weeks after sowing resulted in taller plants. Increasing the quantity of biochars to 60 t ha^{-1} led to an improvement in the number of leaves. The optimal biochar rate for the highest shoot dry weight, root dry weight, and nodules was found to be 70 t ha^{-1}, 10 t ha^{-1}, and 50 t ha^{-1} respectively.

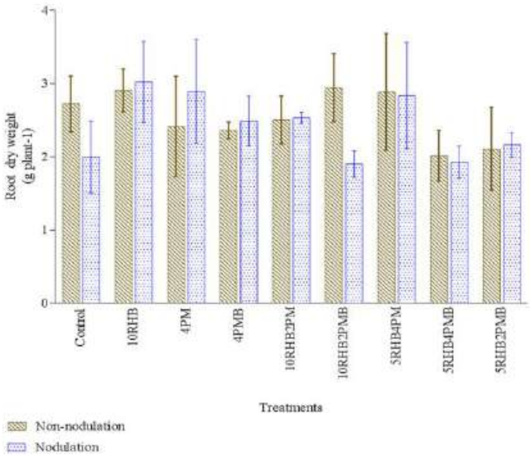

Fig. 2: Root dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Shoot dry weight is not significantly different ($p<0.05$).

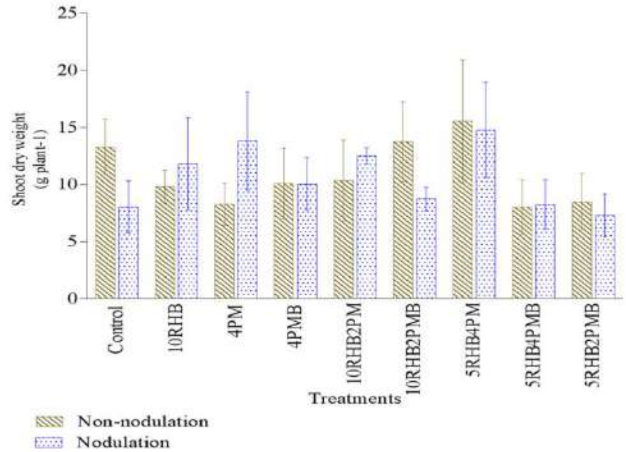

Fig. 3: Shoot dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Shoot dry weight is not significantly different ($p<0.05$).

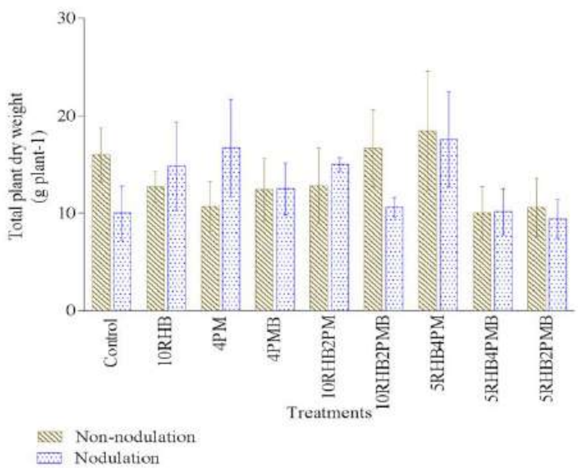

Fig. 4: Total plant dry weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Total plant dry weight is not significantly different ($p<0.05$).

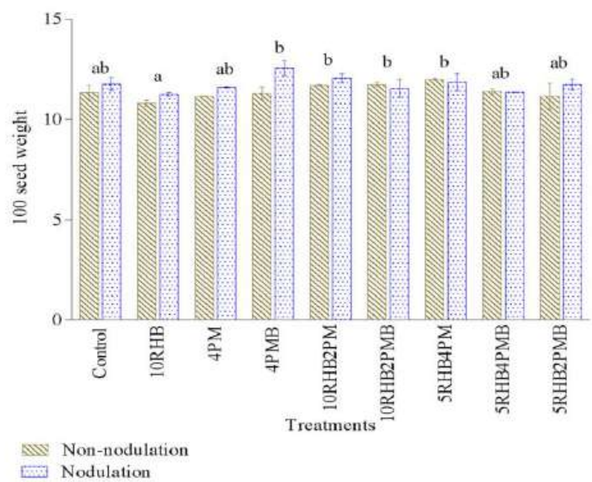

Fig. 5: 100 seed weight of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Total plant dry weight is not significantly different ($p<0.05$).

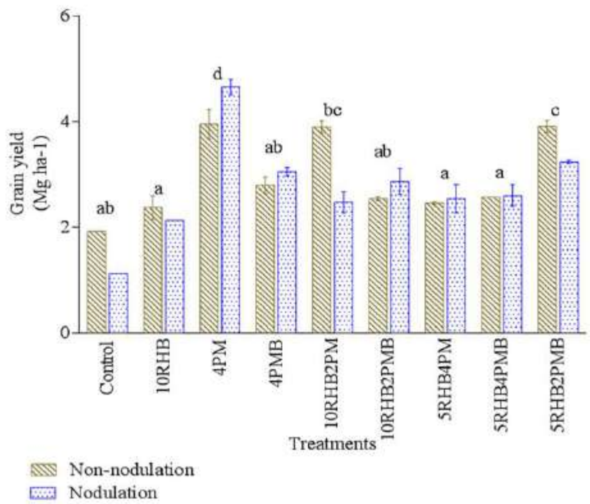

Fig. 6: Grain yield of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (*p<0.05*).

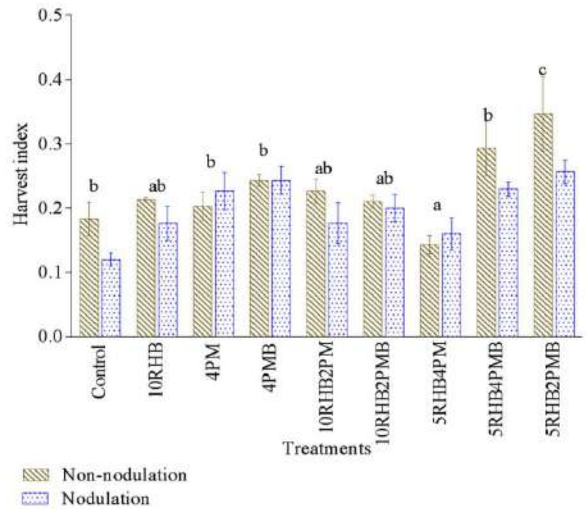

Fig. 7: Harvest index of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (*p<0.05*).

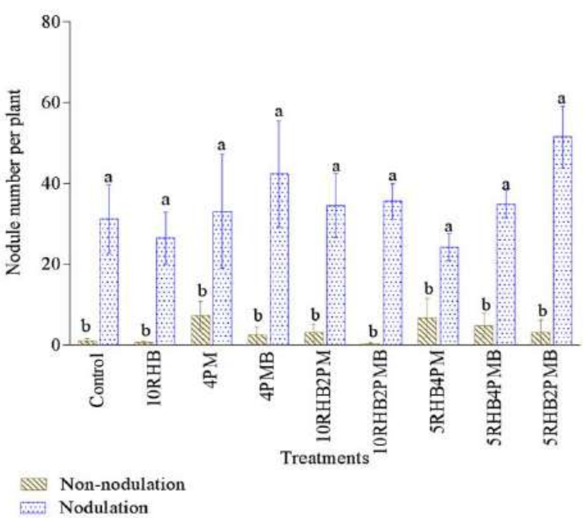

Fig. 8: Nodule number per plant of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bar with the same letters are not show significantly different (*p<0.05*).

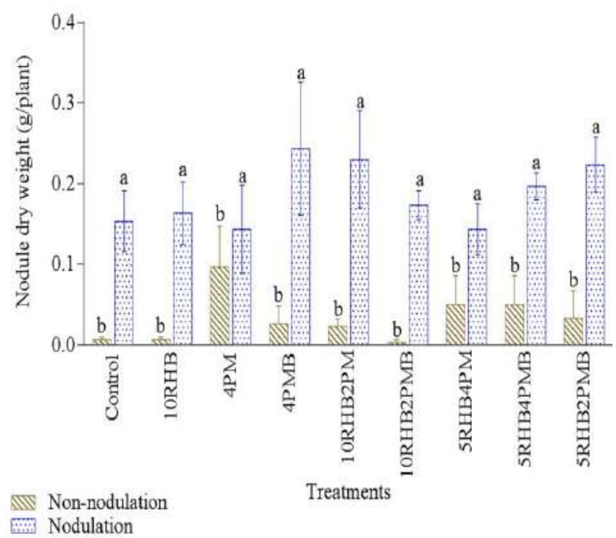

Fig. 9: Nodule dry weight per plant of soybean as influenced by the treatments in forest-savannah transition agro-ecology. Error bars represent standard deviation of the mean. Bars with the same letters are not significantly different (P<0.05).

In line with our previous experiment (Elebiyo & Bachmann, 2024), biochar greatly increased the growth and yield of soybean crops in the ferric acrisol of Ghana's Guinea savanna agro-ecological area, where organic carbon levels were moderate, and provided a concept for soybean cultivation. It indicates that more organic amendment may be required in this area.

In the study by Howard (2011), dry root mass of soybeans was found to depend on whether the seeds were grown in sand or soil. For example, in sand, an increase in dry root biomass was observed at 1.5% biochar compared to control. However, a decrease in dry root biomass was found when biochar application increased to 3.0%. The opposite effects were observed for dry root biomass grown in soils. Biochar at 3% produced the highest dry root biomass in soil, while comparably low results were observed at 1.5% and 6% biochar usage.

In the study by Zhu *et al.* (2018), biochar applications at 1.5% increased total root volumes by 52.1% relative to control samples. Similarly, a 31.5% increase in total root surface area was also evident. Root vitality was found to increase by 225.7–384.7% compared to controls at 7 days after germination. At 10 days after germination, root vitality was 92.7% higher than in the control samples.

In the study by Shekedir (2022), applications of 10 t ha^{-1} biochar and *Rhizobium* were found to boost root dry mass by 1.6-fold (2.06 g) compared to control (1.30 g). Total root volumes were also improved by such applications.

3.3 Soybean 100 seed weight, grain yields, and harvest index using biochar-enriched soil and *B. japonicum* on a continuous cropping farm

Using PM, RHB, and PMB alone or in combination significantly boosted soybean seed weight, grain yield, and harvest index ($p < 0.05$). *Bradyrhizobium* coated soybean seeds had a substantial impact ($P < 0.05$) (Fig. 5–7). Shekedir (2022) showed that for common beans treated with 10 t ha^{-1} biochar + *Rhizobium*, the number of nodules increased by 221.2% compared to the control samples. When lowering the application rate to 10 t ha^{-1} biochar + *Rhizobium*, a 36.52% increase in nodule number was reported compared to controls.

The highest 100-seed weight of soybean was measured with the application of 4PMB (11.94), while the lowest weight was recorded for 10RHB (11.03). The greatest grain yield at harvest was obtained under the application of 4PM (4.306), whereas the lowest was reported for 5RHB4PMB (2.433). The greatest impact on harvest index was recorded for 5RHB2PMB (0.3036), while 5RHB4PM gave the lowest value of 0.1527 PM was more impactful on nutrients due to its stronger response in terms of grain yield.

The increase in soybean grain yield and harvest index might be attributed to both single and combined treatments of PM, RHB, and PMB, as the control showed the lowest yield. The impact was stronger for RHB enriched with PM and PMB than for RHB alone. The results are consistent with Elebiyo and Bachmann (2024), although the yield observed in this study was lower than in a similar experiment conducted on ferric acrisol in a semi-deciduous forest in Ghana, where organic matter was higher. This suggests that additional organic matter is required on rhodic lixisols to improve grain yield and harvest index. It also implies that there is room for further improvement in yield outcomes.

Bradyrhizobium was able to influence 100-seed weight and harvest index, likely due to enhanced P and K availability from the organic amendments aiding nitrogen fixation, although this was insufficient to significantly affect overall yield. *Bradyrhizobium* inoculation, in combination with or separate from applications of PM, RHB, and PMB, has the potential to substantially enhance soybean grain yields.

According to Shekedir (2022), the combination of biochar and *Rhizobium* inoculation had a significant ($P < 0.01$) effect on nodule number, dry biomass, root volume, pod count, and seed yield. When compared to *Rhizobium* inoculation alone, a combined application of 10 t ha^{-1} biochar and *Rhizobium* significantly increased pod and seed production. Similarly, Sun *et al*. (2020) validated that both biochar type and inoculation influenced seedling growth performance. Their findings demonstrated that combined application of 10 t ha^{-1} biochar and *Rhizobium* improved pod number and seed yield compared to *Rhizobium* alone.

Ayalew *et al.* (2021) further reported that inoculation of cowpea with strain CP-24 significantly increased 100-seed weight by 13% relative to the control, although this did not translate into a significant improvement in overall yield.

3.4 Soybean nodule number and nodule dry weight with biochar-enriched soil and *B. japonicum* on a continuous cropping farm

Bradyrhizobium japonicum-coated soybean application significantly increased nodule number and the dry weight ($P < 0.05$) (Fig. 8 and 9). The sole and combined application of PM, RHB, and PMB did not significantly ($P < 0.05$) improve nodule number but caused variation across the treatments. Fig. 8 and 9 revealed that the performance of *B. japonicum* depends on the availability of organic matter and nutrients.

The lowest number of nodules was found in 10RHB (13.60) and control (16.13) plots, while the plot with 5RHB2PMB (27.33) and PMB (22.42) had the most. The control (0.0802) and 10RHB (0.0847) had the lowest dry weights, but the plot amended with 5RHB2PMB (0.1282) and PMB (0.1345) had the greatest.

Overall, the result indicated that inoculation treatments outperformed non-inoculated therapies. This result revealed that the application of *Bradyrhizobium japonicum* stimulates nodulation, particularly in tropical soils with a low native *Bradyrhizobium* strain population, which may be insufficient, and so increased the plant's response to *Rhizobium* strain inoculation (Abaidoo *et al*., 2007). Moretti *et al*. (2018) found that *Rhizobia* inoculation increased soybean nodule dry weight compared to the control. When *B. japonicum* inoculant was applied to soybean, the nodule dry weight and number increased by two to three times compared to the control. The positive increase in nodule number in soybean plants is consistent with the findings of Głodowska *et al*. (2017). Biochar improved nodulation performance, but not significantly. Ofori (2017) found that mixing rock phosphate and *Bradyrhizobium* spp. promoted nodulation in soybean and cowpea by around 61.5%. According to Shamim *et al*. (2015), nodulation increased when biochar and NPK fertilizer were applied together, with the combined application having the greatest influence. Shikha *et al.* (2023) demonstrated that biochar-based *Rhizobium* inoculants boosted nodulation, root weight, shoot weight, nut yield, and soil nutrient uptake in groundnut.

In conclusion, our data show that utilizing alkaline biochars and *B. japonicum*-inoculated seeds in soils without a history of soybean farming can increase the number of nodules. 4PMB and 5RHB2PMB will be effective organic additives for improving soybean nodulation.

4. Conclusion

The findings from the rhodic lixisol in the forest-savannah transition agro-ecology imply that soil pH and organic matter levels should be increased for improved legume yield and nodulation.

PMB outperformed PM in terms of soybean nodule formation. It indicates that nodulation requires slow-release nutrients. The results suggest that nutrient release from PM was faster than that of PMB on soybean crop growth biomass. As a result, PM is more effective in enriching RHB and has a shorter time effect than PMB, which informs agricultural applications. Under a sufficient soil pH, the combined application of PM or PMB could result in a short-term improvement in overall performance.

The soybean's root, shoot, and total plant dry mass remained unchanged ($p > 0.05$) after applying PM, RHB, and PMB alone or in combination, likewise the application of *B. japonicum*-coated seed. Using PM, RHB, and PMB alone or in combination significantly boosted soybean seed weight, grain yield, and harvest index ($p < 0.05$). *Bradyrhizobium japonicum* application resulted in a significant ($P<0.05$) increase in nodule number and dry weight (Fig. 8 and 9). This confirms the study's alternate hypothesis that nutrient-enriched biochar has a higher fertilization potential than RHB or non-biochar. The application of *B. japonicum* coated soybean seeds considerably boosted nodule number and dry weight in a ferric acrisol of the semi-deciduous agro-ecological zone.

The addition of 4 Mg PM and 5RHB2PMB resulted in the maximum number of nodules and grain yield when compared to 10 Mg RHB and 4 Mg PMB because the pH, phosphorus, and potassium levels in the soil were highest. Available phosphorus and potassium were shown to be connected with root, shoot, and total plant dry weight, but NPK in soil appeared to be somewhat correlated with grain ($R2 > 0.46$).

This study illustrates the feasibility of employing PM or 5RHB2PMB as an alternative or addition to synthetic inorganic fertilizer for soybean growth. PMB generated at 350°C should be used instead of PM to reduce odour and weight while retaining nutrients. PMB can also address nutrient shortages in RHB".

The results obtained from the rhodic lixisol in the forest-savannah agro-ecological zone show that there is a need to boost soil pH and organic matter content to improve the production and nodulation of legumes

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Effect of vegetable farming on poverty status and livelihood of farming households in Bosso and Chanchaga local government areas, Niger state, Nigeria

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ABSTRACT

This study examines the effect of vegetable farming on the poverty status and livelihood of farmers in Bosso and Chanchaga Local Government Areas of Niger State, Nigeria. The study describes the socio-economic characteristics of vegetable farmers, determines their poverty and livelihood status, and evaluates the profitability of vegetable farming. A sample size of 152 farmers was randomly selected, and data were obtained through structured questionnaires administered via the Kobo Toolbox. Data analysis was carried out using descriptive statistics, the United States Department of Agriculture (USDA) poverty index, the livelihood index, logit regression, and multiple regression models. The results show that 48.7% of respondents were between 41-50 years, while 28.9% were below 31 years. Additionally, 53.3% of the farmers were classified as poor, while 46.7% were non-poor. In terms of livelihood, 44.7% of respondents had a moderate livelihood, while 30.9% had a high livelihood status. Cost and return analysis indicated that vegetable farming is profitable, with an estimated total cost of ₦66,170.50, an average net income of ₦32,567.50, and a gross margin of ₦39,097.00 per production cycle. The major constraints faced by vegetable farmers included high input costs (51.9%), limited farmland (47.4%), and poor road networks (42.8%). The study concludes that vegetable farming has the potential to alleviate poverty and improve livelihoods. It recommends the provision of subsidized farm inputs, improved rural infrastructure, and enhanced extension services to boost vegetable farming and improve farmers' economic well-being.

KEY WORDS: *Vegetable farming*; *Poverty status; Livelihood*; *Profitability*; *Niger state.*

1. Introduction

Agriculture is a major sector of Nigeria's economy, engaging approximately 70% of the population and contributing significantly to the nation's GDP (FAO, 2020). Vegetable farming, in particular, plays a crucial role in providing food security, income generation, and employment, especially in rural areas (Schreinemachers *et al.*, 2018). Due to its short gestation period and high market demand, vegetable farming is considered an important avenue for poverty alleviation (Effiong *et al*., 2021).

Poverty is a condition where basic needs like food, clothing, and shelter are unmet, classified into absolute and relative poverty (Sulaiman *et al.*, 2015). Over 70% of Nigerians live below the

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poverty line, with 52.4% of urban dwellers surviving on a dollar per day, indicating high levels of absolute and relative poverty (Remi *et al*., 2017). It results in low income, hunger, malnutrition, disease, and poor access to necessities, threatening human survival (Joseph, 2010; Moshin, 2019). Despite Nigeria's resource wealth, poverty continues to rise, leading to hopelessness (Oyebanjo *et al*., 2023). However, increasing vegetable production, from 15.76 million tonnes in 2021 to 16.09 million tonnes in 2022, has helped reduce poverty and created employment for rural women (Ogunbo *et al*., 2015; Sanusi *et al*., 2015).

From the beginning of human civilization, agriculture has become the main source of people's livelihood (Sanusi *et al*., 2015). However, the term livelihood can be used in many different ways. A livelihood in its simplest sense is a means of gaining a living. Livelihood patterns are changing rapidly in the world with respect to time and space. A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stress and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Jatto *et al.*, 2021). Livelihood strategies include how people combine their income generating activities; the way in which they use their assets; which assets they chose to invest in; and how they manage to preserve existing assets and income (Jalapa *et al.*, 2021).

Despite the potential of vegetable farming to improve economic conditions, many farmers still struggle with poverty due to challenges such as high production costs, lack of access to modern farming inputs, limited extension services, and poor infrastructure (Fadipe *et al*., 2014). Furthermore, there is limited empirical evidence on the extent to which vegetable farming impacts poverty reduction and livelihood improvement in Niger State. This study seeks to bridge this gap by examining how vegetable farming influences the socio-economic status of farming household in Bosso and Chanchaga Local Government Areas of Niger State, determine their poverty and livelihood status, estimate farming costs and returns, analyze the effect of vegetable production on poverty and livelihood status, and identify the major constraints they face.

The objectives of this study are centered on a comprehensive examination of vegetable farming and its socio-economic implications for farmers in the selected study area. Specifically, the study aims to describe the socio-economic characteristics of vegetable farmers to provide a contextual understanding of their demographic and economic conditions. It seeks to determine the poverty status of these farmers, offering insights into their economic well-being. In addition, the study assesses the overall livelihood status of the farmers, capturing the multifaceted aspects of their quality of life.

Another key objective is to estimate the costs and returns associated with vegetable farming, thereby evaluating its economic viability. The study further analyzes the effect of vegetable production on the poverty status of farmers, investigating its role as a poverty alleviation strategy. It also evaluates the impact of vegetable farming on the broader livelihood status of the farmers. Finally, the study aims to identify the major constraints that hinder the productivity and sustainability of vegetable farming in the area.

2. Material and Methods

2.1 Study area

The study was conducted in Bosso and Chanchaga Local Government Areas of Niger State, Nigeria. The region has a predominantly agrarian economy, with vegetable farming being one of the major agricultural activities. The climate and soil conditions in the study area support the cultivation of various vegetables, including tomatoes, peppers, spinach, and onions (FAO, 2021).

2.2 Sampling Procedure and Data Collection

A multistage sampling technique was adopted. The first stage involved purposive selection of one (1) Local Government Area from Agricultural zone II namely: Bosso Local Government Area of Niger State for the study because of the presence of higher producers/farmers of vegetables in the study area. Second stage; was random selection of six (5) villages from Bosso Local Government Area namely; Lapai Gwari, Garatu, Dama, Gidan Mangoro and Gidan kwano. In all, a total of two hundred and two (202) vegetable farmers were sampled. The third stage involved the use of Yamane formula for appropriate sample size determination as reported by Eboh (2009) and Adopted by (Ojo, 2013).

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

Where:
n= Sample size
N=Population size
e = Level of precision, taken to be 5%.
1 = Constant

Structured questionnaires were used to collect primary data, focusing on farmers' socio-economic characteristics, farming practices, income levels, and constraints (Adams, 2016). Data collection was facilitated using the Kobo Toolbox.

2.3 Analytical Techniques

Descriptive statistics: Tables of frequency, mean and percentage were used to describe the socio-economic characteristics of the respondents such as the age, marital status, educational level, sex and income of household head; household size and expenditure.

Poverty measurement: The USDA poverty index was used to classify farmers as poor or non-poor. Poverty Measurement Model This was achieved using Foster-Greer Thorbecke (FGT) poverty index. The respondents were disaggregated into groups of poor and non-poor categories. Pα was used in analyzing poverty. The model (Pα) relates to different dimensions of the incidence of poverty (P0), depth of poverty (P1) and severity of poverty (P2). These was used for head count (incidence), depth and severity of poverty, respectively. The three measures was based on a single formula but each index puts different weights on the degree to which a household or individual falls below the poverty line. The mathematical formulation of poverty measurements as adopted by (Sallawu *et al.*, 2016) is estimated as:

$$p_{\propto} = \frac{1}{N}\sum_{i=1}^{q} \left[\frac{Z_{1-Y_1}}{Z_1}\right]^{\alpha} \text{-------------------------(2.1)}$$

Where,
p_α= the weighted poverty index for the ith sub-group,
α = Foster-Greer- Thorbecke (FGT) index and takes on the values of 0, 1 and 2 for incidence, depth and severity of poverty measures respectively,

Z_1 = the poverty line for i[th] sub-group,
q = the number of individuals below the poverty line,
N = the total number of individuals in the reference population,
Y_{ij} = the income of household j in the subgroup i,
Z - Y_{ij} = poverty gap of the i[th] household and

$$\frac{(Z_1 - Y_{ij})}{Z_1} = \text{poverty gap ratio} \text{ --------------------- } (2.2)$$

The quantity in bracket is the proportionate shortfall of income below the poverty line.

$\frac{q}{n}$ = the proportion of the population that falls below the poverty line.
This is called the head count or incidence of poverty.
If α = 0, then FGT measures the incidence of poverty,
If α = 1, then FGT measures the depth of poverty and
If α = 2, then FGT measures the severity of poverty.

In this study, the poverty status was defined on the basis of accrued income of the farmers; as a result, poverty line was defined on the basis of average income of the farmers per annum. Estimation of poverty based on the FGT index was used to disaggregate farmers' households into poor and non-poor categories.

Livelihood Index: A composite index assessing access to income, food security, education, and health services. A livelihood status diversification index was created from the different livelihood diversification strategies adopted by the respondents to determine the livelihood diversification status, using the approach by Kimengsi *et al.* (2019) in calculating an index from the different livelihood diversification strategies. The index is specified as:

$$\text{Index Ai} = \frac{A1 - Amin}{Amax - Amin} \text{ --------------------------} (2.3)$$

Where;
Ai = Livelihood index
A1= the actual value of an indicator for the household.
Amin = the minimum value of the indicator for the entire data set.
Amax = the maximum value of the indicator for the entire data set.

Net farm income: Farm budgeting technique was used to estimate the costs and returns of vegetable farmers in the study area**.** The net farm income model is specified as the equation below.

NFI = GR – (TFC+TVC) ------------------------(2.4)

Where:
NFI = Net farm income (₦);
GR = Gross revenue (₦);
TFC = Total fixed costs (₦); and
TVC = Total variable costs (₦).

GM = GFI – TVC ------------------------------- (2.5)

$$RRI = \frac{GM}{TVC} \text{ ---------------------------------------} (2.6)$$

Where:
GI= Gross margin (₦);
TVC = Total variable cost (₦).

$$OR = \frac{TVC}{GI} \text{ ---} (2.7)$$

Where:
OR = Operating Ratio;

TVC = Total Variable Cost; and
GI = Gross Income.

Gross ratio: It measures the ultimate solvency of the farm business.

$$GR = \frac{TFE}{GI} \text{---------------------------------------}(2.8)$$

Where:
GR = Gross Ratio;
TFE = Total Farm Expenses; and
GI = Gross Income. A lower and less than one ratio is preferable.

*Logit Regression***:** Used to determine the impact of vegetable farming on poverty status. Logit regression model was used determine the socio-economic and institutional factors influencing the poverty status of the respondents. The model is mathematically represented as:

Implicitly, the model is stated as

Y = f(X_1, X_2 ……………………….X_3) ------(2.9)

Explicitly it was expressed as:

Y = β_0+ $\beta_1 X_1$+ $\beta_2 X_2$+ $\beta_3 X_3$+ $\beta_4 X_4$+ $\beta_5 X_5$+ $\beta_6 X_6$ + $\beta_7 X_7$+ ………………………β_{15} X_{15}+ e

Where;
Y= Poverty status (poor = 1, non-poor = 0)
X_1= Age of farmer (years)
X_2 = Sex (male = 1, female = 0)
X_3= Marital status (married = 1, single = 0)
X_4= Household size (Number of persons per household)
X_5= Level of education (years)
X_6= Off-farm income (₦)
X_7= Years of farming experience (years)
X_8= Farm size cultivated (hectares)
X_9= Land ownership (owned = 1, otherwise = 0)
X_{10}= Labour usage (man day)
X_{11}= Cost of agro-chemicals (₦)
X_{12} = Cost of seed (kg)
X_{13}= Cost of fertilizer (₦)
X_{14}= Access to agricultural credit (₦)
X_{15} = Distance to farm (km)
β_o = constant
$\beta_1 - \beta_{15}$ = coefficients of the independent variables
e= Error term

Multiple Regression: Applied to evaluate the effect of vegetable farming on livelihood status. The data was fitted into four (4) functional of linear, semi log, cobb-Douglas and exponential. The lead equation was chosen based on coefficients of multiple determination (R^2 value), statistical significance of estimated regression coefficient, size of estimated regression coefficient, as well as the F ratio.

The explicit form of the functional forms are specified in the equation

Where:

Linear: $Cs = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_{13} X_{13} + e$ ------------------------ (2.10)

Double-log: $ln\,Cs = \beta_0 + \beta_1\, ln\,X_1 + \beta_2\, ln\,X_2 + \beta_3\, ln\,X_3 + \ldots + \beta_{13}\, ln\,X_{13} + e$ ----------------- (2.11)

Exponential: $ln\,Cs = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_{13} X_{13} + e$ ---------------------- (2.12)

Semi-log: $Cs = \beta_0 + \beta_1\, ln\,X_1 + \beta_2\, ln\,X_2 + \beta_3\, ln\,X_3 + \ldots + \beta_{13}\, ln\,X_{13} + e$ --------------(2.13)

Cs= Dependent variable
X_1-X_{13}= Independent variables
β_0, $\beta -$ β_{13}= Parameters to be estimated
e= error term.

Where;
Y = Annual income (₦)
X_1 = Farm size (hectare)
X_2= Labour usage (man day)
X_3= Cost of agro-chemicals (₦)
X_4 = Cost of seed (kg)
X_5= Cost of fertilizer (₦)
X_6= Age (years)
X_7= Household size (number)
X_8= Education (years)
X_9= Experience in vegetable farming (years)
X_{10} = (number)
X_{11} = Amount of credit accessed (₦)
X_{12} = Extension contact (number)
X_{13} = Cooperative membership (years)
β_o = constant
$\beta_1 - \beta_{13}$ = coefficients of the independent variables
$X_1 - X_{13}$ = independent variables
U_i = Error term
ln = Natural log

3. Results and Discussion

3.1 Socio-economic Characteristics of Farmers

The study found that 48.7% of vegetable farmers were aged between 41-50 years, while 28.9% were below 31 years. The majority (83.6%) had household sizes of fewer than six members. Regarding farming experience, 56.6% had between three and six years of experience. Furthermore, 58% of respondents were members of cooperatives, and 40.8% had access to agricultural extension services (Adedoyin & Jibowo, 2005).

Findings from Fig. 1, indicated key aspects of cooperative membership, extension access, and land acquisition methods among vegetable farmers in the study area.

Cooperative membership shows that only 39.5 percent of farmers belong to a cooperative, while 60.5 percent are non-members. This indicates low participation in cooperatives, which may limit farmers' access to credit, inputs, and market information. Extension access is also low, with 82.9 percent of respondents reporting no access to extension services, while only 17.1 percent had received extension support. This lack of extension access may hinder farmers from adopting improved practices and increasing productivity.

The number of extension visits was also analyzed. a total of 82.9 percent of farmers reported receiving no extension visits. Only 9.9 percent had two visits, 3.3 percent had three visits, and 3.9 percent had five visits, this shows poor extension coverage, which can negatively impact farmers' knowledge and productivity. Land acquisition methods indicate that 65.3 percent of farmers inherited their farmland, making it the dominant method of land acquisition. Other methods include borrowing at 12.5 percent, renting at 9.9 percent, and purchasing at 3.3 percent. The reliance on inheritance and borrowing suggests that many farmers lack secure land ownership, which may limit their ability to invest in long-term improvements.

3.2 Poverty status

Poverty remains a significant challenge among vegetable farmers in the study area. Fig. 2 presents the distribution of respondents based on their poverty status. The study found that a frequency of 81 respondents (53.3 percent) were classified as poor, while a frequency of 71 respondents (46.7 percent) were non-poor. This implies that more than half of the vegetable farmers in Bosso and Chanchaga LGAs are living below the poverty line, indicating a high level of poverty in the region. The poverty line was established at ₦52,471.45, calculated as two-thirds of the mean per capita income of the sampled farmers. The poverty incidence (or headcount ratio) was 0.5328, meaning that 53.3 percent of the sampled farmers were below the poverty threshold. The study also analyzed the poverty gap, which was 0.2017 (20.2 percent), implying that the average income of poor farmers must be increased by 20.2 percent to lift them out of poverty. Furthermore, the poverty severity index was 0.1042 (10.4 percent), indicating that not only are many farmers below the poverty line, but there is also significant income inequality among them. The severity index accounts for the depth of poverty and the degree of disparity among poor farmers. These findings contrast with Pelemo *et al.* (2020), who reported that poverty was only prevalent among a small proportion of farmers in North-Central Nigeria. This discrepancy could be attributed to differences in farm productivity, access to resources, and policy interventions in different locations.

Effect of vegetable farming on poverty status

The impact of vegetable farming on poverty reduction was further analyzed using a logit regression model, as presented in Table 1. The results indicate that several socio-economic and farming-related factors significantly influence poverty status among vegetable farmers. Marital status (-0.6582836, $p<0.01$) had a negative and significant effect on poverty status. This implies that married farmers are less likely to be poor compared to single farmers, possibly due to

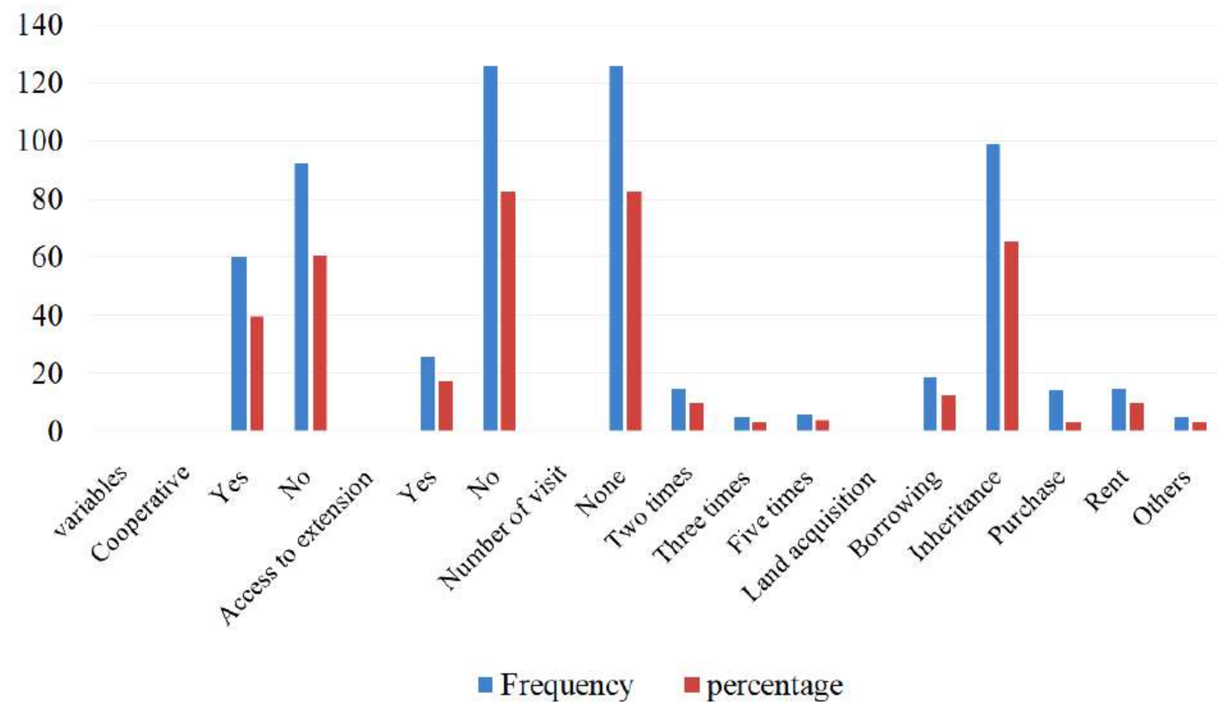

Fig. 1: Distribution of vegetable farmers according to cooperative membership, access to extension and land acquisition (n=152). (Source: Field survey, 2024)

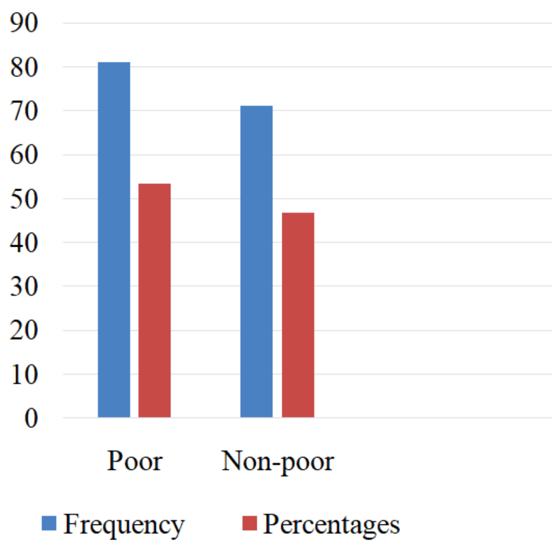

Fig. 2: Disribution of respondents based on their poverty status (n=152). (Sources: Field survey, 2024)

household income pooling and shared economic responsibilities. Household size (-0.0571015, p<0.10) had a negative effect on poverty status, meaning that as household size increases, poverty tends to decrease. This could be due to the availability of more labor for farm work, leading to higher productivity and income generation. Farming experience (0.0198272, p<0.10) was positively significant, meaning that as farmers gain more experience, their likelihood of being poor increases slightly. This contradicts expectations and suggests that longer farming years do not necessarily lead to better financial conditions, possibly due to low mechanization, outdated farming practices, or decreasing land productivity over time. Primary occupation (0.1532406, p<0.10) was also positively significant, indicating that farmers who rely solely on vegetable farming struggle financially due to fluctuating market prices, post-harvest losses, and lack of diversification into other income sources. Vegetable output (0.0091112, p<0.01) was positively correlated with poverty status, meaning that increased production does not necessarily reduce poverty. This might be due to factors like low market prices, high input costs, and exploitative middlemen who lower farmers' profits. Cooperative membership (0.684253, p<0.01) was positively significant, meaning that members of agricultural cooperatives had a higher probability of being poor. This could be due to ineffective cooperatives, mismanagement, or lack of real financial benefits from group affiliations. Extension services (0.7193884, p<0.01) had a negative impact on poverty, meaning that farmers with access to agricultural training, new technologies, and better farming techniques were less likely to be poor. This suggests that government and non-government organizations should strengthen extension services to improve farmers' financial well-being. Farm size

Table 1: Effect of vegetable production on poverty status of farmers (n=152)

Variables	Coefficient	t-value
Age	0.101571	1.18
Marital status	-18.75855	-2.15**
Household size	-1.627174	-1.73*
Farming experience	0.5880065	1.87*
Primary occupation	4.366767	1.79*
Vegetable output	0.2596336	2.42**
Cooperative society	19.49858	2.51***
Extension society	20.4998	2.31**
Farm size	2.421703	2.41**
Distance to market	0.0929304	1.40
Constant	-36.08858	-2.76***
Chi^2		174.73**
Pseudo R^2		0.8379

Sources: Field survey, 2024
*** Significant at 1% level of probability,
**=Significant at 5% level of probability,
*=Significant at 10% level of probability

(0.0849835, $p<0.01$) was negatively related to poverty, implying that farmers with more land resources tend to be wealthier due to the ability to expand production and earn higher revenues.

3.3 Livelihood status

The study assessed the livelihood status of vegetable farmers using a livelihood index, as shown in Fig. 3. The findings revealed that 24.34 percent of farmers had low livelihood (Index < 0.333), 44.74 percent had moderate livelihood (Index between 0.334 - 0.667), and 30.92 percent had high livelihood (Index > 0.667). The mean livelihood index (A1) was 0.5592, suggesting that most farmers fall within the moderate livelihood category. The minimum livelihood index (Amin) was 0.1112, and the maximum index (Amax) was 1.0000, indicating a wide disparity in livelihood conditions. These findings align with Mukaila *et al*. (2022), who reported that vegetable farming significantly improves rural livelihoods by providing steady income, food security, and employment opportunities. Using the USDA poverty index, 53.3% of vegetable farmers were classified as poor, while 46.7% were non-poor. Regarding livelihood status, 44.7% of respondents had a moderate livelihood, while 30.9% reported a high livelihood. These results suggest that while vegetable farming contributes to economic well-being, many farmers still face financial challenges (Akpan, 2010).

Effect of vegetable farming on livelihood status

Table 2 presents the results of a multiple regression analysis that examined the impact of vegetable farming on livelihood status. The key

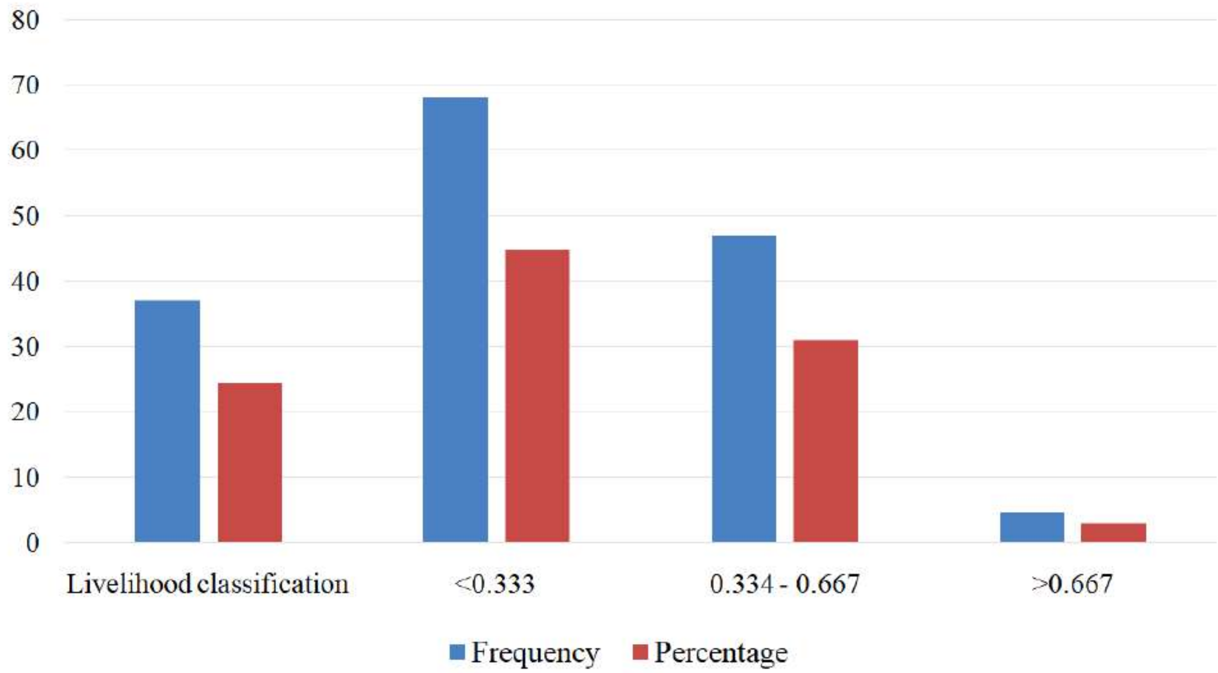

Fig. 3: Distribution of respondents based on their livelihood status (n=152).
(Sources: Field survey, 2024)

findings include the following. Age (-0.0070062, p<0.01) had a negative and significant effect on livelihood status, meaning that older farmers had lower livelihood scores. This suggests that younger farmers are more productive, adaptable to new farming techniques, and willing to explore market opportunities. Household size (0.0780138, p<0.01) was associated with higher livelihood scores, likely due to more available labor for farm work and diversified sources of income within the household. Farming experience (0.0103578, p<0.01) was positively significant, implying that experienced farmers achieve better livelihood outcomes due to greater knowledge of market trends, improved production techniques, and better resource management. Primary occupation (0.0572969, p<0.10) showed that farmers engaged primarily in vegetable farming had higher livelihood scores, indicating that full-time vegetable farming can sustain livelihoods if properly managed. Vegetable output (0.0003037, p<0.01) was associated with improved livelihood status, suggesting that higher productivity contributes positively to financial well-being. Cooperative membership (0.200648, p<0.01) significantly improved livelihood status, as cooperatives provide better access to inputs, credit, and market linkages. Extension visits (0.1088783, p<0.01) had a positive effect on livelihood, reinforcing the importance of agricultural training and advisory services. Farm size (0.0002321, p<0.01) contributed to better livelihood status, supporting the idea that land ownership plays a critical role in economic stability. Expenditure factors such as increased spending on food, education, healthcare, and house rent were negatively significant, indicating that higher living costs reduce disposable income, affecting overall livelihood scores.

Table 2: Effect of vegetable production on livelihood status of farmers (n=152)

Variables	Coefficient	t-value
Age	-0.0070062	-4.23***
Household size	0.0780138	8.86***
Farming experience	0.0103578	2.94***
Primary occupation	0.0572969	1.94*
Vegetable output	0.0003037	5.32***
Cooperative	0.200648	6.31***
Extension visits	0.1088783	5.20***
Farm size	0.0002321	4.67***
Food expenditure	-1.21e-06	7.99***
Clothing expenditure	-0.0000297	-4.31***
Healthcare expenditure	-2.20e-06	-0.65
Education expenditure	-6.80e-06	-2.97***
House rent expenditure	-0.0002136	-7.85***
Communication expenditure	2.82e-07	0.16
Transportation expenditure	-4.39e-06	-2.09**
Constant	-0.1431418	-1.84*
Chi^2		196.11***
Pseudo R^2		0.542

Sources: Field survey, 2024

3.4 Profitability analysis

Cost and return analysis revealed that vegetable farming is profitable. The estimated total cost per production cycle which typically lasts between 8 to 12 weeks was ₦66,170.50, with an average net income of ₦32,567.50 per cycle and a gross margin of ₦39,097.00 (Fadipe *et al.*, 2014). The gross ratio of 0.49 and operating ratio of 0.67. A gross ratio of 0.49 means that 49% of the total revenue is spent on production costs, leaving 51% as potential profit. The lower the gross ratio, the higher the profitability. A GR below 1 indicates that the business is financially viable, while a GR above 1 would mean the farm is running at a loss. The gross ratio of 0.49 indicates that vegetable farming in the study area is profitable, as only

49% of the revenue is used to cover total costs, allowing farmers to retain the remaining 51% as earnings. Also an operating ratio of 0.67 means that 67% of the revenue is used to cover variable costs, leaving 33% as earnings before fixed costs and profit considerations. A lower OR indicates better cost efficiency, meaning farmers can retain more income as profit. Since 67% of revenue is used for operational costs, only 33% remains for fixed costs and net earnings. The operating ratio of 0.67 shows that a significant portion of revenue (67%) is spent on variable costs, such as labor, herbicides, and insecticides, which are essential for production. Since the gross ratio is below 1, the farm remains financially sustainable. However, the high operating ratio suggests that reducing variable costs could increase profitability. Hence, it can be inferred that vegetable in the study area is profitable as vegetable farming generates substantial returns for farmers.

3.5. Constraints facing vegetable farmers

The findings from Fig. 4 indicates that vegetable farmers in the study area face multiple challenges that affect their productivity and profitability. The most significant constraints include the high cost of farm inputs, limited farmland, and poor road access. Other notable challenges include

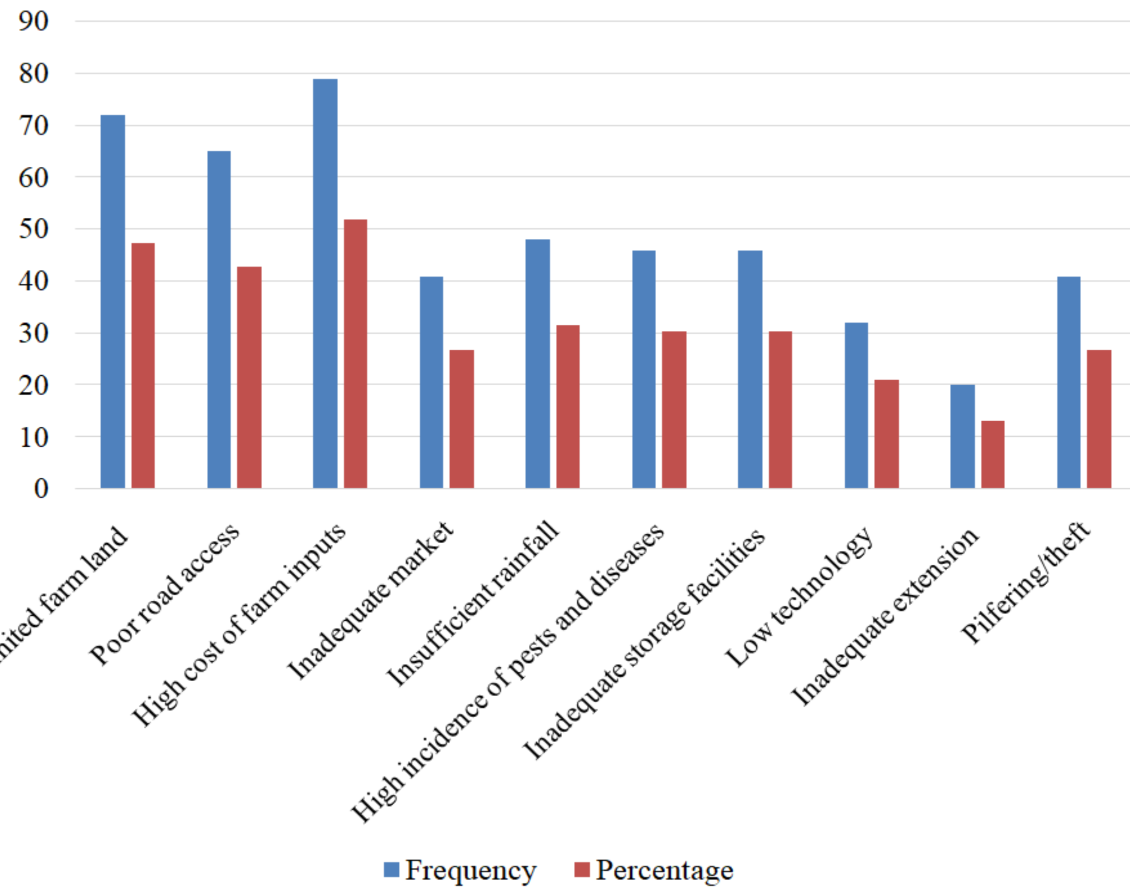

Fig. 4: Constraints facing vegetable farmers in the study area (n=152), (Sources: Field survey, 2024)

inadequate market access, pest and disease incidence, lack of storage facilities, and inadequate extension services. High cost of farm inputs was the most reported constraint, affecting 51.9 percent of farmers. This finding is consistent with Oluwasola (2015), who reported that rising production costs significantly hinder vegetable farming in Oyo state. The increasing prices of seeds, fertilizers, pesticides, and herbicides can be attributed to inflation, currency devaluation, and high import dependency, as highlighted by World Bank (2018). This makes it difficult for smallholder farmers to afford necessary inputs, leading to reduced yield and profitability. Limited farmland was reported by 47.4 percent of respondents, making it the second most critical challenge. Mukaila *et al.* (2022) found similar results, stating that farmland scarcity is a major constraint for vegetable farmers in Nigeria due to increasing population pressure and land conversion for residential and industrial purposes. The availability of arable land is crucial for increasing production capacity, and restricted access to land may limit expansion and mechanization. Poor road access was identified by 42.8 percent of the farmers as a significant challenge. Poor rural infrastructure affects transportation, increasing post-harvest losses and reducing farmers' access to markets. This finding aligns with Adekoya (2014), who emphasized that inadequate road networks increase production costs and discourage investment in vegetable farming. Without good roads, farmers struggle to move their produce to urban markets, leading to reduced earnings and increased wastage. Inadequate market access was reported by 26.9 percent of respondents. Marketing challenges such as price fluctuations, lack of storage, and middlemen exploitation have been widely documented in literature. Effiong *et al.* (2021) highlighted that smallholder farmers often have weak bargaining power, making them vulnerable to price manipulations by traders. Improving market linkages and providing storage facilities could help farmers sell their produce at better prices. Pest and disease incidence was a problem for 30.3 percent of farmers. This is consistent with Fadipe *et al*. (2014), who observed that inadequate pest control measures and climate change effects have increased pest outbreaks, leading to significant yield losses. Proper pest management training and subsidized access to pesticides could help farmers mitigate this challenge. Low technology adoption was reported by 21.1 percent of respondents this agrees with Mukaila *et al*. (2022), who noted that many vegetable farmers still rely on traditional farming practices, which limit productivity. Inadequate mechanization and lack of access to modern farming tools contribute to low efficiency. Inadequate extension services affected 13.2 percent of farmers, making it the least reported constraint. However, the importance of extension services in modernizing agriculture cannot be overstated. Ashagidigbi *et al.* (2018) reported that poor access to extension services limits farmers' knowledge of improved agronomic practices, leading to lower productivity. strengthening agricultural extension programs would enhance farmers' technical know-how and boost production.

4. Conclusion

This study concludes that vegetable farming contributes significantly to income generation and livelihood improvement among farmers in Bosso and Chanchaga LGAs. However, despite its profitability, many farmers still experience poverty due to high input costs, poor infrastructure, and limited access to support services. The study also concludes that most vegetable farmers in the study area are in their active age, predominantly male, and married with small household sizes. A significant proportion of the farmers neither belong to cooperatives nor have access to extension services. More than half of the farmers live below the poverty line, and only a few enjoy a high livelihood status. Despite these challenges, the gross margin analysis confirmed that vegetable farming is a profitable venture. Several socio-economic factors significantly influenced vegetable production and poverty status. The coefficients of age, household size, farming experience, primary occupation, vegetable output, cooperative membership, extension visits, farm size, food expenditure, clothing expenditure, education expenditure, and household rent expenditure all had varying effects on vegetable production. Similarly, marital status, household size, farming experience, primary occupation, vegetable output, cooperative membership, extension services, and farm size were key determinants of poverty status. The major constraints faced by farmers were the high cost of inputs and limited access to farmland. The price of input should be subsidized for vegetable farmers in the study area, good road network should be provided for farmers in the study area and older farmers should be sensitized to embark on vegetable.

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Adoption of climate-smart microgardening practices for root and tuber crops in urban households: A case of Abia state, Nigeria

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ABSTRACT

This study examined the adoption of climate-smart microgardening practices among urban households, with a focus on the cultivation of root and tuber crops, specifically yam, cocoyam, and cassava. The research highlights innovative approaches to urban farming that align with sustainable development goals in light of climate change. The study surveyed 33 households that practice microgardening in Umuahia and Umudike, Abia state, using a snowball sampling technique. Among the respondents, 57.6% grow yams, while 9% cultivate cocoyam and 3% cassava in mainly bags and tyres. Key findings indicate that microgardening reduces household food expenses (mean = 3.64), and promotes the adoption of climate-smart agricultural practices, such as zero use of inorganic fertilizer (mean = 3.15), organic pest and disease control (mean = 3.36) and the recycling of cultivation materials (mean = 3.15). Social and economic benefits include increased access to fresh and nutritious food (mean = 3.93), improved interaction with neighbors (mean = 3.42), and opportunities for skill development (mean = 3.67). However, challenges such as limited space, difficulty in watering during dry seasons, and the high cost of inputs persist. Regression analysis revealed that socioeconomic factors, like age (10%) and income (5%), positively influenced the adoption of climate-smart practices, while experience in microgardening (5%) has a negative impact on adoption. This study underscores the importance of leveraging climate-resilient technologies to enhance the sustainable management of root and tuber crops in urban environments, contributing to food security, poverty alleviation, and economic development.

KEY WORDS: *Microgardening*; *Climate-smart practices*; *Root and tuber crops*; *Urban households*

1. Introduction

The accelerated urbanization of towns and cities in developing countries has created unprecedented challenges, including food insecurity and malnutrition. By 2050, urban populations in the poorest nations are projected to triple, intensifying the strain on food systems and nutrition. Currently, approximately 815 million people face chronic hunger, with more than half living in urban environments (FAO, 2014). This situation is further exacerbated by the prevalence of overweight and obesity among over 800 million people globally. Addressing the food and nutrition requirements of urban populations is a critical challenge, requiring innovative, sustainable solutions.

Microgardening, a small-scale container-based farming approach, presents a viable solution to

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these challenges. It enables the cultivation of diverse crops, including vegetables, roots, tubers, and herbs, in limited urban spaces such as patios, rooftops, and balconies (FAO, 2014). This method exemplifies resource efficiency, producing higher yields with minimal inputs like water, space, and labor while reducing the reliance on pesticides and mineral fertilizers. By shortening supply chains, microgardens minimize food waste, greenhouse gas emissions, and transportation needs, aligning with climate-smart agricultural practices (Climate Action, 2010).

Specifically, microgardens hold promise for addressing nutritional deficits in urban areas. A one-square-meter microgarden can produce up to 36 heads of lettuce in 60 days, 200 tomatoes annually, or 10 cabbages every 90 days (FAO, 2014). This capability supports low-income families in meeting their dietary needs, particularly for vitamins and minerals, and contributes to achieving the FAO/WHO-recommended daily intake of 400 grams of fruits and vegetables (WHO, 2003).

Beyond nutrition, microgardening offers social, economic, and environmental benefits. It reduces household food expenses, enhances access to fresh produce, and creates opportunities for skill development and community interaction. Environmentally, it promotes sustainable practices such as recycling cultivation materials, zero-tillage, and rainwater harvesting (Ba & Ba, 2007; Metropolis, 2014). As an agricultural innovation, microgardening is especially relevant for densely populated urban areas with limited space and water resources, making it a crucial tool for urban food security and resilience. This study examines the adoption of climate-smart microgardening practices among urban households in Abia State, Nigeria, focusing on root and tuber crops such as yam, cassava, and cocoyam. By highlighting the socioeconomic and environmental impacts, the study underscores the potential of microgardening as a sustainable strategy to enhance food security, reduce poverty, and mitigate climate change in urban contexts.

2. Material and Methods

The study was conducted in Umuahia (Urban Area) and Umudike (Peri-urban Area)**,** in Abia State, Nigeria. These locations were purposively selected due to their growing involvement in urban agriculture and microgardening activities. The increasing urbanization of these areas make them suitable setting for exploring the adoption of climate-smart microgardening practices.

A cross-sectional survey design was adopted to collect data from urban households practicing microgardening.

The study employed a snowball sampling technique to identify and interview participants. This approach was chosen due to the relatively small and dispersed population of households actively engaged in microgardening in the study area. The snowball technique relied on initial respondents referring other eligible households, enabling access to a network of participants. A total of 33 households practicing microgardening participated in the study. Data were collected using a structured questionnaire.

The collected data were analyzed using descriptive and inferential statistical tools. A linear regression model was employed to examine the relationship between socioeconomic characteristics (age, income, experience) and the adoption of climate-smart practices**.**

2.1 Model specification

The regression model was specified as:
$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \epsilon Y$
Where:

- Y = Adoption of climate-smart microgardening practices
- β0 = Constant term
- X1 = Age
- X2 = Sex
- X3 = Years of Experience
- X4 = Income Realized from Microgardening
- X5 = Level of Education
- ϵ = Error term

3. Results and Discussion

Table 1 shows the socioeconomic profile of the respondents.

The study reveals that women (57.6%) who were mostly married (78.8%) dominate microgardening, underscoring its potential as a family-centered and gender-sensitive practice. The majority of respondents are middle-aged (63.6%, mean age 41.9 years), with larger households (average of six members) relying on microgardening for food security. High educational attainment (average 18 years) supports the adoption of climate-smart technologies, though moderate experience levels (average 8 years) highlight the need for continuous learning. Low cooperative membership (27.3%) indicates untapped opportunities for collective benefits, while limited access to extension services (75.8% without contact) highlight a critical gap in technical support and outreach efforts. By implication, the socioeconomic profile suggests that microgardening is particularly relevant to middle-aged, educated women in urban settings. Challenges such as limited cooperative membership and lack of extension service visits hinder broader adoption.

Table 1: Socioeconomic characteristics of the respondents

Option	Frequency	Percentages	Mean
Age			
21-35	7	21.2	
36-50	21	63.6	
51-65	5	15.2	
			41.9
Sex			
Male	14	42.4	
Female	19	57.6	
Marital status			
Married	26	78.8	
Not married	7	21.2	
Education level			
Non formal	0	0	
Primary	2	6.1	
Secondary	6	18.2	
Tertiary	25	75.7	
			18
Household size			
1-5	18	54.5	
6-10	15	45.5	
			6
Years of microgardening experience			
1 – 10	23	69.7	
11 – 20	9	27.3	
21 – 30	1	3.00	
			8
Cooperative membership			
Yes	9	27.3	
No	24	72.7	
Extension contact			
Yes	8	24.2	
No	25	75.8	

Source: Field Survey, 2024

The materials used for microgardening in the surveyed households show that bags are the most commonly used material (Table 2), adopted by 84.8% of the respondents. This is followed by tyres at 12.12%, and plastics at 9.09%. Notably, no respondents reported using wood for microgardening, indicating a preference for easily accessible and durable materials like bags and tyres.

Table 2: Materials used for microgardening

Type of Material	Frequency	Percentage
Plastic		
Yes	3	9.09
No	30	90.9
Tyres		
Yes	4	12.1
No	29	87.9
Bags		
Yes	28	84.8
No	5	15.2

Source: Field Survey. 2024

Results of the 5-point Likert scale revealed that the respondents perceived that microgardening offers significant economic, social, and environmental benefits to households (Table 3). These include:

Economic Benefits: It reduces household food expenses (Mean = 3.64), increases access to fresh, nutritious food (Mean = 3.93), and ensures year-round food production and availability (Mean = 3.42) (Table 3).

Social Benefits: It fosters better interaction with neighbors (Mean = 3.42), creates opportunities for skill development (Mean = 3.67), increases sense of fulfillment (Mean = 3.42) and reduces the stress of field cultivation (Mean = 3.27) (Table 3).

Environmental Benefits: Households acknowledged the environmental value of microgardening such as zero use of synthetic fertilizers (Mean = 3.15), organic pest control (Mean = 3.36) and biodiversity (Mean = 4.40) (Table 3).

Resource Management: Efficient use of small space (Mean = 3.97), recycling of waste (Mean = 4.18), and re-use of old materials like plastics, bags (Mean = 3.15) (Table 3).

Table 3: Benefits of adopting climate-smart agricultural practices

S/N	Benefits	Total	Mean
1	Reduces household food expenses	3.64	1.29
2	Increases interaction with neighbors	3.42	1.54
3	Opportunity for urban dwellers to learn new skills	3.67	1.47
4	Increases sense of fulfillment	3.42	1.52
5	Reduces stress of cultivating in the field	3.27	1.63
6	Increases access to fresh and nutritious food within the household	3.94	1.71
7	Improves food production and availability all year round	3.42	1.60
8	Increases efficiency in use of little space	3.97	1.72
9	Zero use of synthetic fertilizer	3.15	1.82
10	Use the microgarden waste e.g leaves, grass clippings or straw as mulch	4.18	0.88
11	Re-use of old materials e.g plastics, bags	3.15	1.66
12	Management of weeds, pest and diseases without using synthetic chemicals.	3.36	1.56
13	Biodiversity	4.39	0.93

Source: Field Survey; Mean score= 3.00: N = 33

With all variables scoring above the mean score of 3.0, the respondents perceive microgardening as highly beneficial. The practice not only supports food security but also enhances social, personal, and environmental well-being, making it a valuable climate-resilient strategy for urban households.

Financial Constraints: These are constraints related to financial resources for expanding operations, purchasing inputs, and managing activities. The constraints include: "Money to adopt new recommendations," "Lack of financial support," "Lack of funds to expand," "Problem of finance," "Finance for pest and disease control," "Lack of funds for acquiring more bags, and poultry manure." Financial constraints (21.2%) are the most significant challenge faced by respondents (Table 4).

Resource Access: Challenges with obtaining seeds, soil, and other essential inputs. These constraints include “Accessing good and healthy seeds”, “Gathering of soil”, “Insufficient nutrients for crops”, “Some microgarden requirements are difficult to obtain” (Table 4).

Infrastructure and Space: Challenges related to land space, storage, and structural requirements. These include “Lack of space to keep bags”, “Space to plant”, “Land space and livestock menace (e.g., goats and sheep)”, “Bags tear and require replacement”. Infrastructure and space issues (15.2%) and resource access (12.1%) follow closely, indicating operational and structural barriers (Table 4).

Environmental Challenges: These are issues with water supply, irrigation, and nutrient depletion during farming. These include: "Irrigation will always be a problem during the dry season," “Water supply”, “Dry season causes plants to dry up”, “Soil loses nutrients at a fast rate” (Table 4).

Pest and Disease Control: These are challenges in managing pests and diseases. These include: “Controlling pests and diseases”, “Lack of skills in pest control for peppers and vegetables” (Table 4).

Production and Operational Challenges: These are miscellaneous production-related challenges. These include: “Meeting demands”, “They require more special attention”, “Weed control”. Environmental challenges, production difficulties, and pest/disease management are also notable, each constituting 12.1%, 12.1% & 6.1% of the total responses respectively (Table 4).

Other Specific Challenges: “Gathering soil”, “Livestock menace, and theft” (Table 4).

Table 4: Constraints to the adoption of climate-smart agricultural practices

Constraint category	Frequency	Percentage
Financial Constraints	7	21.2
Resource Access	4	12.1
Infrastructure and Space	5	15.2
Environmental Challenge	4	12.1
Pests and Diseases	2	6.1
Production and Operational	4	12.1
Others	3	9.1
Total	33	100

The linear regression analysis presented in Table 5 examines the relationship between selected socioeconomic factors and the adoption of climate-smart microgardening practices among urban households in Abia State, Nigeria. The regression model demonstrates a moderate explanatory power**,** with an R-squared value of 0.5823, indicating that approximately 58.2% of the variability in the adoption of climate-smart practices is explained by the independent variables included in the model. The Adjusted R-Squared value (0.4058**)** suggests a moderate fit after adjusting for the number of predictors in the model. The F-ratio (2.17) is statistically significant at 10% level of significance, indicating that the model is a good fit for explaining the relationship between socioeconomic factors and adoption practices.

Age: Age shows a positive and significant relationship with adoption at 10% level of significance. This indicates that older farmers are slightly more likely to adopt climate-smart practices. Older farmers may have more experience or greater awareness of the benefits of sustainable agricultural practices. This aligns with findings of Gudina and Alemu (2024) indicating that age can have a positive impact on the adoption of certain agricultural practices, such as agroforestry, where older farmers may recognize the long-term benefits.

Years of Experience: Contrary to expectations, years of experience has a negative but a statistically significant relationship at 5% level of significance. The negative coefficient of years of experience indicates that more years of farming experience are associated with a decreased likelihood of adopting climate-smart practices. This may suggest that experienced farmers are more accustomed to traditional methods and may be resistant to change. However, other studies have found that farming experience can have a positive effect on the adoption of climate-smart agriculture, as farmers become more conscious of the relevance of good agricultural practices over time (Aniche & Mckee, 2023).

Amount Realized: The amount realized from microgardening activities has a positive and statistically significant relationship at 5% level of significance with the adoption of climate-smart practices. This suggests that as income generated from microgardening increases, there is a corresponding increase in the likelihood of adopting climate-smart practices. This finding implies that households earning higher income from microgardening are more motivated and capable of investing in climate-smart technologies and practices. Financial benefits serve as an incentive, enabling households to purchase necessary inputs, adopt improved techniques, and sustain their microgardening efforts. This finding is consistent with the findings of Agbenyo *et al*. (2022) that show that the adoption of climate-

Table 5: Linear Regression results for socioeconomic factors affecting the adoption of Climate-smart Practices.

Variables	Coefficient	Std. Error	P-value
Constant	1.3265	0.7931	1.67
Sex	0.3330	0.2648	1.26
Age	0.0416	0.0219	1.90*
HHS	0.0769	0.0683	1.13
Level of Edu	-0.0071	0.0478	-0.15
Yrs of Experience	-0.0460	0.0214	-2.15**
Amount Realized	5.84e-06	2.22e-06	2.63**
No. of observations	33		
F-ratio	2.17*		
R- Squared	0.5823		
Adjusted R-Squared	0.4058		

Source: Field Survey, 2024, *** Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level smart practices can lead to significant income increases, suggesting a reinforcing cycle where higher income enables further adoption of beneficial practices.

In summary, the analysis reveals that age and income positively influence the adoption of climate-smart practices, while more years of farming experience may hinder it. These insights can inform targeted interventions to promote sustainable agricultural practices among urban microgardeners.

4. Conclusion and Recommendations

The study highlights the significant potential of climate-smart microgardening in addressing food security, environmental sustainability, and social well-being among urban households in Umuahia and Umudike, Abia State, Nigeria. Key benefits include reduced household food expenses, improved access to fresh and nutritious food, efficient resource management, and enhanced social interactions. However, adoption is hindered by financial constraints, limited access to resources, space limitations, environmental challenges, and pest and disease control issues.

To address these barriers, the study recommends:

1. Provision of subsidies, microcredit schemes, and affordable inputs to microgardeners.
2. Strengthen extension services, offer regular training, and build capacity for effective adoption of climate-smart practices.
3. Promotion of microgardening and other innovative gardening techniques, such as vertical gardening, and provision of durable planting materials to microgardeners.
4. Encourage cooperative formation and collective resource sharing to enhance knowledge and market access.
5. Development of urban agriculture policies to integrate microgardening into urban planning frameworks.

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Extending physiological screening beyond the flag leaf: A canopy-wide approach to Wheat resilience under contrasting field conditions

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ABSTRACT

Understanding wheat's response to drought requires more than focusing on the flag leaf. In this study, 72 elite genotypes were assessed under irrigated and drought field conditions in Obregón, Mexico, using high-resolution phenotyping tools to quantify physiological responses across the full canopy including flag, second, and third leaves. Parameters such as SPAD chlorophyll content, PRI, quantum yield, stomatal conductance, light interception, and pigment-specific spectral indices were measured, alongside soil moisture profiles. Results revealed distinctive patterns in each canopy layer, with lower leaves playing a supplementary yet measurable role in maintaining canopy function under stress. This study highlights the need for integrating full-canopy physiological evaluations into breeding strategies for climate resilience.

KEY WORDS: *Wheat*; *Drought resilience*; *Canopy physiology*; *SPAD*; *PRI*

1. Introduction

Breeding drought-resilient wheat genotypes has traditionally emphasized top canopy leaves, particularly the flag leaf, as the dominant source of assimilates for grain filling (Araus & Cairns, 2014). However, under stress conditions where leaf senescence or accelerated resource reallocation may occur the middle and lower leaves can contribute to biomass production and sink strength maintenance (Zhou *et al.*, 2016). Despite this potential, phenotyping methodologies rarely include full-canopy evaluations, and the roles of second and third leaves remain poorly characterized.

Here, we present physiological and spectral data from a comprehensive field experiment assessing wheat genotype × environment interactions across the canopy using a diverse set of phenotyping tools. Our objective was to quantify variations in photosynthetic performance, pigment composition, and soil-coupled moisture dynamics to better understand whole-canopy contributions to stress adaptation (Mathangi *et al.*, 2024).

2. Materials and Methods

The experiment was conducted during the 2023–2024 wheat season at CIMMYT's experimental station in Ciudad Obregón, Sonora, Mexico. A total of 72 elite bread wheat genotypes were evaluated under two conditions; full irrigation throughout crop development and in drought

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single irrigation at sowing; no further watering (Mathangi *et al*., 2024). Data were collected at booting, heading, and grain-filling stages using the following instruments:

SPAD 502 Plus: chlorophyll content (flag, second, and third leaves)
PlantPen PRI: photochemical reflectance index (PRI)
LI-600 Porometer: stomatal conductance, transpiration, and PSII efficiency
ASD FieldSpec Spectroradiometer: spectral reflectance for pigment analysis
AccuPAR LP-80: light interception across the canopy
Delta-T PR2 Probe: soil moisture at various depths

Measurements were repeated weekly. Leaf-level traits were analyzed in relation to genotype performance, environment, and canopy position.

3. Result

Canopy Layer Differentiation:

Flag leaves consistently showed higher SPAD values, stomatal conductance, and quantum yield under both environments. However, second and third leaves retained physiological function longer than expected, particularly under drought conditions, indicating that their photosynthetic contributions may become proportionally more important under stress.

Spectral Pigment Profiles:

Spectroradiometric data revealed genotype-specific variation in pigment absorption across the 400–700 nm range. Red edge shifts and reflectance ratios correlated with SPAD and PRI values, providing a robust proxy for real-time pigment content and photosynthetic dynamics.

Soil-Plant Interaction:

Soil moisture measurements confirmed rapid depletion in the upper 60 cm under drought plots. Yet, stomatal conductance readings indicated that some genotypes sustained physiological activity, suggesting deeper rooting or delayed stress response. Canopy temperature and light interception patterns further supported these findings.

Stage-Specific Trends:

While all leaves showed declining conductance and transpiration towards physiological maturity, chlorophyll indices (SPAD, PRI) increased slightly over time possibly reflecting stress-induced pigment adjustments or lower leaf senescence lag (Mathangi *et al*., 2024b).

4. Conclusion

This study presents strong evidence that evaluating only the flag leaf under represents the physiological complexity of wheat under stress. A canopy-wide approach reveals nuanced genotype × environment interactions, with potential implications for selecting traits like pigment stability, quantum yield efficiency, and soil-coupled transpiration strategies. Breeding programs aiming at drought resilience must expand trait screening across canopy layers to capture the full range of plant adaptation.

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References (APA Style, 7th Edition):

For Journal article: Kammar, S. C. (2023). Studies on the influence of different organic manures on soil microbial activity, growth and yield performance of blackgram (*Vigna mungo* L.). *Current Innovation in Agriculture Science, 1*(1), 1–7.

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