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# Soil management practice and smallholder agricultural productivity in Nigeria

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**Abstract**
This study investigates how various soil management practices can enhance soil fertility and pest control, ultimately increasing crop yields among farming households in Nigeria. Utilizing descriptive statistics, logit regression and propensity score matching on data from the 2019 Living Standard Measurement Study, the findings reveal that households using herbicides experience higher agricultural productivity. The use of pesticides and certified crops also positively influences productivity. Key determinants of soil technology access include cooperative membership and the age of household heads, both of which significantly affect access to herbicides, pesticides, organic fertilizers, and certified crops. Education plays a vital role, positively impacting the use of organic and inorganic fertilizers as well as certified crops. Additionally, larger farm sizes correlate with better access to these resources. Conversely, the gender of the household head negatively affects access to certified crops. The study emphasizes the importance of capacity building and knowledge transfer to encourage the adoption of effective soil technology practices among farmers, thereby enhancing agricultural productivity and addressing food security issues.

**Keywords** Agricultural productivity · Crop yield · Soil technology · Sustainable development

**JEL Classification** Q12 · D13 · Q16 · O13

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## 1 Introduction

Reduction in agricultural productivity has been ascribed to low use of soil management practices[1] or technology to replenish soil fertility [1–3]. This issue has also been highlighted in reports by the Food and Agricultural Organisation [4], International Fund for Agricultural Development [5] and World Food Programme [6]. Thus, there is the need to look at measures to enhance agricultural yield in sub-Sahara Africa (SSA) in general and Nigeria. To improve productivity, technology adoption, such as soil technology is crucial for agriculture [2, 7].

In Africa, the agricultural sector's efficiency remains one of the most veritable growth and poverty reduction strategies [8, 9]. The sector constitutes above 35% to the Gross Domestic Product (GDP) of African economies [4, 10]. The research problem to be addressed in this study is to empirically examine how soil technology or management practice affect the productivity of household agriculture, using Nigeria as a case study. Despite the growing recognition of soil technology as a means to enhance agricultural productivity, there is a need for a comprehensive and evidence-based understanding of its actual effects on household-level farming systems. Likewise, determining soil technology adoption is also another key factor that can help increase agricultural productivity in any economy [11].

Furthermore, understanding the factors that influence the adoption of soil technology helps improve soil health and fertility, such as soil testing, soil fertilization and conservation which helps improves soil quality and directly impacts crop yields and overall agricultural productivity [12]. Likewise, effective soil management practices help crop performance and understanding the adoption determinants helps in promoting agricultural practices which leads to increased productivity [13]. Similarly, examining soil adoption determinants helps target policies and incentives which will encourage sustainable practices that will help protect soil health in the long term. Lastly, understanding the adoption of soil technology can enhance resilience to climate change which can help improve soil structure and contribute to climate adaption and resilience in agriculture [14].

The agricultural sector in Nigeria is a very crucial sector to its economy, because about 70% of the workforce is employed by the sector, which therefore contributes significantly to the national income. The agricultural sector in Nigeria remains small scale and subsistence, as most of the farmers rely heavily on traditional practices [15]. Therefore, several challenges being faced by the sector such as soil degradation, which depletes the soil quality, climate change issues such as irregular rainfall, increased temperature and extreme weather has significant adverse effect on the soil quality and agricultural productivity. Similarly, the lack of access to inadequate infrastructure, lack of access to adequate modern technologies (improved seeds, pest control methods, fertilizers), destruction of crops and live stocks and pests poses a significant challenge to agricultural productivity in Nigeria.

Furthermore, literature shows that in order to improve agricultural productivity, soil management technologies must be adopted that will restore the soil quality, thereby boosting crop yields and sustainability [16, 17]. Also, soil conservation techniques such as contour farming, cover cropping can help with prevention of soil erosion and maintain soil quality. Likewise, promoting sustainable practices via implementing soil management technologies helps maintain soil health and long-term agricultural productivity and serves as an avenue to overcome challenges faded in the Nigerian agricultural sector. Therefore, examining the impact of soil management technology on household agricultural productivity in Nigeria is crucial for improving agricultural outcomes, supporting economic development, and ensuring food security. Also, it helps make informed policy decisions that can enhance productivity, sustainability and resilience in the agricultural sector.

The specific research questions to be addressed are: #1: what is the quantitative impact of soil management technology, including soil testing and nutrient management practices, on household agricultural productivity? #2: what are the determinants of soil management technology use amongst farming household? #3: what constitution of soil management technology among has a greater impact on household agricultural productivity, amongst pesticides, fertilizer, certified crop and herbicides?

To respond to study questions and actualize the study aims, the research paper proxied agricultural productivity in total value (in naira) of all field crops harvested per hectare farmland (value in naira/ha). This monetary measure used for agricultural productivity proxy because it incorporates various aspects, such as yield per hectare, crop prices and input costs. Thus, implying that it reflects the economic value of the crops harvested, which indicates the productivity in financial terms and a clear measure of economic output. Although, the use of agricultural productivity has its benefits, one significant limitation of the proxy is that crop prices can be volatile due to market conditions, weather and government

[1] The soil management practices in the study include certified crop, pesticide, extension service, herbicide, organic and inorganic fertiliser. Soil management practices is synonymously used with soil technology adoption.

policies which can affect productivity which are not necessarily as a result of soil health. Thus, an inherent limitation is that using monetary value can give a skewed view of productivity over time.

Furthermore, this research paper adopted data obtained from Wave 4 (2018/2019) of the LSMS–ISA for Nigeria. The paper also applied the summary statistics, the logit regression and the propensity score matching model. The methodology used provides information on the data, while the logit regression helps model relationships between variables and binary outcomes, and propensity score matching addresses biases in observational data to estimate causal effects. These methods offer a comprehensive approach to analyzing and interpreting the impact of interventions and treatments. In addition, research has been carried out to examine the nexus between soil and water preservation and agricultural productivity, soil technology and post-harvest losses, fertilizer adoption and effect on output, and how soil adoption technologies such as herbicides, fungicides and insecticides helps agricultural productivity [2, 18–20]. This study further extends the frontier of knowledge by examining factors that determine soil technology use among farming households based on socioeconomic factors, soil technology on agricultural productivity, as well as the likely effect of herbicides, pesticides, certified crop, organic and inorganic fertilizers on agricultural productivity.

## 2 Literature review

Darkwah et al. [19] examined the nexus existing with agriculturalist traits and the extent of soil and water preservation technology used by 300 corn farmers in Techiman Municipality, Ghana. The study found that farm and family size, as well as credit facilities and education of corn farmers have a significant direct relationship with soil amount as well as the preserving technology for water used by corn farmers while other factors like output market location, and input centre location and distance, access to extension services, and the uncertainty involving pest and diseases, have an indirect and significant association with soil amount and conservational practices on water used by corn farmers at 5% significance level.

In examining fertilizer adoption and its effect on output and productivity of maize and households earning in Kenya, Jena et al. [20], engaged four household surveys data, capturing the six maize-manufacturing districts. Results from the study showed that though, the proportion of fertilizer users among maize farming households in Kenya though has increased, however, the productivity of maize remains low. In another study, Lechenet et al. [18] argued that herbicide, fungicide, insecticides among others are crucial in reducing pest while preserving crop productivity. The study engaged data got from a map comprising 946 non-organic arable French demonstrations having different farm level of pesticide usage. The study applied the regression analysis with the least absolute shrinkage and selection operator (LASSO). The result showed that reducing pests will increase productivity. In another similar study, Popp et al. [21] used descriptive statistics to show that pests remain one of the major factors responsible for low productivity. Besides, the study reported that 35% of potential plant production are wasted by crop pests on average. Therefore, it is necessary to apply certified crops which are capable of resisting pest.

In monitoring the quantity and quality of land and reversing the undervaluation in order to reduce the waste of land resources, Wang et al. [22] carried out a comprehensive evaluation of land which was compiled and calculated through the ecological footprint method and equivalent factor method to calculate the value quantity of land and using the ArcGIS to demonstrate the spatial and temporal changes in land resources from 2000 to 2020. Findings revealed that under dual impact of changes in the physical quantity and unit price of land, value quantity of land assets and equity experienced tremendous growth. Also, grassland was found to be the most productive land type and the spatial distribution pattern showed that the value quantity of land was high in the southeast and low in the centre and west of Chongqing.

In the study by An et al. [23], which examined the economic potential of ecosystem services by measuring the perspective of land use transformation in Zhijiang County for the years 2010, 2015 and 2020, using the spatial and temporal analysis and the geographical detector was used to determine the contributing elements in the regional discrepancy in the economic potential of ecosystem services. Findings revealed that the value of ecosystem services generated by water in Zhijiang County constitutes the highest of the total value and except for woodland, the economic potential of the ecosystem services supplied by other land-use types is negative. Similarly, population density, vegetation coverage and urbanisation rate are the most important elements influencing the regional differentiation of economic potential of ecosystem services in Zhijiang County. Lastly, the agricultural-ecological conservation zones have the highest value and economic potential.

Jabbar et al. [24] investigated the potential effects of non-farm income diversification on household poverty and adopting soil and water conservation (SWC) technologies. A survey of 441 farmers was conducted in rain-fed areas of

Punjab, Pakistan, and the propensity score matching (PSM) technique was used. Results revealed that diversified farmers were more likely to adopt soil and water conservation practices and were less vulnerable to poverty.

In a similar study by Jabbar et al. [25], the study examined the determinants of adopting sustainable intensified practices (SIPs) and they selected improved seeds, organic manure, crop rotation, intercropping and low tillage using random sampling techniques to select 612 farmers and the multivariate probit model (MVP) was employed. The outcome of the study shows that education, the area under cultivation, access to information, extension access, social participation, rainfall variability, and temperature significantly leads to an increase in predicting the adoption of SIPs. Also, organic manure and crop rotation was found to have the highest adoption between all the ecological zones, while low tillage was the adopted practice. In examining integrated soil fertility management technology on food production in Pakistan, Jabbar et al. [26] utilized the endogenous switching regression model. The results revealed that age, gender, education, extension access, credit access and social influence are important predictors of integrated soil fertility management technology adoption.

Improved seeds or certified crops signify some of the most recognised and embraced technologies that have been confirmed to enhance crop yields and productivity of all strands. However, only about 30% of crops planted in Africa are certified seeds [27, 28]. In general, in various countries in Africa, certified crops signify only 20 to 30% of total acreage [29]. One of the purposes for the low adoption of improved crop technologies in Africa is the dependence on customary seed mechanisms. Farmers pass on crops to one another [28, 29]. Osabohien [2] applied the marginal score matching to ascertain effects of soil technology on post-harvest losses and found that soil technology is not significantly important for post-harvest wastage in Nigeria.

Furthermore, Suleiman et al. [30] examined soil management practices in Zaria, Nigeria using the purposive sampling technique and the sample size was 384. Findings revealed that the use of animal manure was the most adopted soil management practice while the lowest adoption method was tilling. Also, soil fertility depletion had the most adverse effect on soil management practices. Junge et al. [31] examined the attitude of farmers towards adopting appropriate soil conservation technologies (SCTs). The farmers were selected from the communities in Esa Oke, Elwure and Owode-Ede and Akoda in Osun State Nigeria. The first three communities' farmers received training on soil conservation, while the fourth did not. Findings revealed that most respondents were advanced in years, which was as a result of large households and characterized by low levels of income and literacy. Also, soil erosion was seen as a problem confronting agricultural production by a little extent. The adoption rate of SCTs was low, as only mulching, cover cropping, contour tillage and cut-off drainage were practiced. Also, the availability of common equipment, low costs of application, ease of practice and compatibility with the existing farming system influenced adoption.

Lydia et al. [32] examined the perceived appropriateness of sustainable soil management technologies among farmers through relevant actors linkage activities in Oyo state, Nigeria using the multi stage sampling technique. The farmers selected across the four agricultural development program zone in Oyo state were 336 and result showed that 24 SSM technologies were disseminated and transferred by REFILS and farming system research actors. The farmers in the study area perceived the appropriateness of the technologies based on the ease of application, ecological benefits, economic benefits and socio-cultural acceptability.

In a similar study by Adejumo et al. [33], sustainable soil management was investigated in relation to climate change using Research Extension farmer-input linkage systems (REFILS) activities. They study had a total of 380 respondents which consists of 44 extension agents and 336 farmers across the four agricultural development zones in Oyo state. The outcome of the study identified a total of 24 SSM technologies categorized as soil erosion control, soil nutrient management, minimum soil disturbance, water management techniques, vegetation management and agroforestry system to have been disseminated and adopted among the farmers. The farmers perceived some of the technologies to be appropriate based on their application suitability, ecological importance, economic importance and socio-cultural acceptability.

Lastly, Akinbode et al. [34] assessed the perception and use of digital applications for soil fertility management strategies among small-scale crop farmers in southwest Nigeria with a total of 376 farmers selected randomly across six southwest states. Findings revealed that most farmers relied on perception and other non-scientific approaches such as the appearance of weeds and performance of crops in the previous season to assess soil fertility. A minimal number of farmers (1.1% and 0.3%) assessed soil fertility through soil tests and digital applications. Also, majority adopted bush fallowing and the use of inorganic fertilizers to improve soil fertility, despite having digital applications on their mobile phones, only 2.9% claimed to have used it. A significant number agreed that lack of awareness of the existence of digital applications and internet-enabled telephones were the reasons they have not been able to use digital applications and majority showed interest in the use of new farm decision digital applications which could provide more information, especially on soil fertility.

Based on the foregoing, studies have examined farmers perception in adopting soil management techniques as it relates to digital application, climate change and soil conservation technologies. However, this study would further extend the study by investigating the impact of soil management technology which includes soil testing and nutrient management practices on household agricultural productivity. Likewise, analyse the determinants of soil management technology among households and which of them have a greater effect on agricultural productivity.

## 3 Materials and methods

### 3.1 Data

The research paper used the LSMS–ISA which exists as a Household Survey (HHS), combining with the Living Standards Measurement Study (LSMS) team of the IBRD as part of the Integrated Surveys on Agriculture (ISA) programme [35, 36]. Some of the aims of the GHS-Panel are promoting agricultural data models, inter-institutional collaboration for welfare and other social and economic traits [37–39]. The decision to adopt Wave 4 (2018/2019) lies in it being the newest version for the Nigerian dataset, while this research was carried out. After disaggregation at the household level, the data for the analysis was made of 4980 household heads.

The study examined the impact of soil management practices on smallholder agricultural productivity in Nigeria, while the specific objectives investigated various elements of soil management practices on household agricultural productivity, as well as the determinants of soil management technology use amongst farming household. Lastly, to investigate which of the soil management has a greater impact on household agricultural productivity. The study focuses on the Nigerian landscape because the agricultural sector is characterized by diverse geographic conditions, varying technologies, and climatic challenges. Although, traditional practices are still a common practice, there is a growing adoption of modern technologies. Also, the sector faces socio-economic challenges including limited access to credit, inadequate infrastructure, and price volatility, which impact productivity and development. The study engaged the logit regression and the propensity score matching to achieve its objectives.

### 3.2 Logit regression

The logit regression model is commonly used to estimate the propensity score. The logit function is defined in Eq. (1). In order to achieve the study's objective, the deterministic variable in the regression is binary, which is soil management practice. This is estimated as a function of $X'$ variables, covariates consisting other variables predicting the adoption of soil management practices and $e$ as the disturbance term used in capturing explanatory variables that were not included in the mode. From extant studies such as Díaz-Pérez et al. [40] and Osabohien [37], the Logit regression model can be expressed thus:

$$logit(e(x)) = \ln\left(\frac{e(x)}{1 - e(x)}\right) = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots, \alpha_n X_n + e. \tag{1}$$

From the equation, $\alpha_0, \alpha_1, \ldots, \alpha_n$ are the coefficients estimated from the logit regression, and $\alpha_0 + X_1, X_2, \ldots, X_n$ are the variables predicting the likelihood of adopting various elements of soil management practices. The element of soil management practices in the study include certified crop, pesticide, extension service, herbicide, organic and inorganic fertiliser.

That is, the control variables that determine household's choice to adopt varied soil technologies, and $e$ is the stochastic term, which captures other variables not included in the study. The covariate of the explanatory control variables influencing household choice to adopt various soil input are—household head sex, household head age, household size, household head membership in a cooperative society, educational level of family head, household head location, health and well-being conditions of household head, household farm size, marital stance of the household head. This control variable used are based on literature that have been done and personal and socio-cultural characteristics.

It is expected that an increase in the age of household heads could promote household ability to adopt soil technology. Moreover, household heads belonging to a union or cooperative society may promote soil technology adoption. Similarly, the level of education for household heads, household head location, health of the household heads, size of household farms, marital stance of household heads should greatly determine household adoption choice for soil or soil technology.

### 3.3 Propensity score matching

The PSM is an impact model that examines the effect of a treatment for an individual *i*, noted $\delta_i$, explained as the difference between the expected result when there is a treatment and the expected result when the treatment is not available, shown in Eq. (6).

$$\delta_i = Y_0 - Y_1. \tag{2}$$

Usually, the PSM aims to compute the mean impact of the programme, reached by taking the average of all the households in the study area. This parameter may be regarded as as the Average Treatment Effect (ATE), posited model (3).

$$ATE = E(\delta) - E\left(Y_0 - Y_1\right). \tag{3}$$

From the equation, E(.) is the expected value. In addition, the study is also interested in examining the Average Treatment Effect on the Treated (ATT). This captures the impact of the programme on the participants, given in Eq. (4)

$$ATT = E(Y_1 - Y_0|D = 1). \tag{4}$$

The Average Treatment Effect on the Untreated (ATU) captures the impact that the programme would have had on those who did not participate, as seen in Eq. (5)

$$ATU = E(Y_1 - Y_0|D = 0). \tag{5}$$

One of the main issues associated with impact models is that all of these parameters are unobservable, because, they rely on the untreated groups. For example, using the fact that the average of a difference is the difference of the averages, the ATT may be shown in Eq. (6)

$$ATT = E(Y_1|D = 1) - E(Y_0|D = 1). \tag{6}$$

The ATT is the difference between expected outcome values with and without treatment for those engaged in treatment. The PSM method used in this study considers two groups—the control group, otherwise known as non-adopters of soil management and the treated group, known as the adopters of soil management practice or technology.

The study engages two PSM matching algorithms—Nearest Neighbour Matching (NNM) and Kernel-Based Matching (KBB). The NNM is one of the most straightforward matching mechanisms. In the NNM algorithm, an individual from the control group is selected as a match for a treated individual in terms of the nearest propensity score. On the other hand, the second PSM algorithm used in the study, Kernel-based matching, is a nonparametric matching estimator that relates the outcome of each treated individual to a weighted mean of the result of all the control group, with the highest weight being deposited on those with scores nearest to the treated group. The main merit of these PSM algorithms is the least modification, which is attained because relevant evidence is provided and applied.

The Nearest Neighbour Matching (NNM) algorithm and the Kernel-based matching (KNM) methodology was used in this study. The NNM algorithm is used to find the closest match for each individual in the treatment group by comparing their characteristics to those in the control group and the closest match is then chosen as the individuals nearest neighbour and the difference between their outcomes is used to estimate the treatment effect. The KNM is also similar, however it uses kernel function to determine the distance between individuals, which is then used to match them to their nearest neighbours. The reason for choosing these two methods is because they can be used in situations where there is high degree of non-linearity in the data and it finds the closest matches between treatment and control groups. It good to mention that these methods were used to match treated and control units before running the regression analysis on the matched sample.

## 4 Results and discussion

### 4.1 Summary statistics of variables

Table 1 describes the variables in the summary statistics. From the table, almost all of the household heads are married (about 96%). Moreover, data from the table explains that greater shares of household farming are run by males (52%) while 48% are run by females, averaging 5 persons per household. Education (proxied with the total number of schooling years) has an average of 16 years. This means, averagely, the heads of households spent around 16 years in school.

The findings below from the Table 1 explain that, with age distribution for the household heads, 10.22% are within the age bracket of 15–25 years, 21.68% are between the ages of 26–35 years, while 68.10% are 36 years and above. With age distribution, from the findings in the table, it can be argued that less proportion (31.90%) of the youth [15–35 years of age, as defined by the African Union (AU), 2006] are in agriculture, while greater proportion, 68.10% of family heads are non-youth (36 years and above), with the mean age of 50.61 years.

### 4.2 Factors determining soil technology use among farming households—the logit model

The determinants of various components of soil technology—certified crop, organic fertiliser along with other components are outlined in Table 2. With respect to certified crops, as presented in Table 2, age, membership of a union or a cooperative society and location of by the heads of household are some of the important factors influencing and determining the use of certified plants. Age and membership of a union or cooperative society by the HHH are directly related while the location of the heads of the household is a negative factor influence. These findings suggest that the heads of households that belong to a union or cooperative society are more likely to have access to certified plants than household heads who do not belong to a union or coopera1tive society.

The age of the HHHs greatly gives reasons for the possibility of getting access to certified plants or treated seeds. This can be explained with the view that older HHHs have strong networks that have been built over the years and working relationships needed to improve the possibilities of and access to certified plants. Moreover, existing studies have agreed that older farmers have greater experiences in agricultural activities and could improve their access to agricultural output or resources like certified crops. The authors of these past studies agree that in a situation where household heads grow older, they are assumed to greater experiences in farming activities and networks. However, the location of the HHH has an indirect relationship with the possibility of accessing certified plants. From this finding, heads of households in local and non-urban demographics are less probable to have access to certified crops than household heads living in urban cities and areas. The findings agree with the 'a priori' expectation of the study.

These results obtained for factors that are determinants of the adoption of soil or soil technology—herbicides, pesticides, organic and inorganic fertiliser are outlined in Table 2. In regards to pesticides, Table 2, column 1, explained that age and belonging to a union or cooperative society by the HHHs are important and direct determinants of the adoption of herbicides. This means that in households where heads belong to a cooperative society, the probability of using herbicides is higher when compared to households whose heads do not belong to a union or cooperative society. Similarly, the age of the HHHs is directly related to the use of herbicide. This implies that as the heads of households grow older, access to herbicides for household increases when compared to younger heads of households.

In regards to the use of pesticides, findings show that location and belonging to a union or cooperative society by heads of households is directly related and significant. The implication for this is that household heads belonging to a union or cooperative society will have more access to pesticides than heads that do not belong to a cooperative society. Moreover, the geographic location of the heads of households is also significant and directly related to the adoption of pesticides. The implication for this is that heads of households in local and non-urban environments have a greater chance for accessing herbicides adoption than heads in urban communities.

Findings for organic fertiliser, presented in Table 2, assert that when a household head belongs to a union or cooperative society along with other variables like gender, age, health conditions and status and educational level are all significant factors influencing the use of organic fertiliser. The size of household farms, belonging to a union or cooperative society, level of educational, gender and health status of heads of households are direct factors influents while age of the heads of households is an indirect or negative factor influencing the use of organic fertiliser by households. Findings

**Table 1** Summary statistics of variables. Source: researchers' compilation

Observation (N) = 4980

| Variable | Description | Mean | Std. Dev. |
|---|---|---|---|
| Age (household heads) (years) | Age of the household HHH (years)<br>(15–25 = 10.22%, 26–35 = 21.68%, 36+ = 68.10 %)<br>(Youth as defined by AU, 2006: 15–35 = 31.90%) | 50.6053 | 19.2521 |
| HH size (number) | Total number of members in the household (number) | 5.1157 | 2.8934 |
| Gender of HHH (male = 1) | Gender of HHH (1 if household head is a male, and 0 if the household head is a female) | 0.5194 | 0.5001 |
| Marital status of HHH | Marital status of household heads. Dummy variable for the marital status of the household head: 1 if the household is married and 0 never marry or single | 0.9583 | 0.2620 |
| Education | The educational level of the HHH (total no. of years of schooling) | 16.029 | 3.0657 |
| Cooperative society | Membership of a cooperative society (1 if the HHH belong to a cooperative society and 0 the household head does not) | 0.4712 | 0.4992 |
| Organic fertiliser | Dummy variable for fertiliser usage: 1 if household used any organic fertiliser and 0 if the HHH did not apply any organic fertiliser | 0.1713 | 0.3769 |
| Inorganic fertiliser | Dummy variable for fertiliser usage: 1 if the household head use any inorganic fertiliser, and if the household head did not apply an inorganic fertiliser | 0.2992 | 0.4580 |
| Pesticide usage | Dummy variable for pesticide usage: 1 if the HHH applied pesticide during the agricultural season, 0 of the household head did not use pesticides | 0.3394 | 0.3118 |
| Herbicide usage | Dummy variable for herbicide usage: 1 if the household use herbicides during the agricultural season, and 0 if the household head did not apply herbicides | 0.3394 | 0.4735 |
| Certified crop | Dummy variable: 1 if the HHH applied certified seeds (or treated plants), and 0 if the household head did not use certified seed or treated crop | 0.6508 | 0.4781 |

*HH* household, *HHH* household head

**Table 2** Determinants of soil technology adoption. Source: researcher's compilation

| Dependent variable: | Herbicides | Pesticides | Organic fertiliser | Inorganic fertiliser | Certified crop |
|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | |
| Constant | − 1.2693 (1.03) | − 6.1236*** (3.78) | − 3.023 (2.67) | − 1.2466*** (3.20) | − 2.6415* (1.97) |
| Cooperative society | 1.1039** (2.21) | 1.9491** (2.31) | 0.2839* (1.95) | 0.0141 (0.869) | 2.4730** (2.03) |
| Age of HHH | 0.0222* (1.86) | 0.0157 (0.78) | − 0.268*** (.249) | 0.2686** (2.63) | 2.3983*** (5.25) |
| Education of HHH | 5.9706 (1.000) | − 0.0163 (0.876) | 0.694*** (4.42) | 0.2265** (2.98) | 0.0562** (2.71) |
| Gender of HHH | 0.1439 (0.37) | − 0.8970 (0.254) | 1.968* (1.88) | − 0.4409 (1.62) | − 1.3931* (1.86) |
| Location of HHH | − 0.2730 (0.71) | 2.6530** (0.022) | 0.409 (0.98) | − 0.1245 (0.541) | − 1.44* (1.95) |
| Health status of HHH | − 0.3446 (0.87) | 0.8234 (0.244) | 0.343** (2.34) | 0.1364 (0.122) | 0.5259 (0.500) |
| Marital status of HHH | | 0.738 (0.34) | 0.186 (1.09) | 0.2611 (2.55) | 0.0608** (2.03) |
| Farm size | 1.3700** (2.34) | 0.5913*** (3.55) | 0.008* (1.80) | 0.039* (1.76) | |
| HH size | − 0.0299 (0.37) | 0.013 (0.71) | 0.055** (1.97) | 0.035 (1.08) | − 25.2319 |
| Log likelihood | − 81.7157 | − 31.094125 | − 581.1948 | − 1652.5618 | 0.2507 |
| Pseudo $R^2$ | 0.0656 | 0.0111 | 0.0236 | 0.0087 | 0.0007 |
| Prob > $chi^2$ | 0.1214 | 0.1925 | 0.0009* | 0.0087* | |

The t-statistic is in parenthesis (), while ***, **, and * behind coefficients imply that the it is significant at 1%, 5% and 10% levels, respectively

*HHHs* household heads

suggest that household heads who belong to a union or cooperative society are more likely to have access to organic fertiliser when compared to heads of households who do not belong to a union or cooperative society.

The result, presented in Table 2, columns 2 and 3, showed the level of education of the HHHs is a direct factor influencing household access to organic fertiliser. This explains that more educated heads of households are more probable to utilise organic fertiliser than heads of households that are uneducated. Moreover, the size of household farms as well as the gender of the heads of households is directly and significantly related to organic fertiliser usage, signifying that households headed by male are more probable to use organic fertiliser when compared to households headed by females.

An expansion of household farm could promote the probability of fertiliser adoption and use. Similarly, health conditions of the HHHs is directly and significantly related to the amount of organic fertiliser usage, explaining that better health status of the heads of households are, the greater the chance of adopting and using organic fertiliser. In contrast, the age of the household heads is indirectly related and significant for determining organic fertiliser adoption by households. The implication for this is that as household heads grow older, probability of organic fertiliser usage reduces. Moreover, findings assert that when older people head households, they are less probable to have access to organic fertiliser when compared to households that are headed by young people.

In regards to the factors influencing the use of inorganic fertiliser, the level of education as well as the age of the heads of households are directly and significantly related. This asserts that an when heads of households get older, the chance of adopting and using inorganic fertiliser increases. Moreover, the findings explain that households headed by older individuals have a larger likelihood of adopting and using inorganic fertiliser than when younger people head households. Similarly, results assert that when the heads of households are more educated, there is a higher probability of adopting and using inorganic fertiliser in relation to households being head by less educated people.

### 4.3 Impact of soil technology on agricultural productivity—the propensity score matching model

The result obtained for the impact of herbicides, pesticides and certified crop (HPCC) on productivity are presented in this section. The results are presented in Tables 3, 4, 5, 6 and 7. Using the ATT, herbicides usage by household heads shows a direct and statistically significant effect on productivity. This means that farmers (household heads) who applied herbicides are more likely to experience a higher agricultural productivity than those who do not use herbicides.

The result shows that household heads who applied herbicides experienced ₦248,999.718 (value/ha) (from the NNM result) and ₦209,584.262 (value/ha) (from the KBM) value higher than those household heads who did not use herbicides. This result implies that an increase in farmland acreage on which herbicide is applied will increase agricultural productivity. From the nearest neighbour matching, the result shows that the application of herbicides, on

**Table 3** Effect of herbicides on agricultural productivity. Source: researcher's computation using the LSMS–ISA

| Sample | Adopters | Non-adopters | Mean difference | Standard error | T-stat |
|---|---|---|---|---|---|
| Nearest neighbour matching (NNM) | | | | | |
| Unmatched | 247,528.103 | 30,654.6193 | − 216,873.483 | 57,705.0713 | 3.76*** |
| ATT | 248,999.718 | 30,654.6193 | − 218,345.099 | 46,710.3976 | 4.67*** |
| ATU | 31,116.4178 | 247,528.103 | − 216,411.685 | | |
| ATE | | | − 217,170.249 | | |
| Kernel-based matching (KBM) | | | | | |
| Unmatched | 247,528.103 | 30,654.6193 | − 216,873.483 | 57,705.0713 | 3.765*** |
| ATT | 209,584.262 | 30,654.6193 | − 178,929.643 | 185,278.565 | 2.97** |
| ATU | 228,834.241 | 247,528.103 | − 18,693.862 | | |
| ATE | | | − 81,561.4888 | | |

Values are in Nigerian naira (₦)

*, **, and *** means significance at 10%, and 5% level, and 1%, respectively

**Table 4** Impact of pesticides on agricultural productivity. Source: researcher's computation using the LSMS–ISA

| Sample | Adopters | Non-adopters | Difference | Standard error | T-stat |
|---|---|---|---|---|---|
| Nearest neighbour matching (NNM) | | | | | |
| Unmatched | 477,878.747 | 416,298.148 | 61,580.5984 | 111,776.304 | 2.55** |
| ATT | 477,878.747 | 149,291.979 | 328,586.768 | 117,513.878 | 2.80** |
| ATU | 416,298.148 | 376,118.741 | − 40,179.4076 | | |
| ATE | | | − 2037.69354 | | |
| Kernel-based matching (KBM) | | | | | |
| Unmatched | 154,946.136 | 138,948.462 | 15,997.6743 | 76,266.2258 | 2.21** |
| ATT | 154,946.136 | 142,273.362 | 12,672.7741 | 178,331.359 | 2.07** |
| ATU | 118,191.751 | 181,519.974 | 63,328.223 | | |
| ATE | | | 58,750.9234 | | |

Values are in naira (₦)

**Significance at 5% level

**Table 5** Impact of certified crop on agricultural productivity. Source: researcher's computation using the LSMS–ISA

| Sample | Adopters | Non-adopters | Difference | Standard error | T-stat |
|---|---|---|---|---|---|
| Nearest neighbour matching (NNM) | | | | | |
| Unmatched | 130,673.185 | 56,793.2986 | 73,879.8862 | 123,461.706 | 2.50** |
| ATT | 130,673.185 | 77,183.939 | 53,489.2458 | 109,116.019 | 2.25** |
| ATU | 56,793.2986 | 100,128.134 | 43,334.8359 | | |
| ATE | | | 49,098.1496 | | |
| Kernel-based matching (KBM) | | | | | |
| Unmatched | 130,673.185 | 56,793.2986 | 73,879.8862 | 123,461.706 | 2.60** |
| ATT | 130,673.185 | 41,297.0382 | 89,376.1466 | 120,462.833 | 2.74** |
| ATU | 56,793.2986 | 37,633.5072 | 19,159.7913 | | |
| ATE | | | 42,441.687 | | |

Values are in naira (₦)

**Significant at 5%

**Table 6** Impact of organic fertiliser on agricultural productivity. Source: researcher's computation using the LSMS–ISA

| Sample | Adopters | Non-adopters | Difference | S.E | T-stat |
|---|---|---|---|---|---|
| Nearest neighbour matching (NNM) | | | | | |
| Unmatched | 254,483.815 | 152,698.791 | 101,785.024 | 98,741.2605 | 2.03** |
| ATT | 254,483.815 | 102,453.551 | 152,030.264 | 110,788.527 | 2.37** |
| ATU | 152,698.791 | 286,435.839 | 133,737.047 | | |
| ATE | | | 135,487.594 | | |
| Kernel-based matching (KBM) | | | | | |
| Unmatched | 254,483.815 | 152,698.791 | 101,785.024 | 98,741.2605 | 2.03** |
| ATT | 254,483.815 | 117,517.02 | 136,966.795 | 112,194.484 | 2.22** |
| ATU | 152,698.791 | 280,622.746 | 127,923.955 | | |
| ATE | | | 128,789.298 | | |

Values are in naira (₦)

*S.E* standard error

**Significant at 5%

**Table 7** Impact of inorganic fertiliser on agricultural productivity. Source: researchers computation

| Sample | Adopters | Non-adopters | Difference | Standard error | T-stat |
|---|---|---|---|---|---|
| Nearest neighbour matching (NNM) | | | | | |
| Unmatched | 273,614.7 | 117,670.24 | 155,944.46 | 63,451.5117 | 2.46** |
| ATT | 273,614.7 | 147,098.968 | 126,515.733 | 897,01.7081 | 2.41** |
| ATU | 117,670.24 | 355,931.084 | 238,260.843 | | |
| ATE | | | 206,180.907 | | |
| Kernel-based matching (KBM) | | | | | |
| Unmatched | 241,088.179 | 434,973.758 | – 193,885.578 | 85,530.3723 | 2.27** |
| ATT | 241,088.179 | 178,902.042 | 62,186.1375 | 86,317.4909 | 2.72** |
| ATU | 434,973.758 | 503,348.71 | 68,374.952 | | |
| ATE | | | 66,794.6474 | | |

Values are in naira (₦)

**Significant at 5%

average, increase productivity by ₦218,345.099 (value/ha). In contrast, the result from Kernel-based Matching shows that the application of herbicides, on average, increase the value harvested by ₦178929.643 (value/ha). This implies that for every 1 ha harvested, on average, the application of herbicides increases farm productivity by ₦178929.643 (value/ha) and ₦218345.099 (value/ha), respectively.

Like herbicides, pesticides (Table 4) are used for the control of the pest. The result for pesticides is outlined in Table 4. Using the ATT, findings show that pesticides positively impact productivity for both the Kernel-Based and Nearest Neighbour Matching algorithms. Findings indicate that household heads who applied pesticides experienced ₦328586.768 (value/ha) and ₦12672.7741 (value/ha) higher than household heads who did not use herbicides. From the NNM result, the implication is that for every 1 ha harvested, on average, adopters experience ₦328,586.768 (value/ha) higher than non-adopters (non-users of pesticides). Similarly, from the Kernel-based Matching, the implication is that for every 1 ha harvested, on average, household heads who applied pesticides experience ₦12672.7741 (value/ha) higher than non-users of pesticides. This shows that pesticides usage contributes significantly to household agricultural productivity.

The certified or treated crop also shows a significant and positive effect on household productivity, meaning that non-adopters of the certified crop have experienced a lower level of agricultural productivity than the adopters. This result is the same for both nearest neighbour matching and Kernel-Based Matching, as presented in Table 5. Findings imply that household heads that used certified crops experienced about ₦53489.2458 (value/ha) and ₦89376.1466 (value/ha) higher than non-users of certified crops.

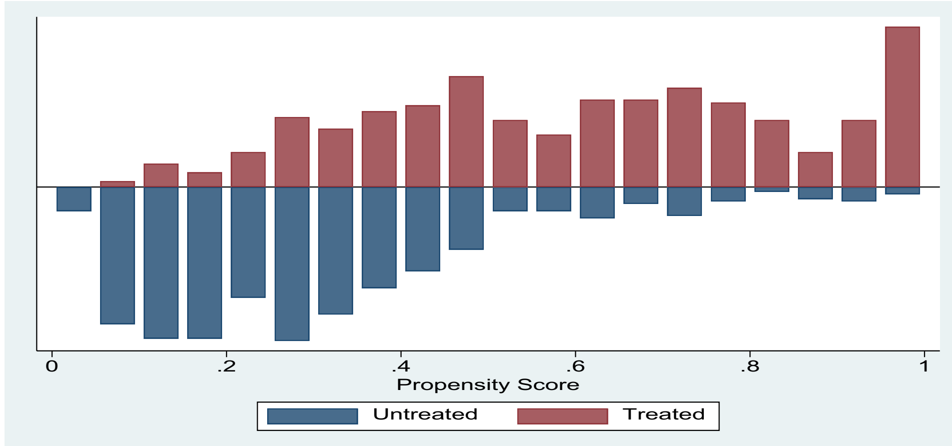


**Fig. 1** Test of common support after PSM

To validate the covariates' divergence, the test of common support was conducted for households who applied soil management practice or technology and those who did not. Figure 1 illustrates the region of common support. The figure shows that the estimated propensity scores for common support are effectively distributed. This indicates a significant overlap in the propensity score distributions between the treated and control groups.

## 5 Discussion

For herbicides, creating targeted and more precise adoption and use of herbicides allow for agriculturalists to have increased productivity, mitigating the necessity to expand land as well as lowering the effects of herbicides on non-targeted plants. Herbicides are one of the tools that farmers have easy access to while combating unwanted plants. Combining with quality seeds as well as the advanced technological progress in an integrated grass management approach, herbicides aid farmers in cultivating enough with reduced effects on the environment.

The result obtained for soil technology is in line with Monger et al. [41], who asserted that only about 16 percent of developing countries' farmers (in Bhutan), use crop protecting chemicals such as pesticides and herbicides. The report further stated that herbicides application is significantly more prevalent for large scale farmers (about 18 percent) of the largest quintile uses plant protection chemicals. The study further asserted that the most used plant protection chemical is herbicides (7% of the farmers applies herbicide in Bhutan), which is a bit lower than what is obtainable in Nigeria, where about 33.94 percent of the farmers used herbicides.

The explanation for this result lies in the fact that soil technology adoption and usage in farms could reduce the likelihood of weed competing with plants, hence promoting plant production and harvest. This finding supports the a priori expectation and is in line with Kughur [42] finding. On the contrary, from Lechenet et al., [18] in France, low adoption and usage of soil technology may not lower productivity, as against the finding by Kughur [42], in the case of Nigeria. The adoption of soil technology is essential. This is because, soil technology (chemicals) helps farmers cultivate more on less land by preserving plants from pests, weeds and diseases, and improving productivity of arable land per hectare [18].

Past researchers and existing studies have shown that, without adopting soil technology (chemical), more 0.5% of plants would be wasted as a result of pests and diseases [37, 43]. Moreover, 26–40% of world's plant production is lost annually because of weeds, pests and diseases [21]. These wastage or losses could increase by 100% without plant protection. Studies have asserted that food plants will fight for land, water and other resources with various species of weeds, worms, plant-eating insects (30,000, 3000 and 10,000 respectively). It should be noted that threats accruable to plants do not end when they exit farms as bugs, moulds, and various forms of rodents can all cause damage in warehouses and other places intended for storing these food crops. Soil technology like pesticides can also mitigate post-yield wastage and losses as well as prolong the life of crops.

Following Popp et al. [21] findings, soil technology always has a significant duty in pest control and management due to the fact that ecological compatibility of resources is rising and competitive substitutes are not globally available. Chemicals are both beneficial to producers and consumers. A significance of chemicals is the preservation of the quality of plants and yield. Soil technology may reduce substantial plant wastage, hence improving output from farmlands and hence, income accruable to farmers. However, studies found soil technology adoption benefits have negative externalities and are usually high risked [18, 21]. Some of these are impact of exposure to the environment and to humans. Negative impacts of chemicals could be mitigated by promoting the adoption and application of technology.

New developments in the method of delivery for pesticide to plants aim at mitigating negative ecological effects some more but are not expected to completely remove them. The result is in line with Umar et al. [44], which found that the mean maize yield in the US is 9.4 tonnes/ha and Canadian farmers attain a mean harvest of 8.2 tonnes/ha as a result of herbicides usage. Contradictory, maize harvests in the 10 largest lower-yielding corn-producing countries are 2.8 tonnes/ha, below the world average. Differences in harvests can be as a result of the use of pollinated or pest infected seedlings instead of treated ones to stand against pests and diseases. In Brazil (29 percent), India (56 percent), and Romania (57 percent) of all crop is lost to pest and disease, as a result of the use of non-treated seedlings.

Studies have found that agricultural production is stagnating, and factor productivity is declining due to the depletion of soil nutrients. Therefore, to enhance soil fertility, soil technology such as fertiliser is necessary [20]. Fertiliser application shows a significant and positive impact on productivity, which means that household heads who applied fertiliser experienced higher yields than those who did not apply. This is in line with the results of Jena et al. [20] as the paper found that soil fertility across much of sub-Saharan Africa is poor, which is a significant constraint to improving farm productivity and farmer livelihoods [20].

There is now wide recognition of the need to integrate increased fertiliser use with other aspects of soil fertility management to combat pests and diseases. A study in Uganda by Centre for Agriculture and Bioscience International (CABI) found that some farmers were struggling with low crop yield before applying fertiliser [45]. After spending 80,000 Ugandan shillings (approximately $22) on fertiliser, they harvested 7 bags of maise compared with 1.5 bags harvested previously. With a much higher soybean yield, they were able to invest in more fertiliser. However, some studies found that applying too much fertiliser will not result in higher yields. On the contrary, the yield may be much lower. To avoid this scenario, farmers have to apply fertilisers in a precisely determined amount according to the crop type.

Therefore, enhancing soil management techniques adoption such as improved fertilization techniques, organic amendments and precision agriculture have positive effects on food security because it would lead to increased crop yields, stability in food supply, improved quality of food nutrients as a result of the soil health, which leads to improved agricultural productivity. Also, sustainable agricultural development can be achieved as a result of adopting sustainable practices which helps maintain soil health and fertility in the long term. Therefore, by adopting soil management technologies, it improves resource use efficiently and leads to long-term agricultural sustainability and contribute to broader goals of food security.

## 6 Conclusion

This research paper is motivated by the relatively low technology adoption among farming households, has resulted in low agricultural productivity in Nigeria. The research on the effect of soil technology for the agricultural productivity of households in Africa's largest economy is of great importance as the sector contributes greatly to the economy of Nigeria and the continent as a whole. The study provides insights into the factors that influence the utilization of soil technology and the effect of its application and usage on agricultural productivity. The results indicate that farmers whose household heads applied herbicides experience higher agricultural productivity. This means that a direct and significant relationship exists between the use of herbicides and agricultural productivity. Also, pesticides which is used as a control for pest positively impacts productivity. Likewise, the certified or treated crops shows a significant and positive effect on household productivity. Also, in determining soil production technology, results show that being in a cooperative society had a positive and significant effect on having access to herbicides, pesticides, organic fertilizer and certified crop. The age of household heads also significantly affects all the variables positively with the exception of a negative relationship with organic fertilizer. Education was seen as a significant determinant has it shows a positive effect on organic and inorganic fertilizer and certified crops in order to improve agricultural productivity. Likewise, farm size had significant positive effect in getting access to herbicides, pesticides, organic and inorganic fertilizer. Lastly, gender of the household head related negatively in getting certified crops.

The findings of this research are useful for policymakers, farmers, and other stakeholders in Nigeria's rich agricultural sector along with other African countries. The implementation of policies to promote the adoption of soil technology can lead to reduced poverty, increased agricultural productivity and improved food security in rural areas. Also, the promotion of effective best and sustainable practices will lead to the adoption of effective soil management practices that will enhance soil fertility and productivity. Some of the limitation encountered in the course of the study that the data used was gotten from datasets already collated and compiled, where we have no knowledge on the data collection methods, thus could lead to biased result. Also, the measurement of the impact of soil technology on household agricultural productivity could have been influenced by other social, economic and institutional factors not considered in the study. Also, other variables that affect household agricultural productivity might have been omitted in the course of the study. The study can be extended to include comparisons among countries or region. Also, other soil management technologies can be included in the study to further extend the study.

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**Author contributions** Romanus Osabohien conceived the idea, data curation, estimation, result and wrote the first draft of the manuscript. Amar Hisham Jaffar, Oluwatoyin Matthew and Evans Osabuohien supervised, edit and review the manuscript. Adeleke Oluwayemisi carried out the discussion of the results, methodology, and revision. Olawale Y. Olonade, Andaratu Achuliwor Khalid and Gloria Onyemariechi Okoh conducted the literature review and conclusion. All authors wrote the paper.

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**Data availability** Data will be made available upon request.

## Declarations

**Ethics approval and consent to participate** The study made use of no human or animal subjects.

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