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A decision supporting algorithm for improving sunflower production amidst changing weather in the Singida Region, Tanzania

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Abstract
The purpose of this study was to design decision support algorithms (DSA) that will aid sunflower farmers in the Singida Region in managing the risks associated with weather variations and consequently improve crop yields. Overall, sample size of 80 respondents was used including farmers with smart and feature phones, agricultural extension officers (AEOs), and meteorologists, informed the study. Using design science methodology, the decision support algorithm was designed and validated in this study. As revealed, farmers who use both smartphones and feature phones are extremely used the Decision support algorithm. The decision support algorithm provided in this study integrates smart and feature phone elements that were overlooked in comparable, prior systems and algorithms. The designed DSA processes and translates information about a predefined set of daily activities of sunflower farmers for making decisions. The farmers currently will not rely exclusively on the web-based system because internet connectivity is a major challenge in Tanzania's rural areas.

Keywords: ICTs, decision support algorithm, smart-feature phone, technology supports, productivity

Introduction

Agricultural production in Africa is significantly impacted by adverse weather shifts owing to variability (Stevanovi'c *et al.*, 2016) [17]. The continent's vulnerability is attributable to several challenges, including extreme poverty, limited employment opportunities, and a lack of sustainable development (Churi *et al.*, 2013; Nhemachena *et al.*, 2020) [1, 16]. For instance, it is anticipated that agricultural production in the African region will decrease by 15% to 50% (Nhemachena *et al.*, 2020) [16]. Insufficient strategic efforts are geared towards persuading small-scale farmers and others to embrace innovative mitigation strategies (Churi *et al.*, 2013) [1]. Therefore, it is critical to comprehend weather change management strategies and the facets that farmers consider when making decisions in farming varieties of crops including sunflowers, which are popularly produced in semi-arid regions.

Approximately 50.2 million tonnes of sunflower seeds are produced worldwide (FAO, 2020) [8], with a harvested area of about 27.8 million hectares. Europe leads the world in sunflower seed production with 36 million tonnes produced, followed by Asia (6 million tonnes), America (4.9 million tonnes), and Africa (2.4 million tonnes). The Russian Federation is the world leader in sunflower production with 13,314,418 tonnes, closely followed by Ukraine with 13,110,430 tonnes. With 390,000 metric tonnes or 55.8% of the entire commercial production, South Africa is the continent's top producer (TABD, 2019; Chacha, 2021) [19, 4]. Tanzania produces 35% of the total sunflower production in Africa, making the nation the second-largest producer of the crop (FAOSTAT, 2017) [9].

Tanzania is one of several countries that cultivate sunflower oilseeds, which are then processed into by-products that are fed to livestock and used as a raw material in the production of cholesterol-free edible cooking oil. Approximately 13% of the world's edible sunflower oil is produced in Tanzania (Douglas and Yoshiyasu, 2011) [5]. Sunflower thrives in the arid climate of the Central Corridor, unlike other crops like maize and wheat. Initiatives are in place to improve sunflower production in Tanzania; for instance, the Tanzania Agricultural Development Bank (TADB) recently issued a TZS 1.3 billion cheque to 458 Agricultural Marketing Co-operative Societies (AMCOS), recognizing the importance of sunflower production in Singida Region sunflower agriculture initiatives (Chacha, 2021) [4].

Although sunflower oilseed production is widespread across Tanzania, the Singida Region's production is significantly affected by adverse weather conditions.

Farmers in Africa, particularly sunflower growers in Tanzania's Singida region, are confronted by the hostile impact of weather variability (Stevanovi'c *et al.*, 2016 and Benedict & Majule, 2015) [17, 2]. Weather changes harm rice, maize, coffee, and sunflower production due to limited knowledge and appropriate information on which farmers rely when making decisions (Nhenio *et al.*, 2019) [14]. While a small number of farmers rely on radio and television stations, the majority, particularly in the Singida region, make farming decisions using conventional and local methods, including indigenous knowledge and intuitive prediction (Nhenio *et al.*, 2019 and Churi *et al.*, 2013) [14, 1]. Even though these strategies have historically worked, the recent extreme weather change conveys the need for technological innovation. Therefore, designing an algorithm-capturing mobile technology is essential to aid farmers in the Singida region of Tanzania in making decisions, accessing agricultural information, and sharing decision-making strategies and practices.

Jones *et al*. (1998) [10] assert that to create strategies or policies to achieve their goals, agricultural decision-makers at all levels need an extensive amount of information to better comprehend the implications of their decisions. For instance, it is critical to provide weather forecast information to sunflower farmers to respond to weather changes accordingly and make better agricultural decisions (Nhemachena *et al.*, 2020) [16]. Ad hoc seasonal weather forecasts are now issued by several meteorological agencies in the Singida region, which have historically and insufficiently concentrated on a broader coverage of sunflower growers and their specific needs (Churi *et al.*, 2013) [1]. ICTs must be employed as a contemporary innovation to improve decision-making among sunflower growers in the Singida region by facilitating knowledge and communication exchange of meteorological information.

One of the uses of information and communication technology (ICT) is to enable sunflower farmers to better share agricultural knowledge and disseminate weather information. Sunflower farmers currently receive information through a range of existing dissemination channels and strategies, including radio, television, in-person conversations, and email (Nhenio *et al*., 2019) [14], to support their farming decisions. However, these techniques fall short of adequately supporting sunflower farmers to carry out their farming activities effectively and efficiently. The use of contemporary and inventive technologies to support interactive communication among agricultural stakeholders has been insufficient (Churi *et al.*, 2013 and Nhenio *et al.*, 2019) [1, 14]. This study sets out to design an algorithm that supports decision-making to aid sunflower farmers in Tanzania's Singida region practice farming activities efficiently, amidst adverse weather shifts.

Globally, existing algorithms, systems, and models support agricultural sector production and these include the Agricultural Production Systems Simulator (APSIM) Gaydon *et al.*, 2011) [9], the web-based decision support system (Soyemi & Bolaji, 2018) [20], and the Decision Support System for Enhancing Crop Productivity of Smallholder Farmers in Semi-Arid Agriculture in Tanzania (Churi *et al.*, 2013) [1]. The primary goal of the current methods is to support agricultural production. However, they face several challenges, such as primarily using SMS to distribute information from weather sources without contextualising it to the daily activities of farmers (Soyemi & Bolaji, 2018) [20]. Additionally, the data sets used were not from Tanzania; rather, they originated from other countries such as Bangladesh, and others. Thus, the system or algorithm may not function as envisioned (Soyemi & Bolaji, 2018) [20]. Additionally, no offline text was used; hence, the lack of internet access in the majority of developing countries such as Tanzania was not considered (Churi *et al.*, 2013) [1]. Therefore, to address the issues raised by the existing systems and algorithms, this study designed a feasible support algorithm for sunflower production among farmers in the Singida region.

Even though sunflower products in the Singida region significantly contribute to household income, small-scale farmers are facing low crop yields, attributable to ineffective decision-making processes (TABD, 2019 and Tripath *et al.*, 2022 and Zilihona *et al.*, 2013) [18-19]. The current decision-making tools, such as algorithms, rely on farmers having smartphones and internet connection, yet the majority of farmers possess feature phones and lack internet access. Additionally, current systems do not include all crucial decision-making components in a way that allows them to deliver information about options independent of actual agricultural activity. Currently, farmers use local indicators to predict the forthcoming season's features and organize farm management. In contrast to new technologies, farmers assume those traditional knowledge systems, which have developed through generations, are safer, and less risky (Masere & Worth, 2021) [13]. However, since these systems were not designed for this purpose, continual dependence on them renders it difficult for farmers to adapt to weather variations. In light of this, this study designed an algorithm that supports farmers in the Singida Region in making informed decisions in the face of major weather shifts in relation to series of farming activities.

This study is significant in general because, for example, through the developed and validated decision support algorithms (DSA), both farmers with smart and feature phones benefits not only from the context of Tanzanian rural areas, but also from other rural areas in developing countries, including Africa, that have been affected by weather changes. This is because the DSA assists farmers with feature phones and smartphones in making decisions depending on their set of farming activities, independent of the availability of internet connectivity in remote locations. Farmers considerably employ the informed decision information from DSA to boost productivity of sunflower and other crops farmed in areas with similar characteristics to the Singida region of Tanzania.

2. Materials and Methods

The current study was conducted in Tanzania's central region of Singida. The study area was purposely selected because it is the area where sunflowers produced more compared to other regions in Tanzania. Small-scale farmers are the major producers of sunflowers in Singida, and they are the most susceptible to weather variations (Churi, 2013) [1]. The study involved nine (9) villages in two districts that are prominent in producing sunflowers. Simple random sampling techniques were used to select 80 respondents and 72 of these were farmers

(3 smartphones and 69 users of feature phones); six (6) were extension agents; and 2 were agrometrologists.

This study used the design science method for generating solutions to problems, advancing knowledge, evaluating designs, and communicating findings to the right audiences as recommended by Kussul *et al*. (2022) [12]. Prototyping was employed in the system design for this investigation. This methodology enabled the researcher to test the algorithm solution, as some of the user requirements were not well defined. Prototyping was used to explore and manage ambiguity in the process of designing the DSA. In some cases, the DSA was only partially designed to determine whether it was a viable solution. It enabled end users to fully participate in prototype development, thus enhancing system acceptability. The decision support algorithm (DSA) was designed and practically validated using the design science approach while interviews with AEOs and meteorologists were conducted to empirically validate the algorithm.

3. Results and Discussion

This section presents and discusses the results of the development of the algorithm for making informed decisions. The results of the decision support algorithm (DSA) design, including the DSA architecture, architectural implementation, and decision support, algorithm evaluation, are also presented and discussed in this section. As above, the findings of this study will have a significant impact on other farmers who grow different crops in the area and are not as reliant on internet connectivity as the Singida region.

3.1. Proposed DSA Architecture

The designed DSA for boosting sunflower production in the Singida region is graphically represented in Figure 1 below and it operates as follows. Users must first download and save the DSA, which is a web-based application system to their smartphones. When their mobile phone numbers are registered, those without smartphones can communicate with the system by receiving plain text messages sent to them. The web-based system, an API (Application Programming Interface), and a Short Messaging web-based System engine make up the DSA's backend (SMS Engine). The super users are in charge of providing all customers with the necessary information and have access to all resources from the backend through the APP (farmers).

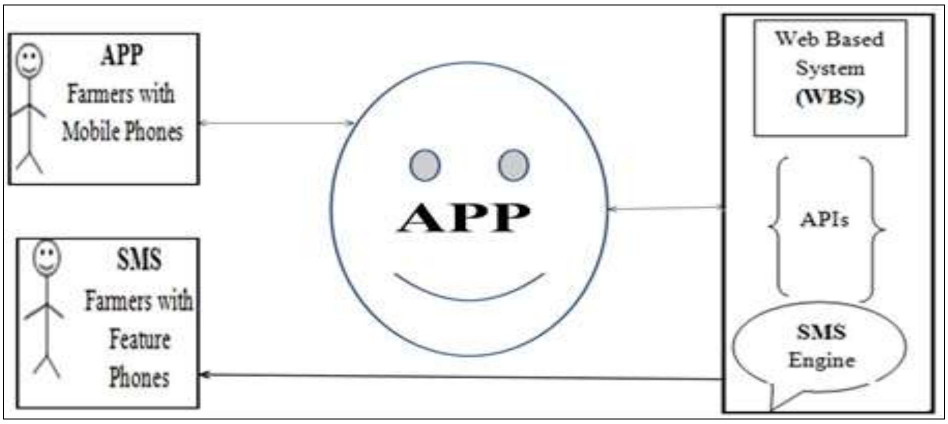

Fig 1: DSA Architecture (Drawn by Researcher, 2022)

Figure 2 depicts the results of the database, which was designed using the MySQL database management system (DBMS). The database was designed to store both predefined data and rain intensity after classification.

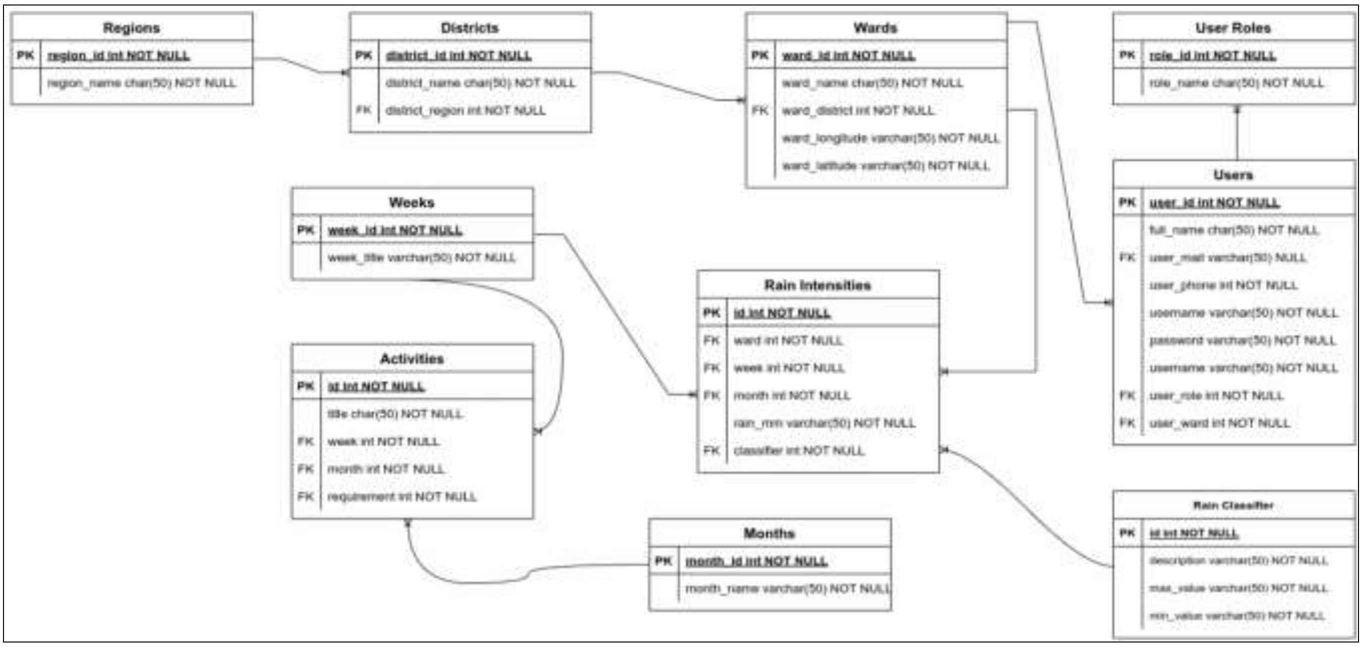

Fig 2: Entity Relationship of DSA (Researcher Design 2022)

Furthermore, the database captured and stored the predefined data on daily sunflower activities in the Singida region, and information comparisons before dissemination to farmers. A week ID field, for example, is included in the rain intensity entity to provide a mapping between rain intensity and the specific week that the rain will fall. Using this information, farmers forecast when to prepare land, cultivate it, or apply fertilizer. According to this design, if a farmer knows how much rain is expected in a given week, they can request advice about the type of activities they should undertake about the amount of rain. The DSA then compares the two circumstances and determines an appropriate course of action.

3.2 Implementation of the DSA

Another outcome of this research is the DSA implementation architecture (depicted in Figure 3) which is split into two parts namely: the front end and the back end. A client serves as the system's front end, and a web server serves as its back end. Sunflower growers and extension agents use both a text-messaging feature and a mobile application. The farmer can take action on activity Z in week X of the month Y if the favourable weather condition Q is met owing to the system's analytical backend and front-end functions. The second section, namely decision, contains some API queries for reading weather data from various sources including TMA as input to DSA, which is the monthly or weekly rain amount or quantity. This raw data is classified using pre-defined and database-stored criteria. Furthermore, the weather data stored in the database as shown in Figure 2 was compared to the seasonal sunflower activities performed by Singida sunflower farmers, which were also pre-defined and stored in the database. The DSA compares the amount of rain recorded for a specific ward to the programmed classified amount of rain. The third component is information dissemination (output), in which the second part decision automatically disseminates information about the status of weather.

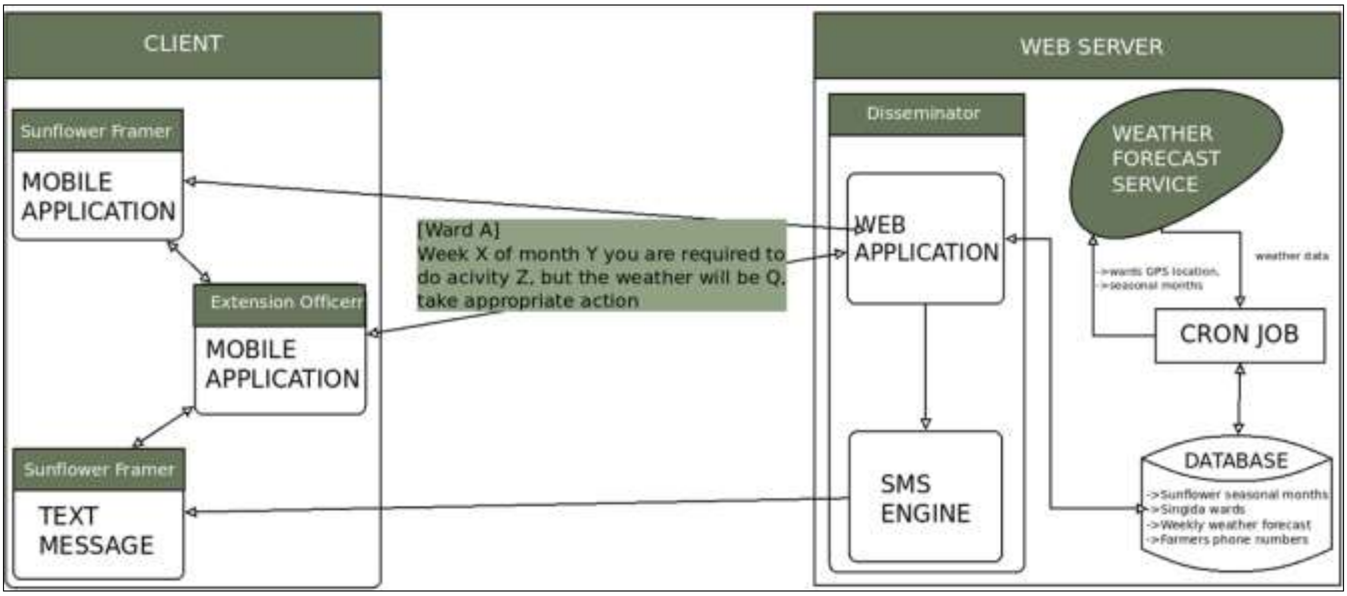

Fig 3: DSA Implementation Architecture (Researcher Design, 2022)

On the back end (server side), the DSA functions in the following phases: Stage I: The TMA and other sources, including the DSA, are automatically consulted for weather information. Stage II: The DSA categorizes generated data (raw data) using predefined classifiers as low, cloud, moderate, and heavy. Stage III: The system stores the predefined practices for growing sunflowers and the categorized data. The database includes weeding, planting, and land preparation tasks. Stage IV: Comparison and Dissemination; the DSA compares the weather data that has been stored. Proceed through a predetermined series of sunflower cultivation activities before displaying. The app requests this information about a specific ward.

The DSA functions in the following ways on the front end (client side): The program automatically locates the ward when the user launches it. The app searches the database for the ward if it already exists and displays the results. The program prompts the user to select an award from the database's list of awards if the specified ward is not readily available. The software then searches the database, forwards the information, and displays it after receiving the ward name. It should be mentioned that the mobile app matches the stored meteorological data to a predetermined set of sunflower farming operations before providing information to the user upon request (for example, if at ward x, there is minimal rainfall, start field preparation). Users with feature phones who have registered with their numbers and wards receive text messages, as shown in Figure 4, informing them of the appropriate course of action concerning the situation of the rain.

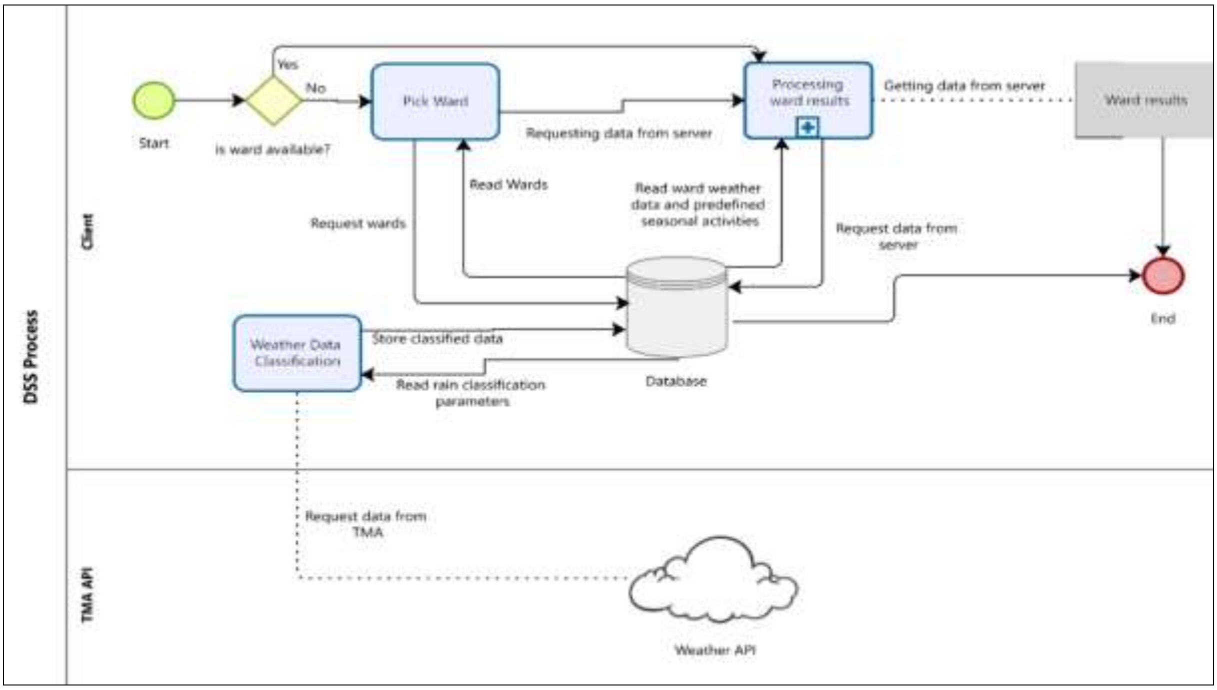

Fig 4: Decision Support Algorithm Process (Researcher Design, 2022)

Figure 5 is an illustration of how DSA operates in principle. The decision-making and the registration features are the two primary elements of the devised algorithm as shown in Figure 5.

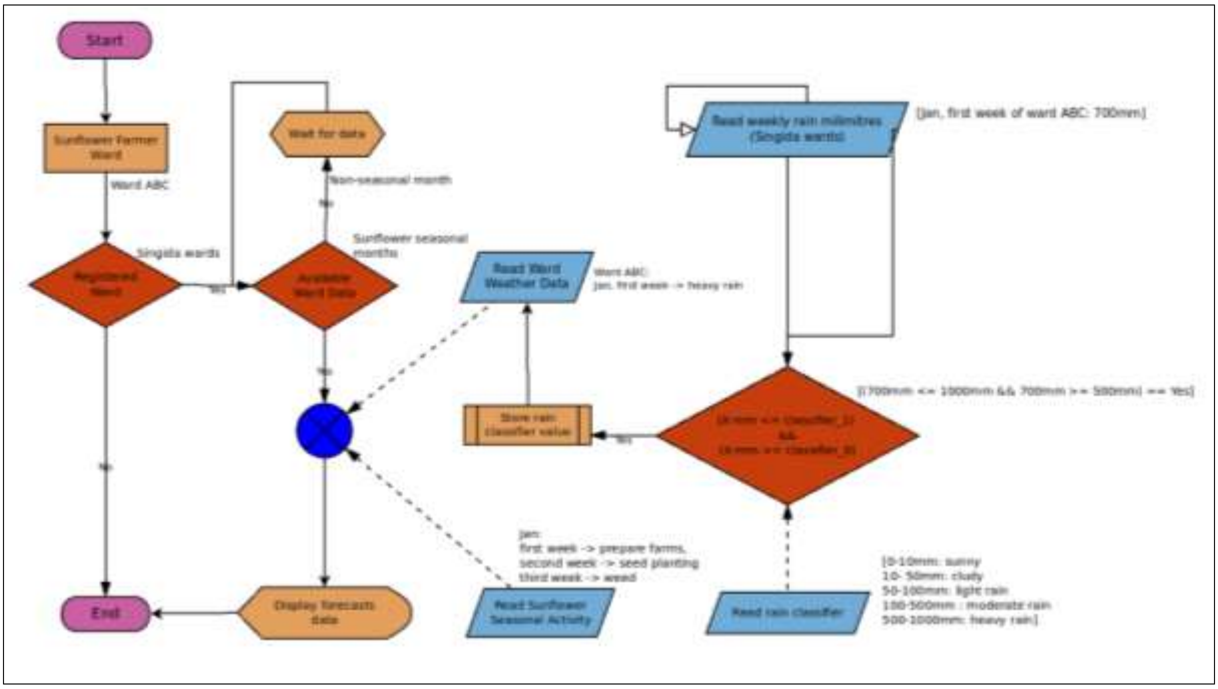

Fig 5: How Decision Support Algorithm Works (Researcher Design, 2022)

The registration feature also has two main categories, one for smartphones and the other for feature phone users. Smartphone users have to download the software and launch it by simply typing their Ward's name to begin interacting with it. AEOs use the mobile number and ward name to register users with feature phones.

There are queries for reading ward weather data from multiple sources, including the Tanzania Meteorological Agency (TMA). The weather data includes weekly rainfall anticipated amounts, classified rainfall quantities and the activities to be undertaken depending on the state of the rainfall intensity as shown in Figure 5. The algorithm determines the type of activity to be performed at a specific ward by comparing the quantity of rain observed and classified for a specific ward with the established daily activities, information for use and then subsequent action is conveyed.

3.3. DSS Evaluation

It was crucial that consumers experienced the newly designed product during this phase and offered input, which enabled the system's improvement. Iterations and modifications based on user feedback during this phase led to a viable product. Involving consumers at every level of product development was one method for promoting the usage of digital technologies. Because users are the main stakeholders in the system, this study used the approach to guarantee both the usability and acceptance of the DSA. The DSA was evaluated by sunflower growers in two different wards and was improved according to their usability suggestions.

The application instantly requests a password when launched by smartphone users. If the ward is present, the app searches the database, forwards information, and displays the decision. The algorithm prompts the user to choose ward from the database's list of wards if the specified ward is not accessible. The app searches the database, forwards information, and presents it after retrieving the ward name. The mobile app offers user information upon request after matching the stored meteorological data to the present set of sunflowers in a series of farming activities, as shown in Table 6. The app then makes decision on the next course of action according to the current status of the amount of rain. For instance, at Kitenkete and Kinampanda wards, farmers may acquire information through their smartphones based on the results presented in Table 6.

Table 6: Evaluation results of DSA in relation to rain status in two wards of the Singida

WARD	Receiver Number	Week	Status of Rain	Activity to be done
Kitenkete	+255713285519	1st week -Oct	moderate	No activity
		2nd week-Oct	cloud	Start weeding
		3rd week-Oct	Heavy rain	No activity
		4th week -Oct	Light rain	No activity
		1st week-Nov	Sunny	No activity
		2nd week-Nov	Cloud	Apply fertilizers
		3rd & 4th week-Nov	Heavy rain	No activity
		1st week-Dec	Moderate	No activity
		2nd week-Dec	Heavy rain	No activity
		3rd week-Dec	Moderate rain	No activity
		4th Week-Dec	Heavy	No activity
WARD	Receiver Number	Week	Status of Rain	Activity to be done
Kinampanda	+255744829002	1st week -Oct	moderate	No activity
		2nd week-Oct	Heavy rain	Start weeding
		3rd week-Oct	Heavy rain	No activity
		4th week -Oct	Heavy rain	No activity
		1st week-Nov	Light rain	Apply fertilizer
		2nd week-Nov	Light rain	Continue with fertilizers
		3rd & 4th week-Nov	Moderate rain	No activity
		1st week-Dec	Moderate rain	No activity
		2nd week-Dec	Moderate rain	No activity
		3rd week-Dec	cloud	No activity
		4th Week-Dec	cloud	No activity

Table 7 displays the application programming interface (API) test and validation results for the DSS's operations. Farmers with non-smartphones receive text messages after registering their mobile numbers and wards, as illustrated in Table 7. The SMS is delivered over the API, and the status is clearly displayed in Table 7. The results reveal that even non-smart people can get SMS messages describing what should be done in light of the present rain status. The SMS engine interface of the DSA was used to monitor and analyze communications amongst famers utilizing feature phones. Participants were also asked if they had received SMS messages in response to the DSA requests they had made. Farmers gave favorable feedback and asked for more information.

Table 7: Validation results of SMS status for Non-smartphone Farmers Using API

Date & Time	Direction of SMS	Sender Number	Receiver Number	Number of Segments	Status of SMS
2021-11-15 8:00:08 UTC	Outgoing API	(239) 237-3298	+255713285519	4	Delivered
2021-11-15 8:00:08 UTC	Outgoing API	(239) 237-3298	+255784727735	4	Delivered
2021-11-15 8:00:07 UTC	Outgoing API	(239) 237-3298	+255744829002	4	Delivered
2021-11-15 8:00:07 UTC	Outgoing API	(239) 237-3298	+255713285519	4	Delivered
2021-11-15 8:00:13 UTC	Outgoing API	(239) 237-3298	+255784727736	4	Delivered

4. Discussions

The needs of farmers in the Singida region, where access to agricultural information for well-informed decision-making was limited, served as the driving force for the development of the algorithm platform. Farmers in Tanzania were able to request meteorological information from the Tanzania Meteorological Agent (TMA) decision support system by using straightforward, reasonably priced smart phones and feature phones.

When it comes to the pre-programmed set of activities and the weather or rain, farmers can utilize the APP to communicate with the system and receive SMS notifications that are sent to them in plain language. The findings of (Masere and Worth, 2021) [13] that emphasized the use of APP to enhance information exchange among farmers on agriculture and advised that there should be a technology that can be used by both farmers with feature phones and smartphones have also been used to support this. The study's conclusions showed that farmers who use feature phones or smartphones have advantages while utilizing DSA rural areas. Nhenio *et al.* (2019) [14] and Tripath *et al.* (2022) [19] have concurred with the study's findings, stating that most farmers own feature phones and are proficient in using the DSA.

Based on the findings of this study, a decision support algorithm was developed that allows farmers of all stripes to manage and access weather forecast data using feature phones and smart phones. The results of this study are corroborated by (Soyemi and Bolaji, 2018) [20], who contend that it is extremely difficult to provide farmers with information solely through online applications because most farmers live in remote areas with poor internet connectivity. According to the findings of this study, Nhenio *et al.* (2019) [14] and Masere and Worth (2021) [13] support the effectiveness of this approach in decision-making for increased productivity: linking farming operations to the amount of rain that is currently available.

According to the findings of this study, the database as part of the DSA is crucial since it stores a predetermined set of faming activities as well as the classified state of the amount of rain. Similarly, the findings of Soyemi and Bolaji (2018) [20], Churi *et al*. (2013) [1], and Tripath *et al*. (2022) [19], the data base serves as the component that facilitates queries of stored information by making comparisons for decision making. According to previous research, it is adequate for DSA to use SMS-based mechanisms to convey information from weather sources by contextualizing it to farmers' everyday activities.

TMA offered weather data throughout data collection; these data are frequently received over time and include daily, weekly, monthly, and annual weather forecasts; nonetheless, these data are inconvenient for farmers while making farming decisions (Inovia and Bretiginieres, 2020) [22]. The findings of this study differ from earlier studies in that they reveal that the farmer must be kept up to date on weather information at all stages of sunflower growth. This study made use of weekly weather data, and there are queries on the DSA for retrieving this data from the TMA and processing it using pre-defined parameters specified on the system to provide the user with clear and useful information so that they may make informed judgments. The findings of this study are comparable to those of Churi *et al*. (2013) [1], who proposed that farmers use satellite data to boost agricultural yield. Farmers must also be kept informed at all stages of crop development. Farmers require seasonal climate estimates prior to the start of the season in order to make strategic farm-level decisions that improve household food security and revenue.

This study discovered that TMA's credible meteorological information influences strategic farm-level decisions. Respondents used the information provided to select seeds, prepare land, and make crucial strategic decisions. Farmers' decisions to plant short-duration sunflower seeds were influenced by low rainfall estimates, according to this study. Irrigation proved to be the most effective means of adapting to unforeseen weather fluctuations. Inovia and Bretiginieres (2020) [22] confirmed these findings by revealing that depending solely on weather data, including TMA, had no effect on sunflower yield. According to Inovia and Bretiginieres (2020) [22], a decision support algorithm is required to convey processed information for decisions as well as to inform and compare weather information to farmers' normal operations.

The findings of this study suggest that the usage of AEOs is critical since they are specialists who can use the knowledge and aid fathers in making appropriate decisions. The TABD (2019) [19] reports back up the study's findings by applying AEOs to aid farmers in reinforcing the usage of DSA information. The algorithm identifies the type of activity to be conducted at a certain ward by comparing the amount of rain observed and classified for a specific ward with the predefined daily activities, and then conveys information for use and subsequent action. The DSA mechanism is similar to that discovered by (Soyemi and Bolaji, 2018; Nhenio *et al*., 2019; Churi *et al*., 2013) [20, 14, 1].

Sunflower growers in two separate wards assessed the DSA, and it was enhanced based on their usability comments, as proposed by Tripath *et al*. (2022) [19] and Kaur *et al*. (2022) [11]. The findings of this study are similar to those of Zilihona *et al*. (2013) and Kaur *et al*. (2022) [11], who suggested that additional research is needed to assess the benefits of basic, low-cost mobile phones for smallholder farmers in rural areas.

Conclusions and Recommendation

The use of ICTs to simplify decision-making among sunflower farms in a sequence of operations under changeable weather circumstances has the potential to have a significant impact on farmers' efforts to increase yields. According to the findings of this study, farmers in Tanzania can make informed judgments regarding a variety of agricultural activities by leveraging feature and smartphone phones to get weather forecast information from TMA through the use of DSA developed.

This can be accomplished by submitting queries or getting notifications. This is due to the fact that Tanzania rural areas' are restricted access to internet connectivity. Farmers in rural areas are more inclined to acquire and use technology that is perceived as advantageous for achieving performance goals as they seek to boost productivity. DSA will be valuable as a technology if it assists farmers in making informed decisions and bridges knowledge gaps, allowing them to make better decisions concerning weather changes, resulting in greater farm productivity.

Improving the amount and quality of sunflower output under changing weather circumstances is one thing; when and where to sell their products, on the other hand, remains a difficulty, most likely necessitating suitable and integrated technology to give marketing information for optimal outcomes. Future academics should think about including marketing information and weather changes into the DSA to boost production and selling as critical components of the farming supply chain. Furthermore, agricultural DSA development should focus on connecting research inputs and making research findings available to farmers and other agricultural operators.

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