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Article

A Farmers' Digital Information System (FDIS) for Sustainable Agriculture Among Smallholder Farmers in Tanzania

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Abstract: Digital technologies are promising tools for sustainable agriculture; however, the cutting-edge digital solutions in agriculture are impractical for smallholder farmers in developing countries. Smallholder farmers need access to credit and insurance services, quality farm inputs, advisory services, subsidies, and market services to be able participate in sustainable agriculture. This paper is part of an extensive study conducted using the design science research (DSR) methodology. As part of our previous research, we conducted a thorough survey of the various stakeholders in Tanzania to assess their needs. Thereafter, we designed a conceptual digital framework called Farmers' Digital Information System (FDIS), which provides all the necessary services to smallholder farmers and other stakeholders and addresses the identified needs. This paper presents a technical implementation of FDIS that aims to deliver essential services to smallholder farmers for sustainable agriculture within a comprehensive single mobile application. We used Android Studio Iguana and a Flutter framework to develop four service modules that include farmer and farm data, advisory services, and financial and marketing services as part of the FDIS platform. The system reflects the services offered in a real-world environment, as farmers can directly request advice from experts, apply for credit services from financial institutions, and market farm products to meet potential customers. It solves problems of access to farm advisory services and credit services for farm investment and helps farmers to find reliable markets for their products without going through intermediaries (middlemen). The completion of the FDIS development presented here will be followed by a test of the platform with real users for evaluation and improvement. Future research will focus on the scalability of FDIS for different regions, the embedding of more advanced technologies, and the adaptability of FDIS to different agricultural ecosystems. The FDIS solution has the potential to improve sustainable farming and empower smallholder farmers in Tanzania and beyond.

Keywords: information system; sustainable agriculture; smallholder farmers; system implementation; ICT in society; digital technologies; farmer digital information system (FDIS); Tanzania

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1. Introduction

Digital technologies are increasingly becoming an integral part of all social–economic activities surrounding human life. Indeed, technology innovations have tremendously altered the agriculture sector, promising sustainable agriculture, with increased productivity, income, and some environmental conservation [1,2]. These innovations include the use of big data and machine learning, artificial intelligence, robotics, the Internet of Things, and virtual and augmented reality, to name but a few, all leading to more efficient and

climate-smart agricultural production [2–4]. However, these technological innovations are unevenly accessible to farmers around the world [5]. The cutting-edge technologies are mainly used by a minority of large-scale farmers, while many smallholder farmers continue to use old, inefficient tools and production methods. According to the UN Food and Agriculture Organization (FAO), large-scale farmers produce only around 30% of the world's food, while smallholder farmers account for 70% [5]. Therefore, it is worth noting that investing in new technologies for smallholder farmers could eradicate hunger and extreme poverty for the current and future anticipated population growth in the world.

Most smallholder farmers reside in rural and semi-urban areas in developing countries [6]. Smallholder farmers are facing various challenges that hinder them from practicing sustainable agriculture. Mushi et al. [7] established that a lack of access to agricultural knowledge and advisory services, poor access to financial resources (credit and insurance services), the presence of middlemen between farmers and the market, poor distribution of subsidies, the presence of counterfeit farm inputs, and poor policies are common challenges facing smallholder farmers in Tanzania and most other developing countries. The urgency of digital technologies as an essential component of production in all human socio-economic activities has influenced the need to solve the challenges of smallholder farmers. Indeed, many governments and non-governmental organizations have developed various digital solutions for smallholder farmers. For example, a recent study identified 94 digital agricultural solutions and startups in Tanzania, some of which are active while others are inactive [8]. To mention a few developing countries, government-initiated digital solutions in agriculture include the Online Fertilizer Recommendation System (OFRS) in Bangladesh, which provides location-specific fertilizer recommendations to improve the efficiency of farm input use, thereby reducing input costs and safeguarding the environment and consumers' health [9]; various digital solutions for different agricultural value chains by the Kenya Agricultural and Livestock Research Organization (KALRO) and a mobile service (m-service) for the dissemination of agrometeorological information in Kenya [10,11]; an e-Government platform serving the general agriculture community in India [12,13]; and many more.

In Tanzania, e-Government services in the agriculture sector have witnessed the implementation of M-Kilimo—a web-based and mobile application for farmers to access extension services and market information—a call center for farmers and general agriculture stakeholders, and a fertilizer subsidy distribution platform called the Digital Fertilizer Subsidy Distribution System (DFSDS), all in favor of smallholder farmers in the country [7]. However, all these digital solutions in developing countries only solve a particular problem, sometimes for specific agricultural value chains, which does little to solve the problems of smallholder farmers as part of a complete farming cycle. John [14] argued that most digital innovations for smallholder farmers use complex technology and lack testing, leading to incompatible systems. Moreover, most digital solutions do not integrate the components of sustainable agriculture, namely, the sustainability of the Information and Communication Technology (ICT) infrastructure and the resources that support the digital service, economic sustainability (increased income and productivity), and environmental sustainability.

This paper is part of a larger research study inspired by the theories of ICT for development (ICT4D), which posit that technology innovations must have an impact on people's lives [15,16]. Therefore, we intended to design and develop digital solutions that work well for smallholder farmers in developing countries, without copying and pasting the theories and technologies used by large-scale farmers, mainly in developed countries. As a part of a more in-depth study, this paper contributes to the body of knowledge on the implementation of *Farmers' Digital Information System (FDIS)*, a digital platform that aims to provide all essential agricultural services as part of a complete farming cycle and under one roof. The previous parts of the study focused on the design phase, which analyzed the challenges and needs of agricultural stakeholders in Tanzania—a low-income country [17,18]. Chandra and Collis [19] found that the challenges of smallholder farmers in developing countries are

more similar to each other, so the FDIS concept could be adopted with minimal contextual adjustments to fit the agricultural system of any other developing country.

As said above, our previous research reviewed digital technologies for sustainable agriculture in Tanzania [5]. We then thoroughly investigated the needs of smallholder farmers and other stakeholders in Tanzania [7,17] in order to establish a proposal of the design of FDIS, a comprehensive digital framework regrouping all services useful for farmers [18]. To validate our proposal and to bridge the gap towards a concrete digital solution, we discuss in this paper how we implemented a few FDIS services and provided them in an integrated way to the farmers through a single mobile phone or web application. More specifically, the main contribution of this paper is the implementation and illustration of three modules (i.e., data on farm and farmers, financial, advisory, and market services) as part of the complete FDIS platform. Section 2 presents the methodology and materials required to implement the platform. Section 3 explains the results of the implementation, including the designs of the implemented part of the system and the interface and functions of the modules. Section 4 discusses and illustrates the impact of the implemented part of the system in the real world and the impact on the development of the agricultural sector. Moreover, Section 4 discusses various issues regarding the actual implementation of FDIS, while Section 5 concludes the paper with key notes on the findings and future areas of research.

2. Materials and Methods

We adopted a design science research (DSR) method, which strives to develop high-quality digital solutions that interact with the problem's context and result in effective and efficient information systems [20]. DSR is a solution-oriented methodology that has been established as an effective method that goes beyond descriptive–explanatory research and takes steps to solve problems. DSR is gaining ground in the field of information systems, information technologies, and related disciplines due to its ability to solve a social–technical problem by designing an artefact, a model, and a procedure that fit well into the context of a specific environment. However, behavioral science research (BSR) and other conventional methodologies dominate research in the areas mentioned due to the low awareness of DSR among scholars [21]. This study is guided by the theories of ICT4D—Information Technology for Development—which emphasizes that "Key elements in the ongoing work towards sustainable development will be the ability of stakeholders in development initiatives to collaboratively and effectively design, implement and evaluate innovations that will be adopted and utilized within specific development contexts and environments" [21]. DSR is the preferred methodology for ICT4D projects because of its ability to develop and implement digital solutions that meet the evolving needs of stakeholders. Indeed, DSR uses qualitative and quantitative tools to collect and analyze data with a view to developing a sustainable digital artefact and models for solving socio-technical problems in society [15,21].

Adopting and customizing the DSR process by Peffers et al. [22], we developed eight steps for designing and implementing the FDIS platform. The first step was to identify the problems facing smallholder farmers that need digital technology intervention. The problems were identified through a literature review, which identified the lack of investment capital and financial services, the poor subsidy distribution system, and the lack of access to quality farm inputs, advisory services, and a reliable market for farm products as common challenges for smallholder farmers [5]. The second stage consisted of gathering the system requirements by defining the objectives that would meet the challenges identified. This was followed by a third stage of the preliminary design of the artifact based on the requirements identified in the previous stage [23]. The fourth stage was to conduct a survey of key stakeholders to orient users to the preliminary design of the artifact and to collect their opinions on the problem solution. We conducted a user survey to gain user input early in the design phase, as user opinions are important for digital solutions projects [24]. In the fifth stage, we developed a concrete design based on the opinions and needs of stakeholders

that were missing from the preliminary artifact that was designed. The sixth stage was the pilot implementation of the refined FDIS design, i.e., the actual development of the system.

We introduced agile methodologies in the implementation phase (in the dotted box in the phase sixth and seven) in order to gradually build the FDIS system from scratch and rapidly adopt contributions for system improvement in an iterative approach. Agile methodologies, unlike others, allow for a gradual implementation of the system, the adoption of changes for necessary improvement, and the involvement of stakeholders at all levels of the system's development [25,26]. This stage brings together designers, developers, and users, who contribute to the continuous improvement of the system. The seventh stage was the evaluation of the implemented part of the FDIS platform. This involved monitoring the effectiveness and efficiency of FDIS, while allowing users to provide feedback, thereby returning to the design stage. The eighth stage was the communication and documentation of the system through scientific and professional publications. This stage was reached at every stage of the DSR methodology used in this project. Figure 1 illustrates the eight stages of the DSR methodology:, from the identification of the problem and requirements to a preliminary proposal of an artefact design (in our case, a preliminary FDIS proposal), to a user survey that helped us revisit and refine our FDIS proposal, to the actual development and evaluation of the FDIS platform, and to finally communicating the results. This process is iterative, and at any point in time, we may go back and revisit previous decisions or embark in a new DSR research cycle. Figure 1 specifically highlights the sixth stage (in yellow) described in this paper, which concerns the implementation and evaluation of the FDIS platform.

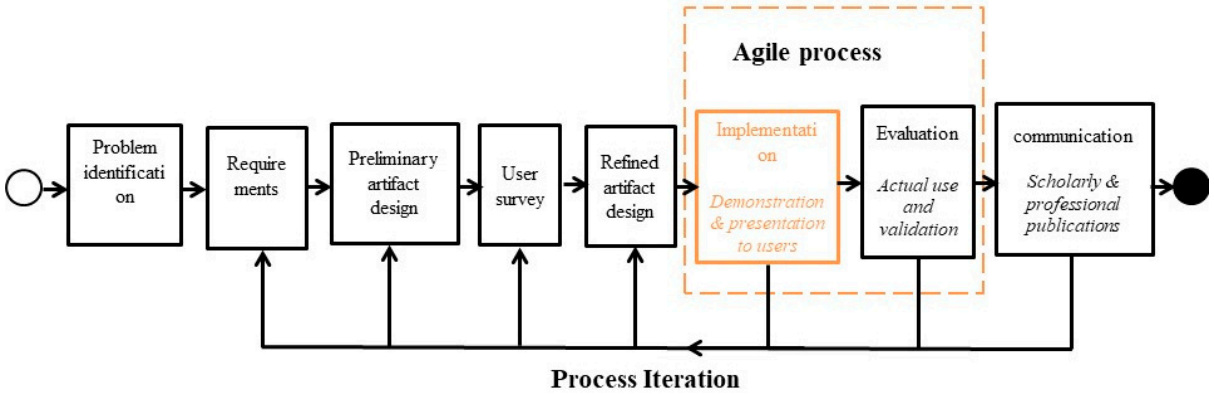

Figure 1. The DSR method used in this project.

3. FDIS Implementation—Design, Development, and Deployment

The section presents the technical design, development, and deployment of the system for demonstration purposes, showing how the system meets the needs of users with a view to the adoption of sustainable agriculture. We present here the software components of FDIS and how they interact with each other, as well as the deployment of FDIS for access to the various users. Concerning the actual implementation, we used the Android platform to develop farm and farmer data modules, financial modules, and advisory and market modules as part of the FDIS services. The researchers used Android Studio Iguana and a Flutter framework to develop four service modules that included farmer and farm data, advisory services, credit services, and marketing services as separate services [27]. The services developed can be accessed on Android and iOS devices and via web applications.

3.1. FDIS Services Components

Figure 2 below shows a Unified Modeling Language (UML) component diagram that corresponds to the complete FDIS designed services shown in the Business Process Modeling and Notation (BPMN) by Mushi et al. [18]. On the left of the figure, the farmers services component can be seen, which is itself composed of several sub-components

(farmer database, get advisory service, get financial service, get agro-dealers services, get subsidies service, manage harvest, and manage market). These components communicate with the components (shown in the middle of the figure) providing those services to the farmers (advisory, financial, agro-dealers, subsidies, logistics, and market services). Those services, in turn, need access to additional services shown by the components on the right of the figure, such as permit or warehouse services. The four service modules highlighted in color in Figure 2 below correspond to the components implemented for the demonstration. The UML component diagram shows the deployment of FDIS platform and service interactions solving critical challenges of the farmers and other stakeholders towards sustainable agriculture.

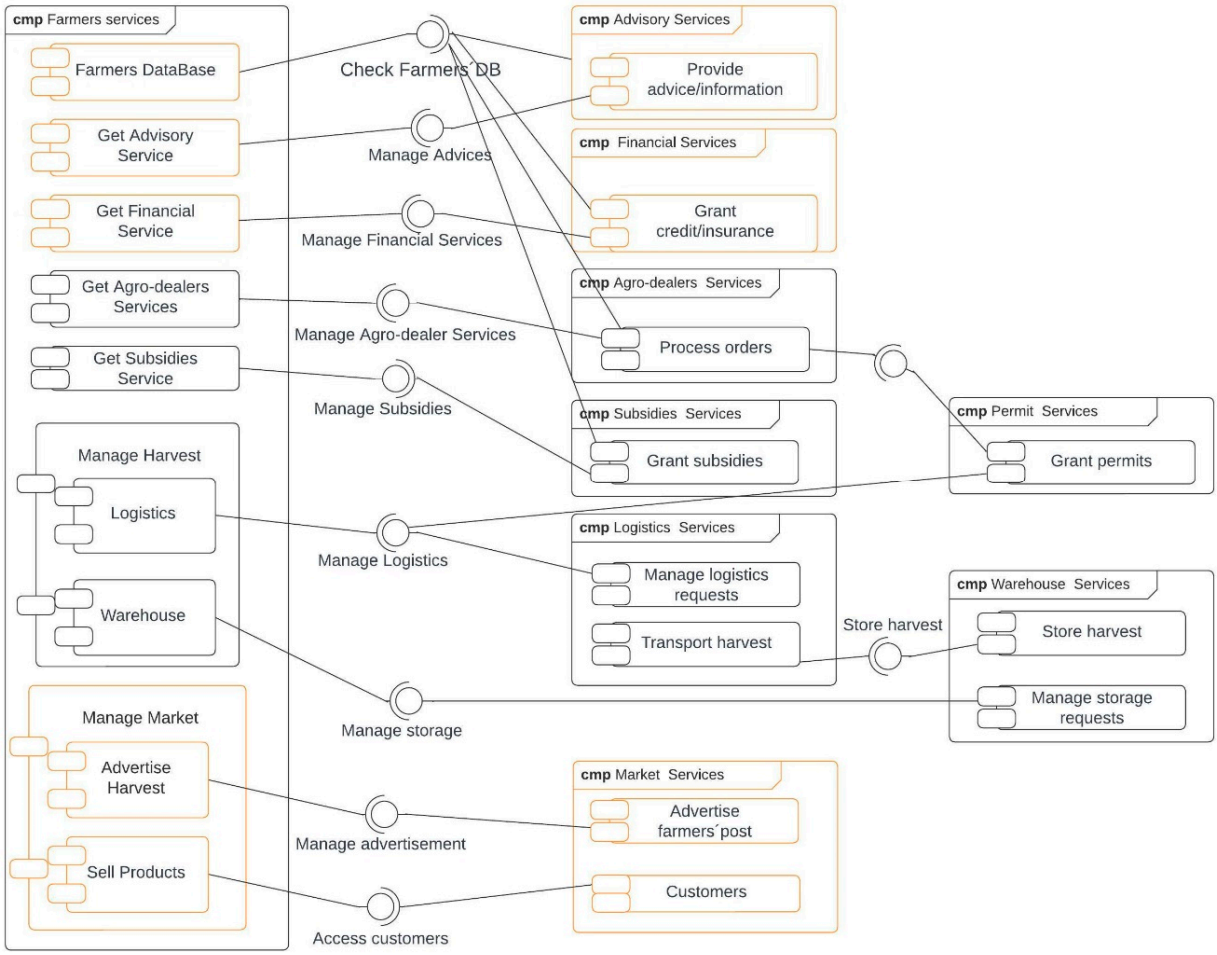

Figure 2. FDIS UML component diagram.

More precisely, FDIS comprises several essential services that bring together all key stakeholders in the agriculture sector, including the government. The fundamental component of FDIS is the "farmers services" component (left side of Figure 2). This component hosts several sub-components, including the farmers database, that other stakeholders can request data from during the service delivery. The farmers database presents comprehensive data regarding the farms and farmers. Other sub-components of the farmer services include access to advisory, financial, agro-dealers, and subsidies services, as well as two components for managing the harvest and the market (advertising and selling products). FDIS also comprises components for services providers (in the middle of Figure 2), such as financial (credit and insurance services), advisory, agro-dealers, and subsidies. The agro-dealer service is further linked with the permit service. These services require data from the farmers for quality and timely service delivery. Additional components concern services in relation to logistics and the market. The harvest and logistics services

are further linked with the warehouse services for storing the harvest. Therefore, farmers can request and receive services from all the stakeholders through the system that can be accessed by all mobile devices (Android and iOS) and also from the website. Subsidies are government-initiated services in Tanzania; thus, the responsible department uses farmer data (after registration) to deliver the service (see Figure 2). For the market service, farmers are expected to post their farm products so that interested customers can contact the farmer for business.

3.2. FDIS Development

The developers used Android studio Jellyfish 2023.3.1 patch 1 (which includes version AI-233.14808.21.2331.11842104, built on 15 May 2024). The development of FDIS was supported by Flutter plugins with dependency features such as a curved navigation bar, firebase core, firebase auth, cloud firestone, random string, shared preferences, image picker, and firebase storage.

Moreover, we used the Google's Firebase (version 13.15.1) mobile application development platform for the project as it offers a comprehensive toolset that includes services like analytics, authentication, databases, file storage, and push messaging. Firebase is a cloud-based service that interacts directly with the client Software Development Kit (SDK) provided by Firebase, eliminating the need for developers to build and maintain backend infrastructure. The platform caters to various app development needs across different platforms such as iOS, Android, the web, Flutter, Unity and C++.

3.3. FDIS Deployment

The client–server model was adopted, whereby users can access services via personal computers and mobile devices. Users have to register either through the application or the website to obtain access to the services stored in the web server. The main application (back-end) runs on a dedicated computer (web server). Access to the application occurs either through a web interface (front-end) via a personal computer or through a mobile application to be downloaded on a mobile device. The web server enables access to the FDIS platform from a computer or mobile device. The client–server model approach is crucial to enabling access for multiple devices to the application while synchronizing media libraries between devices. We used the Firebase database, a mobile application development platform from Google that supports a variety of application development needs, including the major mobile device operating systems (iOS and Android) and web services.

4. Discussion

The FDIS platform is a promising tool for sustainable agriculture among smallholder farmers, as it provides essential services in a complete farming cycle. Moreover, the platform could contribute to smallholder farmers' adoption of climate-smart agriculture (CSA), namely, increased productivity, support resilience, and climate mitigation [4,28]. FDIS is a comprehensive digital platform designed to offer eight essential services as it brings agricultural stakeholders together. These services include financial, advice from experts, agro-dealers and farm inputs, warehouse and logistics services, administrative services from government agencies, subsidies, and market services [17]. The basis of the FDIS platform is the management and sharing of comprehensive farm and farmer data. The three services implemented provide farmers with access to financial, advisory, and market services via digital devices such as smartphones, tablets, and computers. We focused the discussions on the impact of digitized services and the contribution to sustainable agriculture for most smallholder farmers in developing countries. In what follows, we present an illustration of the three services implemented for demonstration and presentation purposes.

4.1. Illustration of FDIS Applications

4.1.1. Financial Services

According to Kirui et al., [29], Simbakalia [30], and Kimaro [31], farmers lack investment capital because they rely on their personal assets to invest in production. A survey conducted under this project revealed that only a few farmers approach financial institutions for services in Tanzania. Meanwhile, farmers experience long application procedures and denial or have insufficient credit needed for production. On the other hand, the financial institutions consider farmers as high-risk customers and impose strict conditions for access to credit services [23]. Therefore, the majority of smallholder farmers are unable to invest in modern farming and animal-keeping, resulting in poor production, low income, and environmentally unfriendly agricultural practices. The poor relationship between smallholder farmers and financial institutions is due to a lack of data. There are no reliable data that introduce farmers to other stakeholders for a service. For example, for a bank to verify the information provided by farmers when applying for a loan, it must call on its agent to physically visit the farm, interview neighbors and local authorities, etc. Farmers have complained about the time it takes to obtain a loan, and most of them obtain the loan when the time needed for farming has elapsed. As a result, they use the loan for other unplanned purposes, which prevents them from repaying the loan [23]. This vicious cycle of mistrust and lack of cooperation is hampering the growth of the agricultural sector and efforts to eradicate extreme poverty and hunger in the global community.

The digitization of the financial service within the FDIS platform was designed to solve the problem of data management for smallholder farmers. The platform accurately collects farm and farmer data to share with other stakeholders as a service. FDIS was designed to collect all essential data needed by different stakeholders, including financial institutions. These dataset categories include personal information, communication information, location details, farm and field data, financial instruments and credit information, insurance, production data, and business information [17]. Data collection in the platform involves different actors and levels of verification for quality assurance. FDIS applies data shielding during data sharing for services to adhere to the privacy and security of data. Therefore, not all farmer data will be openly available when exchanging services with stakeholders. Pre-defined conditions for data access by each stakeholder must be defined to ensure that each stakeholder has access to sufficient data to enable the provision of services to farmers. For instance, financial institutions could use FDIS to request and access farmer data, like the manual forms used to collect data from farmers when applying for services.

FDIS could increase efficiency and collaboration between smallholder farmers and financial institutions. Smallholder farmers could apply credit services by simply sharing the information needed by financial institutions. Simplified verification of farmer information by financial institutions could trigger timely credit services, grant sufficient loans needed for production, and improve the conditions of access to financial services for smallholder farmers. The survey carried out as part of this project revealed that one of the reasons for the poor relations between smallholder farmers and financial institutions is the lack of data on farms and farmers. FDIS can promptly provide financial institutions with comprehensive information on farms and farmers. Information such as the business plan, production history, and farm financial statements are essential for assessing the financial stability of the farm and for risk management. This information is critical to reducing the risks of loans granted by financial institutions as well as to offering other credit services effectively.

4.1.2. Advisory Services

The digitization of information and advisory services to smallholder farmers could solve many economic and environmental challenges in developing countries and in Tanzania in particular. It should be noted that most smallholder farmers do not have access to modern agricultural farming knowledge or expert advisory services, so they rely on their own knowledge and that inherited from the farming community [7]. A recent study on the extended knowledge system in Tanzania revealed a disconnect at multiple levels,

thus hindering sustainable agriculture among smallholder farmers [32]. This leads to poor farming practices, such as poor selection of breeds and the use of sub-standard farm inputs, posing a serious threat to the quality and quantity of production, the health of farmers and consumers, and the environment [33–35]. A survey undertaken in this project revealed that most farmers are not trained to adopt basic farming and animal-keeping practices and technology. For these reasons, the Tanzanian government employs extension workers—agriculture experts employed to transfer agricultural knowledge and technology from various sources to farmers. These extension workers work closely with farmers at a ward level. However, this method of transferring knowledge is ineffective because of staff shortages and the difficulty of reaching large numbers of farmers in remote areas [23]. However, some other parts of the country are using radio and short messages (SMS) to disseminate and access extension information, with radio being the preferred channel of sharing information to smallholder farmers [36]. Figure 3 presents the front-end (or interface) implementation of advisory services, enabling farmers to access and request information on various farming activities such as seeds, farm machinery, crops, crop diseases, labor sources, pests and diseases, farm inputs, etc. It is the interface that is presented to the farmers to obtain access to the services. It corresponds to the FDIS get advisory service components highlighted in color on the left side of Figure 2.

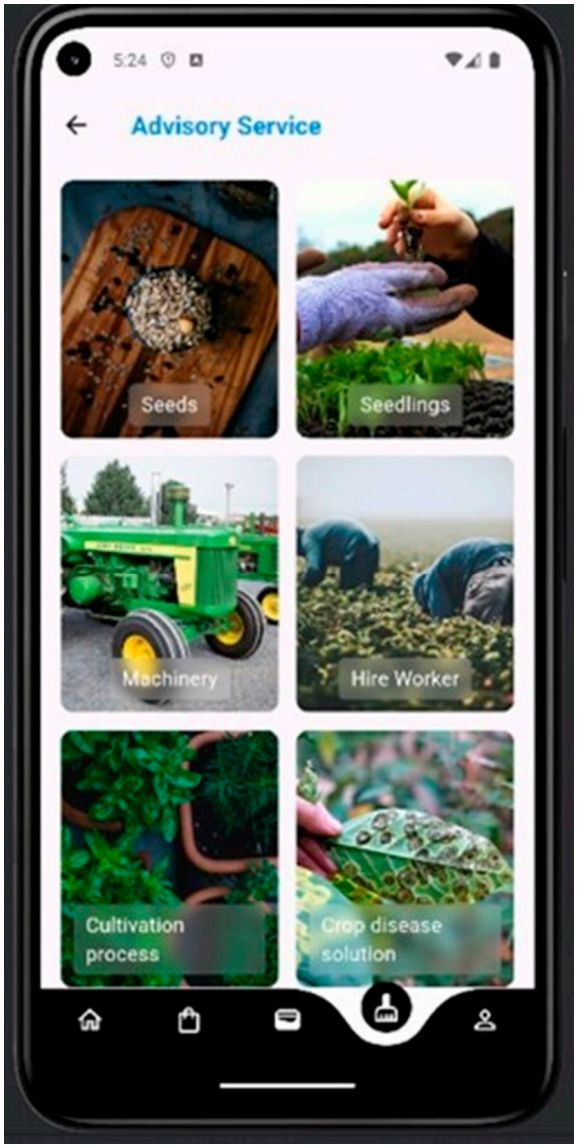

Figure 3. Advisory services—a part of the FDIS implementation (farmers' access).

Figure 3 shows six advisory services available for the user. The user can select a service category for more specific needs, for example, a specific type of crop disease under the "crop disease solution" or a specific crop cultivation process under the "crop cultivation". We implemented these few advice categories for demonstration purposes, but other advice categories may be introduced as part of the actual implementation of the FDIS platform.

The FDIS platform's advisory services are designed to mitigate the challenges identified in terms of sustainable agriculture. It involves the registration of agricultural experts and farmers [17]. The experts will be registered in the system and will be able to respond to the various information or advice needs of farmers. This solves the problem of farmers' dependence on their knowledge in all farming activities, including the application of farm inputs. The ability of farmers to request and receive information and advisory services on various farming activities is essential to increasing productivity and income and to avoid inferior inputs that could be harmful to the health of farmers, consumers, and the environment. The systematic adoption of these practices and other FDIS services would ensure that smallholder farmers are committed to sustainable agriculture.

4.1.3. Market Services

Smallholder farmers could increase their income and profitability if they found a reliable market for their products without intermediaries in the supply chain [17]. Intermediaries (middlemen) play the role of information brokers. They identify areas where farmers are selling their products at low prices because they lack market information, usually before or shortly after harvest. Intermediaries set the price for farmers and buy without government control, selling at higher prices to processors and consumers [37]. This practice demotivates farmers and diminishes their ability to increase their investment in agricultural production [38]. We conducted a survey of farmers, processors, and consumers, among other stakeholders. The results revealed that farmers mainly sell to intermediaries at very low price, while processors and consumers buy from intermediaries at higher prices [23]. Processors and consumers felt that buying directly from farmers could not only increase their profitability but also enable them to buy agricultural products at a fair price, unlike with intermediaries. However, the lack of information and communication between the agricultural processing industries, consumers, and farmers is a challenge that is exploited by intermediaries. To avoid the frustrations of the market and the inability to grow, farmers cut back on production, as they primarily aim for subsistence rather than agribusiness, leading to a shortage of food and raw materials produced by agriculture.

Figure 4 below shows the interface implementation of market services that enable farmers to display their products and meet potential customers. It is the interface that is presented to farmers to obtain access to the market services. It corresponds to the FDIS manage market component highlighted in color on the left side of Figure 2. This interface shows three cereal crops as a demonstration of the FDIS platform: rice/paddy (in the illustration), wheat, and maize.

Customers can navigate to any of the cereal crops they wish to buy directly from farmers. After selecting the crop, customers can browse a list of products posted by farmers, identifying price tags, location, farmer contact details, and quality and quantity of produce. This information is critical to enable customers to decide whether or not to buy the products. We implemented the three crops only for demonstration purposes, but other crops may be accessible when the platform is actually implemented.

FDIS is designed to link all the key stakeholders in agriculture, including farmers, processing industries, and consumers. This link could radically change the supply chain for agricultural products by eliminating intermediaries. In addition to access to market information, farmers would be able to market their products and meet potential customers directly, particularly from the processing industries and consumers. The survey revealed that on the one hand, farmers would be able to sell their products at a fair price and earn a deserved income if the platform enabled them to access market information and reach a wider market; on the other hand, the processing industries believe that buying raw

materials directly from farmers reduces production costs and the cost of processed food for end consumers [23]. As a result, farmers can increase their investment in agriculture and productivity, which promotes sustainable agriculture and the development of the majority of people employed in the sector.

Figure 4. Market service—another part of the FDIS implementation (farmers' access).

4.2. Towards the Effective Implementation of FDIS

Although FDIS has the potential to make the agriculture sector more dynamic and sustainable, a number of issues need to be considered for its effective implementation. FDIS is a comprehensive digital platform that requires the efforts of various key agricultural stakeholders, including experts from different disciplines, governmental, and non-governmental organizations. Smidt and Jokonya [39] ascertained that government and institutional support is critical to bringing together agricultural stakeholders and to develop a localized developmental implementation framework for supporting the adoption of digital solutions to support smallholder farmers. The FDIS platform is a data-driven digital solution to the challenges faced by smallholder farmers in developing countries. Farmer and farm data are the key components of the FDIS platform, and farmers, service providers, and other stakeholder can share these data when requesting and providing services. This raises issues of data quality (completeness, accuracy, timeliness, and precision of data), data ownership and sovereignty, and legal issues relating to data protection. Implementing the FDIS platform will require training stakeholders on the importance of data quality and training staff responsible for collecting and regularly updating the data. Moreover, FDIS could use the Application Programming Interface (API) to verify stakeholder data from existing systems such as the National Personal Identification System. More advanced technology, such as sensors, unmanned ground vehicles, and unmanned aerial vehicles, could be used to collect quality data; however, such technology requires a considerable initial cost [13].

Data ownership and sovereignty have become a critical topic of discussion when implementing data management systems. The debate about data ownership between farmers, companies, and the organizations that manage the digital platform infrastructure is still ongoing. Many existing data ownership models show that agricultural technology providers are taking control of data and reusing it for their own benefit [40]. Although new policies transfer ownership of data to farmers, the problem of data dispersal remains; data can be copied, transferred, and migrated and can exist in different locations and under different ownership [6]. Nonetheless, good practice of data ownership can be adopted when developing policies governing the implementation of data-driven systems. For example, an open data charter would allow farmers to share all or part of their farm data with service providers, such as fertilizer companies, while giving data owners (farmers) the right to delete their data and opt out of the platform, thereby exercising data ownership and protection [3,40]. Many governments of developing countries are developing policies and legislation on data protection and data sovereignty. For instance, Tanzania has drafted its personal data protection legislation to control the collection, storage, and sharing of data [41]. In the meantime, common legislation can be used to implement the FDIS platform, according to which the collection, storage, and sharing of personal data require the consent of farmers, who must be aware of the purpose for the data collection and the list of companies or organizations with which the data will be shared [42].

FDIS is a complete digital artefact designed to digitize the national agricultural system. Therefore, the effective implementation of FDIS requires enormous resources, namely, infrastructure, trained staff, and financial resources. The partnership between the government and the private sector could benefit from the use of existing infrastructure and resources for the adoption of the FDIS platform. For example, the Tanzania Ministry of Agriculture (MoA) has invested in digital technology to serve farmers and other players in the country's agricultural sector. ICT-based services implemented by the MoA include M-Kilimo, which is a web and mobile application for farmers to access extension services and market information, a call center for farmers and agricultural stakeholders in general, and a fertilizer subsidy distribution platform called the Digital Fertilizer Subsidy Distribution System (DFSDS), all for the benefit of smallholder farmers in the country [7]. FDIS can inherit existing infrastructure, human resources, and data from farmers and other stakeholders without starting from scratch. Moreover, other government employees, particularly agricultural extension officers (employed throughout the country) could play a

key role in the collection and regular updating of farmer data in the platform. All of these elements could significantly reduce the cost of implementing FDIS but could also ensure the quality of the data and services and guarantee the sustainability of the infrastructure and resources that support the platform.

5. Conclusions

Service providers such as financial institutions offering credit and insurance services, agriculture experts, government agencies, agro-dealers, processing industries, and others lack reliable and comprehensive information on farms and farmers. It is difficult to provide services such as credit and insurance, advice, subsidies, farm inputs, and market services to farmers without a reliable source of information on the farms and farmers. As part of an ongoing research project, we designed and implemented a digital framework called FDIS that brings all agricultural services together. FDIS facilitates key stakeholders' access to comprehensive data on farms and farmers for the provision of those services. Our contributions are three-fold: (1) from the academic point of view, we provide a proposal, called FDIS, for a novel data management system that integrates farmer data as well as farmer services within a comprehensive single system that gathers the various stakeholders [17]; (2) from a technical and practical aspect, we designed and described the various software components and their interactions, as well as an interface design for farmers, all supporting the concrete implementation of FDIS; (3) from a societal point a view, we provide a proposal for a system aiming at empowering smallholder farmers [7,18].

This paper highlights the second point above, i.e., the design and implementation of the FDIS digital platform and its provision to farmers in the form of a mobile application. The management and sharing of farm and farmer data play a key role in this platform. The FDIS platform has the potential to make the agriculture sector more dynamic and increase its contribution to sustainable development in low- and middle-income countries.

However, the implementation of FDIS requires consideration of issues that are essential for the sustainability of the platform and the agricultural services offered to farmers. Indeed, farm data management has become a topic of interest in recent years, raising new challenges such as data ownership and sovereignty, data quality, and legal issues relating to data protection. In addition, the implementation of FDIS could face the challenges of digital illiteracy among farmers and other stakeholders, network coverage, particularly in rural areas, and the lack of young people in agriculture. Therefore, we are calling on local governments, non-governmental organizations, and international partners to work together to alleviate the challenges of harnessing the full potential of digital technologies in agriculture. Areas for collaboration include digital literacy training, the development of good policies, infrastructure development, particularly in rural areas, and encouraging young people to invest in agriculture.

This paper is a steppingstone for future research and development of the platform. FDIS has been developed in the context of the Tanzanian agricultural system, which is similar to that of many other developing countries. Therefore, future research could focus on examining the scalability of the FDIS platform in the context of other countries. Furthermore, we recommend that future studies explore technological advances that could further enhance the FDIS platform. For instance, by looking at AI and the IoT, the FDIS platform could improve precision agriculture. This also provides an opportunity to examine the long-term impacts on smallholder productivity, income, and environmental sustainability, which is valuable for further development.

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