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Farmers' Perception and Practice of Soil Fertility Management and Conservation in the Era of Digital Soil Information Systems in Southwest Nigeria

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Abstract: This study assessed the perception and use of digital applications for soil fertility management and conservation strategies among small-scale crop farmers in southwest Nigeria. A total of 376 farmers were randomly selected across the six southwest states. The data collected were analyzed using descriptive statistics. The majority of the 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. Only 1.1% and 0.3% of the farmers assessed soil fertility through soil tests and digital applications, respectively. Most farmers adopted bush fallowing and the use of inorganic fertilizers to improve soil fertility. Although 4.8% of the farmers indicated that they had digital applications on their mobile phones, only 2.9% claimed to have used these. More than half (56.4%) of the farmers stated that a 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. The majority of the farmers (97.3%) indicated their willingness to embrace the use of new farm decision digital applications which could provide more information, especially on soil fertility, if introduced. More extensive services focusing on older, less literate farmers and farmers who hitherto did not belong to any farmers' association are advocated for in order to encourage the use of digital applications and soil fertility management and conservation practices.

Keywords: digital soil mapping; smallholder farmers; soil conservation; soil fertility; soil information systems

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1. Introduction

Soil, which is the unconsolidated material covering most of land surfaces, comprises both inorganic particles and organic matter. It serves as a crucial source of water and nutrients for plant growth and provides structural support for agriculture [1]. The chemical and physical properties of soil can vary significantly depending on its location and composition [2]. Soil fertility is vital in ensuring agricultural productivity, which is essential for achieving food security. In addition to other factors such as rainfall, weed control, and pest management, soil fertility is a critical determinant of crop production and yield [3]. Therefore, proper soil management practices that enhance soil fertility are crucial for sustainable agriculture and food security.

There has been an increasing human population and competing demands for land for housing, road networks, telecommunication, and industrial development [4,5]. Yet, land is fixed in supply [6]. Hence, these make the effective use of available land and, indeed, land management imperative. Land management is the act of the judicious utilization and maintenance of land resources. Land resources are used for various purposes, which may include agriculture, afforestation, the management of water resources, and eco-tourism projects [7]. To ensure effective land management and land's usefulness for farming activities in Nigeria, conscious efforts need to be made, especially including the use of emerging cutting-edge technologies such as the application of artificial intelligence (AI) to soil fertility and conservation management in Nigeria [8].

Soil fertility refers to the inherent ability of soil to provide crops with an adequate supply of nutrients in the right quantities and proportions [8,9]. It also encompasses the capacity of the soil to sustain the production of economically valuable crops while maintaining soil health, which ultimately determines the level of crop yields [10]. Effective soil management practices are crucial for optimizing soil fertility and maximizing land productivity, and their importance has become increasingly apparent in the face of growing concerns about food security, climate change, and environmental degradation. Such practices are typically oriented towards the long-term use of soil and aimed at safeguarding soil against nutrient depletion and ecological or human-induced degradation [3]. Burning plant residues or the removal of crops without replenishing the soil with residues such as stalks can result in soil nutrient depletion, leading to low crop yields and food insecurity [11]. Therefore, proper soil fertility management strategies are essential to ensure sustainable agriculture and food security. Soil fertility degradation is often acknowledged to be a deceptive and slow process [12], yet farmers' perceptions of the significance of the problem and the yield losses associated with soil degradation are critical in influencing their adoption of soil fertility-enhancing practices [13].

Studies have shown that soil fertility management and conservation strategies are critical for sustainable agriculture and food security in Nigeria, particularly for small-scale farmers who rely on rainfed agriculture and often have limited access to external inputs [14,15]. According to [14,15], the soil fertility in smallholder farms remains a major issue in many developing countries. Despite this, the bulk of food crops that are consumed locally and beyond in southwest Nigeria are provided by arable crop farmers. Hence, they play an important role in food security within the country and in other neighboring countries [16]. To ensure fertile soil for sustainable food production after about 4 to 5 years of continuous cropping, small-scale farmers in developing countries used to practice natural fallowing up until about a century ago [17,18]. However, this practice has been rendered unrealistic by high population densities, increasing food demand, and the reduction in arable farmlands [19].

However, the emergence of machine leaning, the internet of things, artificial intelligence, and cloud computing over the last century has transported soil fertility management from the abyss of traditional procedures into the realm of digital soil fertility management using computer algorithms [20]. According to [21], digital soil management starts with digital soil mapping, which involves identifying and making graphical representations of the nature, type, properties, and potential uses of different types of soil in a georeferenced location. The process of digital soil mapping includes delineating natural bodies of soil, classifying and grouping the delineated soils into mapping units, and capturing soil information for interpreting and depicting the soil's spatial distribution on a map [22]. Furthermore, digital soil mapping (DSM) is a computer-assisted production of digital maps of soil types and soil properties [23]. Until now, in Nigeria, no systematic digital soil fertility mapping has been conducted for the appropriate allocation of farm resources towards improving farm productivity [24]. The country still maintains its conventional soil maps [25], whereas the major advantage of DSM is that it provides realtime information about the soil in a given location. This aids farmers' decisions and impacts positively on agricultural production and productivity [22].

However, the adoption of digital soil management (such as digital soil maps) and these conservation practices which have been described as important depend on the farmers' perception, and their perception is mostly determined by their knowledge, perhaps from formal education, experience, or through the use of decision-aiding devices where available and adopted. Internet penetration in Nigeria was put at 55.4% at the beginning of 2023 [26], and there is an increasing use of internet-enabled mobile phones and the proliferation of activity-deciding applications, including those useful for on-farm decisions.

Obviously, little to nothing is known about the approaches local farmers adopt to improve soil fertility, and their desire to adopt the use of farming-related digital applications, among others. To interface scientific research with the human users of invented technologies, there is a need to assess the human components of DSM and their associated behavioral issues. The present study was therefore conceptualized to address this obvious knowledge gap. The study aimed to achieve some key objectives, which were to (1) describe the levels of the existing knowledge of smallholder farmers about soil fertility management and conservation practices; (2) describe the areas of soil fertility management where farmers require training; and (3) examine farmers' awareness and use of digital applications in farm decision making.

The second part of this paper delves into the theoretical, and some empirical, literature relating to soil fertility management and the adoption of agricultural innovations. The third section describes the methodology adopted for this study. The fourth section presents the results and a discussion on the subject matter, while the last section summarizes and concludes accordingly. The results of our study have implications for the dissemination and implementation of digital innovations for accessing soil information and modern soil management practices in Southwest Nigeria.

Technology Adoption Process—Theories and an Empirical Review of Soil Improvement Practices

Technology adoption is regarded as a decision to change to a complete use of an innovation or technology as a better method compared to previous practices. The majority of farmers pass through several logical problem-solving processes known as adoption processes when considering new technology [27]. In adopting a new technology, a typical farmer passes through five basic stages, which are awareness, interest, evaluation, trial, and adoption. Awareness describes the stage at which the farmer first hears about the innovation. The interest stage describes the stage where the farmer gets interested in the innovation and seeks more information about it. At this stage, the farmer is interested in how the innovation works and its benefits. At the evaluation stage, the farmer considers both the advantages and disadvantages of the technology and the resources and the technicalities it requires, among other things. The trial stage is the stage at which the farmer tries the innovation, perhaps on a small scale, while the stage of adoption involves the full acceptance and use of the technology on a large scale. It is, however, important to note that the adoption of technology or any innovation may not strictly follow the highlighted process, as adoption depends on the technology and the individual in question. This highlights the importance of personal characteristics in the adoption process.

There are a number of theories which have been used to describe the technology adoption process. Some of these include (a) the diffusion theory, which describes adoption as the process by which an idea is communicated through certain channels over time among members of a social system [28]; (b) the individual innovativeness theory, which states that farmers who are predisposed to being innovative will adopt an innovation earlier than those who are less predisposed to being so [29]; (c) the rate of adoption theory, which states that an innovation goes through a period of a slow rate of adoption and thereafter gradually experiences a period of rapid adoption; (d) the theory of perceived attributes—this posits that adopters evaluate an innovation/new technology on the basis of the perception of five qualities of the innovation, which are relative advantage, trialability, observability, complexity, and compatibility; and (e) the economic theory of adoption—this theory has been described as the theory of the maximization of utility and is used to explain the response of farmers towards a newly introduced technology [30]. The economic theory of adoption (which is not the focus of the present study) states that farmers would adopt a given technology if the utility derived from the new technology exceeds that of the previous one. This theory is also based on the assumption that a farmer or potential adopter makes decisions with respect to the satisfaction that may be derived from the technology. The adopter could also make a choice about the maximization of the expected utility subject to prices, policies, personal characteristics, and natural resources.

Meanwhile, the whole process of adoption is determined by a number of established factors. In [31], it was asserted that farmers' level of formal education has a direct relationship with their adoption of new technology, as it facilitates an easy comprehension of the technicalities, mechanisms, and benefits of innovations. In [32], the factors affecting the adoption of technology were categorized into (a) Economic Factors—the cost of technology, scale of production, and perceived benefits; (b) Social Factors—the age of the adopter, their education and gender; and (c) Institutional Factors—information and extension contacts.

Several studies have been carried out to assess the factors affecting farmers' adoption of soil improvement and conservation practices, and there have been some degrees of concordance, while, at the same time, a noticeable degree of divergence in these findings. For instance, [33] examines the extent of the adoption of technologies which promote soil organic carbon (SOC), such as manure, fertilizer, and crop residues, in Ethiopia. The study utilized data from 381 households analyzed using a probit model and reported that technology adoption was obviously constrained by a low level or outright lack of education, access to extension services, and access to credit services. It was further reported that large plots constrained the use of manure and fertilizer.

In a similar study, Maurura [34] investigated the patterns of the adoption of multiple soil technologies using a multivariate analysis and regression modeling to analyze a set of cross-sectional survey data obtained from a sample of 300 small-scale farmers in a central region of Kenya. The study reported that farmers' perceptions of soil fertility, income distribution, the site, education qualifications, access to credit, labor availability, and extension contacts influenced their technology adoption patterns and recommended more education on soil fertility management. Also, [35] assessed soil fertility and land use management practices in the Gindeberet area, Western Ethiopia, using data from 86 households. Farmers use inorganic and organic fertilizers for soil fertility improvement. Most farmers prefer applying inorganic fertilizers. Invariably, the major factor found to be of importance was the high unit price of fertilizer, which had over time been a major constraint limiting the use of inorganic fertilizers. Most of the available studies emphasized the important roles personal characteristics and other exogenous factors play in the technology adoption process, though the directions of influence are not the same across studies.

2. Materials and Methods

2.1. Study Area

This study was carried out in southwest Nigeria. The area was formerly known as the Western State until 1976, when it was further divided into 3 states. Presently, the southwest geopolitical zone of Nigeria consists of six (6) states, namely Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo (Figure 1). The six states together have a total of 137 Local Government Areas (LGAs). The region is the ancestral home of the Yoruba ethnic group of Nigeria, with different dialects spoken even within the same states. The region lies between longitude 2°311′ E and 6°211′ E and latitude 6°211′ N and 8°371′ N, with a total land area of 77,818 km². The weather conditions vary between two distinct seasons; the rainy season spanning March–November and the dry season, from November to March. The majority of the people in the region live in rural areas and practice farming due to the large expanse of fertile agricultural land consisting mainly of tropical rainforest and some derived savanna land. This study covered all the six states in the region.

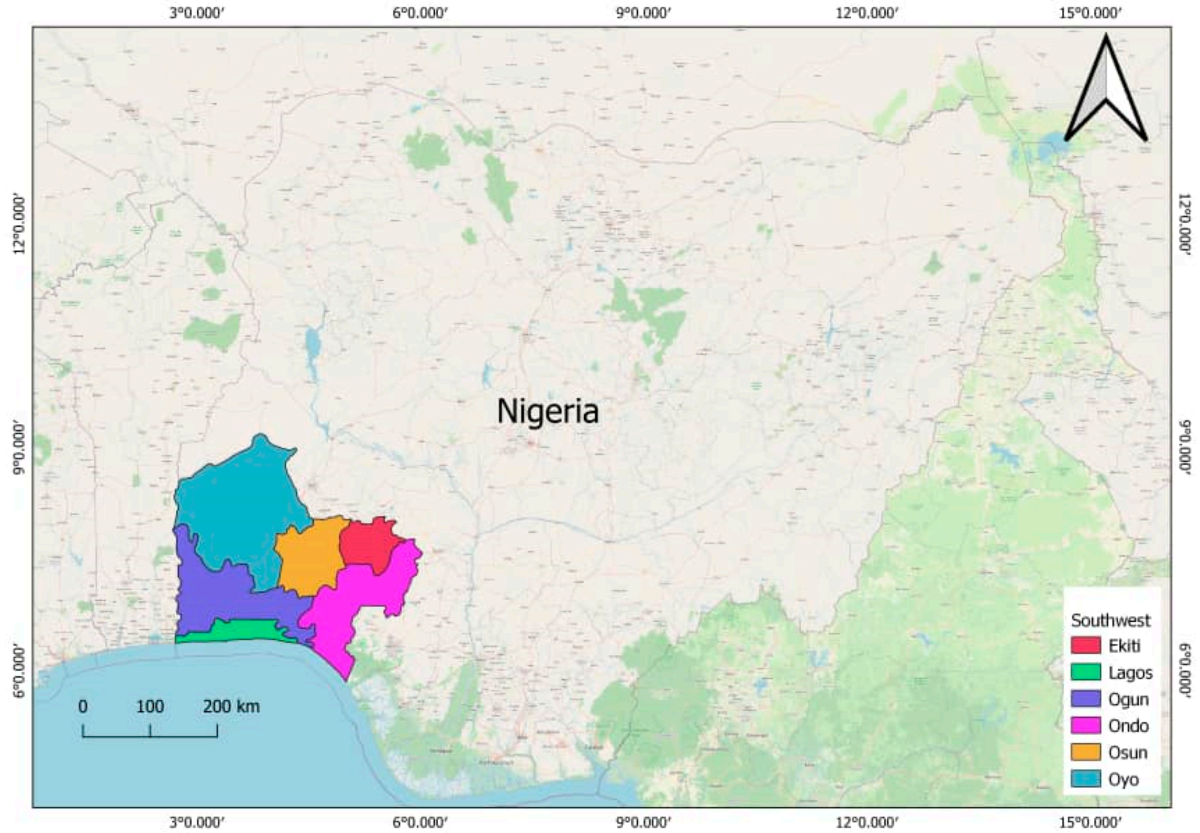

Figure 1. Map showing study area.

2.2. Sampling Technique, Sample Size, and Method of Data Collection

Multi-stage sampling involving cluster sampling and simple random sampling was adopted in the selection of farmers from whom data were collected for this study. The agrarian community in each state was the main cluster, while the agricultural development zones in each state formed the sub-groups. A range of 12 to 26 smallholder farmers from each agricultural development zone, randomly selected, participated in the survey. A total of 376 smallholder crop farmers made up of 41 farmers from Ekiti state, 39 from Ondo state, 53 from Osun state, 104 from Oyo state, 105 from Ogun state, and 34 from Lagos state were selected. The sample size was governed by the extent of the agrarian community in each state, though security concerns during data collection limited the samples that could be collected in Ondo state. Data were collected via a personal interview and recording using a structured questionnaire, from 26 July to 17 August 2022, with the aid of the Open Data Kit (ODK), Version 2022, 2.0. Relevant data were collected on farmers' knowledge about soil fertility and its management, their awareness and use of digital applications in soil fertility assessments, the areas of soil fertility management in which farmers needed training, their willingness to use new digital applications, etc.

2.3. Analytical Techniques

Descriptive statistics: this involved the use of averages, tables of frequencies, and percentages in the description of background facts such as basic socioeconomic characteristics, knowledge of soil fertility, conservation strategies, the knowledge and use of digital applications on the farm, etc.

3. Results and Discussion

3.1. Socioeconomic Characteristics of Farmers

The results of our findings revealed that, cumulatively, about 80% of the farmers were <60 years of age, and this implied that the majority were still economically active. This was further corroborated by the average age of the farmers, which was 48.7 years old. The majority (67.3%) of the farmers were male, as expected. This is more so as it is believed that farming work is tedious, and females are generally not molded for it. Only 14.4% of the farmers do not have any form of formal education. This category of farmers may be aversive to adopting new innovations such as the adoption of improved soil fertility management and conservation practices because, as [31] has asserted, farmers' level of formal education has a direct relationship to their adoption of new technology. They may also find it difficult to use internet-enabled mobile phones and farm decision applications.

Our study conformed to the findings of [36], who reported a slightly lower average age of farmers, 47, with only 23% above 60 years, and 91% having formal education up to a secondary school level, in a similar study conducted to categorize farm households and determine the influence of socio-economic characteristics and soil fertility management practices on soil fertility in upper Eastern Kenya. In [37], a similar finding was reported in a study investigating the role of soil moisture information in developing robust climate services for smallholder farmers in Ghana. However, contrary to our findings, Asule et al. [38] reported the average age of the male farming population to be 52 years. However, they reported that over 85% had formal education up to a primary school level in a study conducted to investigate the simultaneous use of sources of soil fertility information, as well as its determinants and barriers, in the central highlands of Kenya. In any case, our study, and other findings, have revealed that sub-Saharan Africa has an agile, basically literate farming populace who are ready to adopt new digital innovations which could drive the vehicle of agricultural production towards self-sufficiency.

Most of the farmers claimed to not have access to credit for their farming activities. This may be a major impediment to the expansion and possible adoption of modern farm practices, because [32] identified economic factors as one of the major factors impeding technology adoption. In the same vein, the majority of farmers (59.6%) were not members of cooperative societies, but the majority (60.1%) were members of farmers' associations. Membership to cooperative societies is expected to enhance their access to credit, while membership to farmers' associations is expected to the enhance technical knowledge of farmers due to opportunities for knowledge sharing. The average years of farming experience among the farmers in the study area was 22.1 years, and this is long enough to have acquired sufficient knowledge about farming practices. Extension contacts are supposed to provide access to informal education and learning for the farmers [32], and the majority (70.5%) claimed to have contact with extension agents (Table 1).

Several studies have reported the importance of information sharing for the adoption of new digital innovation among smallholder farmers, which membership to a farmers' association promotes [39–41]. In [42,43], the ease of information sharing among members of farmers' associations was attributed to their trust and access to relevant information. The revelation made by our study, that more farmers had agricultural extension contacts for information dissemination rather than ones obtained through membership to farmers' associations was premised on the fact that farmers do not attend association meetings as often as is expected of them. While some of them cited a shortage of farm assistants as the reason for irregular meeting attendance, others cited the far distance to the meeting venue and other logistics, whereas agricultural extension agents have on-farm visitation as part of their statutory obligations, thereby bringing information to farmers from time to time. This finding corroborates the reports of [44,45], who found that agricultural extension workers were the most important source of soil fertility management information for farmers in Southwest Nigeria and Zimbabwe. However, there was also high farmer-to-farmer information sharing, which is consistent with our study. The authors attributed this factor particularly to the utilization of participatory technology development approaches, which also improved farmers' interactions [38]. In contrast to our findings, however, [46] and [47] reported that more farmers obtained soil fertility management information through farmer-to-farmer interactions than through the services of agricultural extension workers in Ghana, Kenya, Mali, and Zambia. Notably, farmers' sourcing of soil fertility information depends largely on their behavioral attitudes toward an information source [37].

Table 1. Socioeconomic characteristics of farmers.

Description	Freq.	%	Description	Freq.	%
Location (State)			Access to Credit		
Ekiti	41	10.9	Yes	88	23.4
Lagos	34	9.0	No	288	76.6
Ogun	105	27.9	Total	376	100.0
Ondo	39	10.4	Household Size		
Osun	53	14.1	1–5	125	33.2
Oyo	104	27.7	6–10	195	51.9
Total	376	100.0	11–15	44	11.7
Age of Farmers			16–20	9	2.4
< or = 30	35	9.3	>20	3	0.8
31–40	79	21.0	Total	376	100.0
41–50	105	27.9	Mean =7.5 people		
51–60	84	22.3			
61–70	58	15.4	Cooperative Membership		
71–80	15	4.0	Members	152	40.4
Total	376	100.0	Non-members	224	59.6
Mean Age = 48.7 yrs			Total	376	100.0
Gender of Farmers			Farmers' Association		
Female	123	32.7	Members	226	60.1
Male	253	67.3	Non-members	150	39.9
Total	376	100.0	Total	376	100.0
Marital Status					
Single	26	6.9	Farming Experience		
Married	335	89.1	1–10	100	26.6
Widow/widower	14	3.7	11–20	110	29.3
Separated	1	0.3	21–30	81	21.5
Total	376	100.0	31–40	59	15.7
			41–50	18	4.8
Educational Level			>50 yrs	8	2.1
No formal education	54	14.4	Total	376	100.0
Primary School	96	25.5	Mean = 22.1 years		
Junior Secondary School	22	5.9			
Secondary School	115	30.6	Extension Contact		
OND/NCE	48	12.8	Yes	265	70.5
HND/BSc	35	9.3	No	111	29.5

MSc/MPhil	6	1.6	Total	376	100.0
Total	376	100.0			
			Number of Extension Contacts		
Sources of credit			None	133	35.4
Family and friends	14	3.7	One	44	11.7
Money lenders	6	1.6	Two	52	13.8
Cooperative societies	39	10.8	Three	37	9.8
Microfinance Bank	21	5.6	Four	29	7.7
Commercial Banks	9	2.4	Five	31	8.2
Government intervention	6	1.6	Above five	50	13.3
Others, e.g., farmers club	6	1.6	Total	376	100.0
			Mean contacts= 2.5		

3.2. Knowledge of Soil Fertility and Soil Management Practices

Assessment of the soil fertility of the land used for crop farming—Farmers were asked how they assess the fertility of their farmlands before planting. A slight majority (51.1%) stated that the appearance of the weeds before land clearing was a major indicator of the fertility of the soil, specifically at the beginning of the planting season, after second and third rainfall. Farmers in this category believed that green and fresh weeds were indicators that the soil was fertile, while pale green or light-yellow leaves on the weeds indicate that the soil is not fertile. About half (specifically, 50.8%) stated that the performance of the crop(s) planted on that farmland in the previous cropping season was a good indicator of the fertility of the soil (Table 2). Unfortunately, farmers in this category did not consider, or were not aware of, the nutrient mining effect of previously harvested crops [48], which would have diminished the soil nutrients. Furthermore, 32.4% stated soil color was a good indicator, and farmers in this group believed that deep colors (such as black or brown or a combination of these) are good indicators of soil fertility. Other identified indicators were the fallow period and soil texture. About 7.4% relied on the presence of earthworm cast/fecal deposits and past experience. It is worthy of note that farmers were not restricted to selecting only one assessment criterion. These approaches are known to be very subjective methods of assessing soil fertility (Table 2). Empirical evidence of farmers using their intuition for soil fertility management has been advanced by several other studies [38,49,50].

It is worthy of note that only 1.1% and 0.3% of the farmers stated soil tests and digital applications, respectively. The low level of the awareness and use of such objective means of assessing soil fertility calls for urgent intervention in the form of extension services to educate small-scale farmers on the need to carry out objective rather than subjective assessments of soil fertility before utilizing these farmlands for planting (Table 2). This result of our study, which indicates a low awareness of the use of digital applications for soil fertility management among smallholder farmers, is consistent with other studies which reported that farmers in sub-Saharan Africa are still lagging behind in the use of technology-based sources for soil fertility management, despite their huge potential [51–53].

Table 2. Distribution of farmers by their knowledge of soil fertility and management practices.

Description	Freq	%	Description	Freq	%
How farmers assess soil fertility			Method of water conservation adopted		
Soil color	122	32.4	Mulching	166	44.1
Weed appearance	192	51.1	Cover crop	73	19.4
Past crop performance	191	50.8	Strip cropping	6	1.6
Fallow period	121	32.2	Organic manure	28	7.4
Soil texture	65	17.3	Bush fallowing	142	37.8

Soil test	4	1.1	Others	14	3.7
Existing digital applications	1	0.3			
Others, e.g., presence of earthworm cast and experience	28	7.4	Do you care about erosion on your farm?		
			Yes	266	70.7
How farmers improve soil fertility			No	110	29.3
Crop rotation	151	40.2	Total	376	100.0
Bush fallowing	213	56.6			
Application of green manure	45	12	Methods of erosion control adopted		
Application of farmyard manure	57	15.2	Planting vegetation	61	16.2
Animal grazing before cultivation	9	2.4	Contour farming	32	8.5
Application of inorganic fertilizer	201	53.5	Planting cover crops	47	12.5
Application of liquid fertilizer	33	8.8	Improving farm drainage	119	31.6
Practice of zero tillage	31	8.2	Ridging across slope	179	47.6
Mixed cropping	82	21.8	Others, e.g., ploughing, channelization	9	2.4
Erosion control on the farm	17	4.5			
Addition of $CaCo_3$ for liming	2	0.5	Areas of soil management that require training		
Addition of sulfuric acid	1	0.27	Soil fertility management	351	93.4
			Erosion control	171	45.5
How type and quantity of inorganic fertilizers are determined			Site-specific crop/soil management	301	80.1
Physical appearance of soil	54	14.4	Others, e.g., use of model for fertility	3	0.8
Crop performance last season	52	13.8			
Soil test	2	0.5	Presence of micro faunas on farm		
Digital application	1	0.27	Earthworms	358	95.2
Type of crops to be planted	20	5.3	Butterfly	171	45.5
Perception and experience	104	27.7	Millipede	243	64.7
Extension agent advice	70	18.6	Centipede	230	61.2
Others	3	0.8	Others, e.g., snails	62	16.5
Awareness about organic fertilizer			Have noticed earthworm cast recently		
Aware	292	77.7	Yes	354	94.1
Not aware	84	22.3	No	22	5.9
Total	376	100.0			
			Are there termitarium on the farm		
Use of Organic Fertilizer			Yes	344	91.5
Used	132	35.1	No	32	8.5
Never used	160	42.6			
No Response	84	22.3	Harmful practices on the farm		
Total	376	100.0	Bush burning	287	76.4
			Agrochemicals	277	73.7
Practice of water conservation			Chemical fertilizer	234	62.2
Yes	253	67.3	Conventional tillage	162	43.1
No	82	21.8	Continuous cropping	120	31.9
No Response	41	10.9	Charcoal production	31	8.2
Total	376	100.0	Others	3	0.8

Improvement of the soil fertility for crop cultivation—The majority of the farmers (56.6%) adopted bush fallowing in a bid to improve soil fertility (Table 2). This is one of the natural means of restoring soil fertility and one of the traditional methods practiced in Africa. This is, however, an unsustainable method, as competition for land with other non-agricultural uses continues to limit the amount of land available [4,5] for fallowing and shifting cultivation. In addition, a study conducted by [54] has stressed the shortcoming of bush fallowing, especially if the plants left to grow on the soil are not legumes, as they end up depleting the soil further, with evidence of infertility indicator plants. The authors, however, advocated for planted fallows instead of bush fallows. Also, 53.5% of the farmers adopted the use of inorganic fertilizers to enhance soil fertility. Other methods stated by the farmers were crop rotation (40.2%), mixed cropping (21.8%), the application of farmyard manure (15.2%), the application of liquid fertilizer (8.8%), etc. (Table 2).

Determination of the type and quantity of inorganic fertilizers applied on the farm—Farmers who use inorganic fertilizers were asked to state how they determine the type and quantity of the inorganic fertilizers they apply to their farms. Some (27.7%) relied on 'perception and experience', while some others relied on advice from extension agents (18.6%), the physical appearance of the soil (14.4%), and the performance of crops planted on the land in the last planting season (13.8%), among others (Table 2). It is worthy of note that only 0.5% and 0.27% relied on soil tests and digital applications, respectively, to determine the type and quantity of fertilizer applied to their farms. These require urgent intervention to reduce the dangers associated with the misuse of fertilizer such as soil pollution and groundwater pollution [55].

The awareness, use, and availability of organic fertilizers—Given the possible negative implications of inorganic fertilizers, the use of organic fertilizer has been advocated for [56,57]. Hence, there is a need to assess farmers' level of awareness and use of such in their farming activities. The majority of the farmers (77.7%) were aware of the existence of packaged organic fertilizer. Only 35.1% of the farmers have at one time or another applied organic fertilizer to their farms. This may have implications for environmental sustainability, biosafety, and human health in the long run, especially when the fertilizers are used without an appropriate recommendation, as was discovered in this study (Table 2).

Soil water conservation practices on the farm—The majority (67.3%) of the farmers practice one form of soil water conservation or another. In terms of specific methods of soil water conservation, 44.1% indicated that they practice mulching, while some stated the practice of fallowing (37.8%), planting cover crops (19.4%), etc. (Table 2). Our findings, which revealed that a high percentage of farmers practice soil water conservation, corroborate other studies in sub-Saharan Africa, with cover cropping reportedly practiced the least [58,59]. Other forms of soil water conservation practices such as vetiver grass strips, terraces, and check dams have been reported and widely adopted in Kenya, while the introduction of contour ploughing, the establishment of tree plantations, and the implementation of sediment control structures have been conducted in Uganda [58]. Also, it is not an unpopular practice to combine two or more soil water conservation methods, especially in an expanse of farmland with different gradients. Such combined soil water conservation practices have been reported in many works in the literature [60–63].

Concerns about erosion and mitigation measures—The majority of the farmers (70.7%) stated that they felt concerned about erosion on their farm, while others were not bothered about the phenomenon. Given the potential devastating effect of erosion on farmland, it is expected that it would be a thing of major concern to all farmers. The farmers who were not bothered about this may not take any precautionary measures to prevent the occurrence of erosion on their farms. This may have negative effect on crop yield and the land available for crop cultivation. Farmers who were concerned about erosion on their farmland stated that they usually adopt practices such as ridging across slopes (47.6%), improving farm drainage (31.6%), and planting vegetative crops (16.2%). Others mentioned contour farming, planting cover crops, and ploughing (Table 2). According to [30], appropriate land management education is a necessity to keep the farmers aware of the danger and methods for the control of soil erosion on their farms.

Harmful practices on the farm—There are some practices by farmers on their farms which are harmful to the soil. The majority of the farmers (76.4%) reported that they have been practicing bush burning on their farms. Bush burning is known to cause the depletion of nitrogen in the soil, which disappears in the form of nitrogen oxide during burning. Although the burning usually adds some quantity of potash to the soil through wood ash, this is not enough to justify bush burning due to its long-term devastating effect. One of these effects is soil sterilization, where hot and slow-moving fire terminates the soil fungi and microbes moving within the soil. The bacteria and fungi in the soil play a crucial role in the soil nutrient dynamics that the plants use. Soil sterilization can delay recovery for many years after the burning of a fire and it may take some years for soil microbe activities to reach pre-fire levels.

The use of agrochemicals is presently common, even among small-scale farmers. The use of agrochemicals significantly contributes to improved crop yields, improved crop quality, and improves the economics of scale by lowering the unit cost of production as the yield improves. Meanwhile, its use comes with many side effects, which include the contamination of crop products with harmful chemical residues, the contamination of soil and groundwater [55], the development of a crop pest population which are resistant to agrochemical treatments, and finally it poses health risks to the people who apply it. As high as 73.7% of the farmers also reported the use of agrochemicals on their farms in the study area, while 62.2% reported using chemical fertilizers. Other harmful practices identified were continuous cropping and charcoal production (Table 2).

3.3. Knowledge and Use of Mobile Digital Applications in Farm Decisions

This sub-section assessed the farmers' awareness of the existence of digital applications which can help in soil fertility diagnoses, their usage, non-usage, the reasons for this, and other related issues. The results from the data collected and analyzed revealed that the majority (71.3%) of the farmers were not aware of the existence of digital applications which may be of help to farmers regarding soil fertility diagnoses. The low level of awareness among farmers implied that most farmers are not likely to have used such decision support applications on their farms. This has an effect on productivity, return on investment, and food sufficiency [34]. Farmers who claimed to be aware of the existence of digital applications useful for soil fertility diagnoses stated that they became aware through extension agents (18.6%) and fellow farmers (10.9%). Other channels the farmers stated were social media, mass media, and the internet (Table 3). In addition, only 4.8% of the farmers have these digital applications on their mobile phones. The issue here is that although some farmers were aware of the existence of such applications, only a few among them have the applications.

Table 3. Distribution of farmers by issues relating to the use of mobile applications.

Description	**Freq**	**%**	**Description**	**Freq.**	**%**
Awareness of Digital Applications			Reasons for always using Apps		
Aware	108	28.7	To enhance yield	1	0.3
Not aware	268	71.3	Not applicable	375	99.7
Total	376	100.0	Total	376	100.0
Sources of information/awareness			Reliability of existing Apps		
Extension agents	70	18.6	Highly unreliable	4	1.1
Fellow farmers	41	10.9	Indifferent	49	13.0
Social media	15	4.0	Reliable	26	6.9
Mass media	12	3.2	Unstable	10	2.7
Internet	5	1.3	Not applicable	287	76.6
Others	5	1.3	Total	376	100.0
Total	376	100.0			

			Willingness to use improved Apps		
Do you have the application?			Yes	366	97.3
Yes	18	4.8	No	10	2.7
No	90	23.9	Total	376	100.0
Not Applicable (not aware)	268	71.3			
Total	376	100.0	Constraints to the use of soil digital Apps		
			Lack of awareness	212	56.4
Do you use these applications?			Cost of access	113	30.1
Yes	11	2.9	Language barrier	90	23.9
No	7	2.9	Lack of tools (phones)	212	56.4
Not applicable (not have not aware)	358	95.2	Others	16	4.3
Total	376	100.0			
			Areas of desired training in ICT and mobile Apps		
How frequently do you use these Apps?			Receiving soil information	281	74.7
All times	1	0.3	Receiving advisory message	154	41.0
Occasionally	6	1.6	Comm soil info to with other farmers	145	38.6
Rarely	4	1.1	Interpretation of soil info on the App	159	42.3
Not applicable	365	97.1	Application of information on the farm	194	51.6
Total	376	100.0	Others	4	1.1

Usage and reasons for the usage and non-usage of digital applications—Although 4.8% of the farmers indicated that they had a digital application, only 2.9 claimed to have used it. This shows that most of the farmers are yet to appreciate the importance of such digital applications in their farm decision processes. Only 0.3% of the farmers claimed to be using the application all the time, while a few others claimed to use it occasionally. The only farmer (0.3% of all farmers) who claimed to be using the application all the time stated that he does so to enhance his yield. About 8% of smallholder farmers stated that the existing applications they knew of were reliable (Table 3). More than half (56.4%) of famers stated that their lack of awareness of the existence of such useful digital applications and a lack of the appropriate tools (application-enabled telephones) were the reasons they have not been using them in their farm decision-making process. Other reasons mentioned by a few other farmers were the costs of assessing such digital applications and language barriers (due to a lack of formal education). These findings suggest that creating more awareness by strengthening agricultural extension activities and providing appropriate (digital) information [32] will boost farmers' adoption of digital technology.

Willingness to use new applications with new features—Farmers were asked whether they would be willing to use new digital applications which may possibly include more desirable features, especially those not available on existing digital applications, for their farm decisions, specifically as they relate to information on soil fertility. The majority (97.3%) confirmed their willingness to embrace and use these new applications, which is an indication that most farmers are ready for the adoption of beneficial technology if they are well predisposed to it [29].

Areas of desired training in soil management—Farmers were requested to state specific areas in which they wished to receive training and most farmers (93.4%) stated soil fertility management, while 80.1% stated site-specific crop/soil management. Other areas mentioned by a few other famers were erosion control, the use of models to improve soil management, etc. Our interactions with farmers and their responses clearly indicated that soil fertility is among the major issues [14,15] they are contending with and that technology offering a possible solution would be of interest to them.

Areas of desired ICT and mobile application use training—Farmers were asked to state the areas in information communication technology (ICT) and the use of applications that they would like to be trained on. The majority (74.7%) stated "receiving information", while more than half (51.6%) stated "application of information in farm management". Other areas mentioned were "receiving/asking advisory messages", communicating soil information to other farmers, the proper interpretation of soil information from mobile applications, etc. (Table 3).

3.4. Production Activities

Crops cultivated—The majority (92.3%) of the farmers plant cassava and 76.9% plant maize, while only 35.6% plant yam. A few other farmers plant melon, pepper, and rice, among others (Table 4). These results further stressed the fact that cassava and maize are some of the major constituents of smallholder farms' outputs in southwest Nigeria, like in most other regions of sub-Saharan African countries [64].

Sources of Seeds—The sources of the seeds farmers plant are a major factor that may affect their yield, aside from the fertility of the soil. The yield will still be low if poor-quality seeds (e.g., grains) are planted [65] on the most fertile soil. Therefore, selected farmers from the study were asked questions about the sources of the seeds they plant. It is worthy of note that some farmers obtain their seeds from two or more different sources. The majority of the farmers (72.6%) plant 'seeds' from the previous year's harvests, 28.2% obtain seeds from farm produce buyers, and 34.3% obtain seeds from fellow farmers. Supplies from these three sources are mainly grains, as what was planted in the previous year was not foundation seeds that could generate viable certified seeds but ordinary seeds (or grains in some instances), which could only bring forth grains appropriate for direct human and animal consumption and other industrial processing, rather than for planting. More than half (52.9%) of the farmers obtained seeds from registered seed companies and agro-dealers (seed retailers). These are the few who are planting what should be planted, though some of them also planted seeds from improper sources alongside those obtained from agro-dealers. The practice of planting the wrong planting materials (seeds/seedlings/stem cuttings) calls for major policy intervention.

Table 4. Distribution of farmers by production activities.

Description	Freq.	%	Description	Freq.	%
Crops cultivated			Reasons for use the of fertilizer		
Cassava	347	92.3	Increase yield	273	72.6
Maize	289	76.9	Hasten plant growth	12	3.2
Yam	134	35.6	Not applicable (not used)	91	24.2
Melon	13	3.5	Total	376	100.0
Pepper	101	26.9			
Rice	25	6.6	Reason for not using fertilizers		
Others, e.g., cocoyam, soybean, etc.	8	2.1	Soil already fertile	41	10.9
			Financial constraint	38	10.1
Sources of seeds planted			Not enough knowledge on fertilizer	8	2.1
Seed companies and retailers	199	52.9	Negative effects on farm produce	4	1.1
Fellow farmers	129	34.3	Not applicable (used)	285	75.8
Previous year harvest	273	72.6	Total	376	100.0
Farm produce buyers	106	28.2			
Others, e.g., NGOs, ADPs, etc.	18	4.8	Use of Pesticides		
			Used	254	67.6
Use of Herbicide			Not used	122	32.4
Use herbicides	27	7.2	Total	376	100.0
Do not use herbicides	349	92.8			

Total	376	100.0	Why use pesticides		
			To kill destructive insects	31	8.2
Reasons for using herbicide			To prevent the spread of pests and diseases to other plants	56	14.9
High cost of manual weeding	93	24.7	Control pest and diseases	167	44.4
Faster, better and easier method	225	59.8	Not applicable (not used)	122	32.4
Enhance production	23	6.1	Total	376	100.0
Improve fertility	4	1.1			
Not applicable	27	7.2	Why not use Pesticides		
			No fund	25	6.6
Reasons for not using herbicides			Pests are few on my farm	13	3.5
Lack of money	17	4.5	Not necessary	33	8.8
Damages the soil	6	1.6	I have no knowledge of pesticide	3	0.8
Don't just like using it	4	1.1	Not applicable (Used)	254	67.6
Not applicable (used)	349	92.8	Total	376	100.0
Total	376	100.0			
Use of fertilizer					
Use fertilizer	285	75.8			
Do not use fertilizer	91	24.2			
Total	376	100.0			

Fertilizer Use—Soil fertility is intrinsic to crop productivity. The soil nutrients that are removed by crops from the soil are usually replaced by fertilizers [35]. Without fertilizer's application, the crop yields and the productivity of agricultural lands would be reduced significantly in most soils. For this reason, the soil's nutrient stocks are usually supplemented with mineral fertilizers that can quickly be released for the crop's uptake. The majority of the farmers (75.8%) in the study area use fertilizer on their farms to improve soil fertility, while the remaining did not use fertilizer on their farms. Most of the farmers (72.6%) stated that they applied fertilizer on their farm to increase the yield, while only 3.2% stated that they did so only to hasten crop growth. Those who did not apply fertilizer stated that the soils of their farmlands were still fertile (10.9%), which made the need to improve the soil fertility through fertilizer applications unnecessary. Others stated financial incapability (10.1%), the lack of enough knowledge about fertilizer usage (2.1%), and the negative effect of inorganic fertilizer on farm produce, especially at the postharvest stage (1.1%), as reasons they did not use fertilizer on their farms (Table 4).

3.5. Correlation among Study Variables

Correlation measures the degree of joint movement among variables. Before proceeding to an econometric analysis to establish the cause and effects among study variables, and especially to determine the factors affecting farmers' willingness to adopt the use of digital applications, correlation analyses of the study variables are important. This is to avoid situations where strongly correlated variables appear in the same model, thereby causing multicollinearity, which impairs the parameter estimates and reliability of the estimated model. Table 5 presents the correlation matrix of the study variables, and it was revealed that there were no high correlations among any pairs of variables that would portend the danger of multicollinearity. The highest correlation coefficient value of 0.525 was recorded for farmers' age and experience, while their marital status and age had a value of 0.436, and both were significant at the 1 percent risk level. Nearly all other pairs were far lower than the two mentioned above (Table 5). The correlation matrix can also serve as an early indicator of the existence and nature of the relationships among study variables.

Table 5. Correlation matrix of study variables.

	Age	**Gender**	**Marital**	**Education**	**Experience**	**Extension**	**Credit Access**	**Association**	**Cooperative**	**Adoption**
Age	1									
Gender	0.180 (0.732)	1								
Marital	0.436 (0.00)	−0.074 (0.12	1							
Education	−0.312 (0.00)	0.219 (0.00)	−0.176 (0.001)	1						
Experience	0.525 (0.000)	0.175 (0.001)	0.283 (0.00)	−0.302 (0.00)	1					
Extension	0.121 (0.018)	0.133 (0.010)	0.163 (0.002)	0.173 (0.001)	0.011 (0.830)	1				
Credit Access	0.096 (0.062)	0.091 (0.078)	0.089 (0.084)	0.097 (0.000)	0.092 (0.076)	0.22 (0.000)	1			
Association	0.065 (0.207)	0.092 (0.075)	0.049 (0.339)	0.213 ((0.00)	0.014 (0.790)	.342 (0.000)	0.373 (0.000)	1		
Cooperative	0.176 (0.001)	0.135 (0.009)	0.137 (0.008)	0.206 (0.000)	0.126 (0.015)	0.200 (0.000)	0.325 (0.00)	0.069 (0.183)	1	
Adoption	0.065 (0.207)	0.092 (0.075)	0.049 (0.339)	0.213 (0.000)	0.014 (790)	0.324 (0.000)	0.373 (0.000)	0.034 (0.510)	0.428 (0.00)	1

Note: figures in brackets are *p*-values.

4. Conclusions

The majority of the farmers in the study area used perception and other non-scientific approaches to assess the soil fertility of the land used for crop farming. These included the physical appearance of the weeds on the farmland before clearing and the performance of crops planted on the farmland in the previous season. A few farmers also used the soil's color to assess its fertility. Only 1.1% and 0.3% of the farmers assessed fertility through soil tests and digital applications, respectively. The majority of the farmers adopted bush fallowing and the use of inorganic fertilizer in a bid to improve soil fertility. Some of the farmers who apply inorganic fertilizers relied on their experience and perception to determine the types and quantities of fertilizers to be applied and a few others relied on the advice of extension agents. Only about one third of the farmers had at one time or another applied organic fertilizer to their farms. The majority of the farmers have been engaging in harmful practices such as bush burning, the application of agrochemicals and inorganic fertilizers, conventional tillage, continuous cropping, and charcoal production, which result in deforestation and soil degradation, with multiple environmental sustainability implications.

The majority of the farmers were not aware of the existence of digital applications which may be of help to farmers regarding soil fertility diagnoses; only 4.8% of farmers had a digital application on their mobile telephones, while only 2.9 claimed to have used such an application in their farm decisions and only 0.3% claimed to use this application all the time. A lack of awareness, the unaffordability of internet-enabled phones, the cost of accessing the internet, and language barriers were the reasons given for not using digital applications in farm decision making. Meanwhile, most farmers were willing to embrace and the use of new digital applications. Farmers wished to receive further training in the areas of receiving information, the application of that information in farm management, communicating soil information to other farmers, and the proper interpretation of soil information from applications. The existing yields of the major crops planted in the study area were lower than the national and the world averages, and this requires concerted efforts to raise productivity in the region. Most farmers were willing to adopt the proposed new digital application for their farm decisions.

Finally, and moving forward, the low level of the awareness and use of digital applications in assessing soil fertility calls for urgent intervention in the form of extension services to educate small-scale farmers on the need to carry out an objective assessment of soil fertility before planting. Further training in relevant areas, as stated earlier, to enhance the use of mobile digital applications are necessary to encourage the use of applications and improve agricultural productivity. Digital applications in local languages may go a long way toward solving language barriers. Farmers should be encouraged to obtain seeds from the right sources, as planting grains in place of seeds may affect their yield, which may be erroneously ascribed to poor soil fertility. The adoption of digital applications for farm decisions, especially in soil fertility management, should be encouraged through improved extension services, while farmers are encouraged to join farmers' associations and cooperative societies, as these, at most times, serve as channels for vital agricultural information.

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