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Digitalisation of agriculture in Zimbabwe: Challenges and opportunities

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ABSTRACT

To provide insights on the potential of digitalised agriculture in improving output exploring its challenges among the smallholder farmers in Zimbabwe. Literature on the application of digital agriculture was gathered. The research from countries with same or similar Zimbabwean agricultural conditions were then selected in this review. Notably, there are disparities in complexity and level of digitalisation between the developing and developing countries. Unlike in the developing countries, digitalised agriculture is more advanced and highly applied in developed countries. In Zimbabwe specifically, application of digitalized agriculture is skewed towards the commercial farmers than the smallholder communal farmers. The application of digital agriculture e-agriculture) has gained momentum world over in recent years but still low in Zimbabwe where it is more common to the highly literate and resource endowed farming communities than poorly resourced farmers. The digital agriculture is a useful modern technology applied in agricultural production systems in enhancing precision application of resources e.g water, fertilizers, pesticides etc increasing the technical efficiency that translates into high farm outputs (both quantity and quality). Machine Learning (ML) which is a subset of Al, developed to handle various challenges faced during the formation of knowledge-based farming systems. Therefore, digitalisation of agriculture ranges from the use of simple offline programmed production systems installed into information and communications technology (ICTs) gadgets to complex algorithms run by computers. In advanced digitalisation, algorithms are applied in different agronomic practices of crops as well as in animal husbandry.

Contribution/Originality: This review provides a relatively new dimension in enhancing farm efficiency among the smallholder communal farmers in Zimbabwe through the use of ICT.

1. INTRODUCTION

Agricultural productivity in the Sub-Saharan Africa (SSA) region is far below potential (Bjornlund, Bjornlund, & Van Rooyen, 2020). The major reasons are unproductivity soils, pests and disease, drought and poor crop and animal management practices. Efforts should therefore aim at increasing current production levels so as to stave off food and nutrition insecurity (Gitz, Meybeck, Lipper, Young, & Braatz, 2016). The SSA region must achieve these targets while simultaneously adapting to climate change. Climate change has already impacted agricultural production. The impact of global climate change on agriculture forces farmers to constantly adjust to abnormal or atypical weather like poor rainfall patterns, which means high risks of poor yields of summer crops (Gitz et al., 2016). The effects also involve abnormally hot summers and very cold winters, or vice versa. Hence, there is a need for agricultural transformation in Africa. Intensive agriculture is expensive to the farmers, mostly the smallholder farmers as they lack the finance to purchase the production inputs. Farms in the developed countries can be managed by very few people but still with high output due to the application of technology e.g the e-agriculture.

Comparatively to the developed countries, there are low technical efficiencies and high manual labour-intensive practices among the smallholder farmers causing reduced agricultural output (Gitz et al., 2016). Therefore, it is important to reduce pressure on the agricultural sector and optimize the effectiveness of agricultural practices among the smallholder farmers. Currently, the agricultural production systems are transforming from the traditional systems into precision production world-over (Gayatri, Gasso-tortajada, & Vaarst, 2016). This has seen a gradual increase in production output to meet human food demands. Unfortunately, the agricultural transformation rates vary across different countries where it is faster in developed than developing countries (Briones & Felipe, 2013). Nevertheless, the developing countries are worst affected by the poor agricultural management systems hence most farmers are vulnerable to acute food shortages. They are also characterised by high rates of natural resources depletion and environmental degradation. Suggesting that rapid agricultural transformations are required in these if they are to attain food security and clean environments.

One of the most promising and efficient ways to increase agricultural production among the smallholder farmers in Zimbabwe is through digitalisation of agriculture. Agri-technology and precision farming, which can be referred to as digital agriculture, is a new scientific field that uses data intensive approaches to drive agricultural productivity (Singh, Ujinwal, & Singh, 2022). In digital agriculture, data is generated using current agricultural processes and obtained from various sensors that allow a better appreciation of the operation environment (an interaction of dynamic crop, soil, and weather conditions) Figure 1 and the procedure itself (machinery data), leading to more precise and faster decision making (Benos et al., 2021). However, literature has showed a wide gap on the level of digitalisation and complexity of agriculture between the developing and developed countries (Gayatri et al., 2016; Singh et al., 2022). The digital agriculture in the developed countries is more complex and advanced compared to that in the developing countries. It is therefore relatively easy to characterise the status of digital agriculture in developed countries than developing nations. Currently, the applications and complexity of digitalised agriculture in most developing countries e.g Zimbabwe, Malawi and Mozambique are still unclearly defined. Therefore, this review aimed at providing insights on the level of digitalisation in Zimbabwean agriculture production exploring the challenges and opportunities in enhancing crop productivity among smallholder farmers.

Technology has been successfully applied in various industrial sectors where it is critical to affecting change and driving development world-over (Tsan, Totapally, Hailu, & Addom, 2019). The technology breaks boundaries hence connect countries closer together, minimizing barriers to trade and provides an opportunity to digital native agribusiness innovation. Therefore, digitalisation of agriculture especially for the smallholder farming sectors in developing countries could transform the agricultural productivity, increase profitability and resilience to climate change (Bahn, Yehya, & Zurayk, 2021). Nevertheless, rate of digitalising the agricultural production has been slow to embraced by the smallholder farmers that produce 80% of Africa's agricultural output (Tsan et al., 2019). These smallholder farmers are faced with daunting challenges in their production that includes, poor soil fertility, climate change and drought to mention just a few, hence yield is continuously declining. However, there are opportunities for boosting agricultural productivity among the smallholder farmers by integrating modern technologies in agriculture. Zimbabwean agriculture is expected to be a trillion-dollar industry by 2030 but to achieve this, use of technology the production is key (Musungwini, 2018). Agricultural innovations that enhances greater efficiency, sustainable productivity, yield and income are required. Unfortunately, the digitalisation of agriculture in Zimbabwe is still at infant stages and ill-defined.

Digitalization of agriculture offers unlimited possibilities that guarantee sustainability, highest crop productivity, and a safe environment among smallholder farmers (Bahn et al., 2021). Timely and accurate decision making are key in agriculture production. Traditionally, farmers make decisions e.g how much and when to apply fertilizer based on a mixture of rough measurements, experience and recommendations. This delays decision making process that result to low precision causing inefficient use of resources and ultimately low yield. In contrast, decisions made from a digital agriculture system have high precision because data is collected more often and precisely, using peripheral sources (such as meteorology information) (Vangala, Das, Kumar, & Alazab, 2021). The digital agriculture system has strength in combining the data, analyses and interprets it so that a farmer makes a more educated and suitable decision. The decision is also quickly implemented through the use of advanced machinery and robotics, and real time responses which are available to the farmer resulting in increased farm output.

Digitalisation of agriculture involves collecting data by sensors, communication networks, Artificial Intelligence (AI), Unmanned Aviation Systems (UAS), robotics and other advanced machinery and frequently draws on the doctrines of the Internet of Things (IoT) (Shonhe & Scoones, 2022). Each and every one of the modules add something essential to science of agricultural production from data gathering, through to processing and management, also including supervision and direction. Different new insights that improve the nature decisions are made and implemented by this integration system Figure 1.

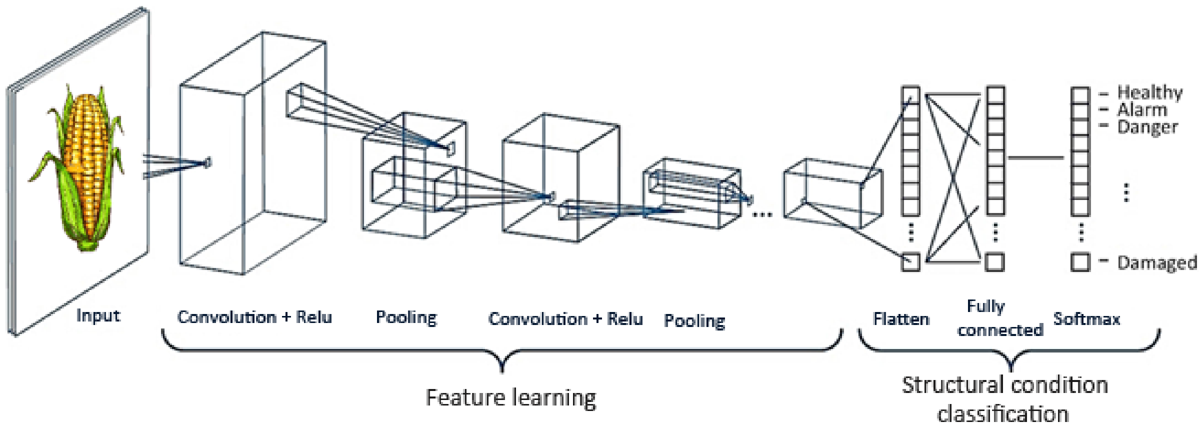

Figure 1. Machine learning (ML).

Source: Tabian, Fu, and Sharif Khodaei (2019).

Currently, the agriculture in the Zimbabwean communal farmers is digitalised mainly through use of cell phones to access farming information (Musungwini, 2018). The common digital agriculture innovations used in Zimbabwe include the Zimbabwe Farmers Union (ZFU) and Ecofarmer Combo programme and Econet Wireless championed. These avails weather-based insurance, farming advice for over 80,000 rural and communal farmers as well as real time location-based climate and weather information (Zimbabwe Centre For High Performance Computing, 2021). There is a positive increase in the way digital agriculture is used but uptake of current technology is normally capital intensive for communal farmers. There are various opportunities in the digitalisation of Zimbabwean agriculture but associated with some numerous challenges. Application of ML has been concentrated in few well financed commercial farms especially under management of large multinational companies (Shonhe & Scoones, 2022). The ML has been successfully used in irrigation and pest control (Vangala et al., 2021).

1.1. Opportunities for Digital Agriculture in Zimbabwe

Digitalisation of agriculture among the smallholder farmers can transform the production systems and make them more productive, more consistent and use of time and resources more efficiently. Although digital agriculture can be applied in all agricultural activities, this paper looked at the potential of digital agriculture with a bias towards crop production.

1.2. Crop Management

Zimbabwe's economy is agro-based but crops contribute to a larger (>60%) proportion compared to livestock (Musungwini, 2018). There are many aspects involved in crop management. Most of them derived from the union of farming methods such as managing the biological, chemical and physical crop environment with the aim of accomplishing both qualitative and quantitative objectives (Benos et al., 2021). Crop productivity is affected by many factors that range from climate, soil factors to management practices. The largest crop yield losses among the smallholder farmers is caused by poor crop management practices (Parwada, Chipomho, & Mapope, 2022). Integrating digital agriculture in the traditional farming practices can easy the crop management challenges among the farmers. Digital crop management could include disease detection, yield prediction, weed detection and crop quality. Digital agriculture can therefore raise the production levels and, consequently, increase financial income from agriculture (Benos et al., 2021). The below diagram illustrates precision agriculture in field soil moisture management Figure 2.

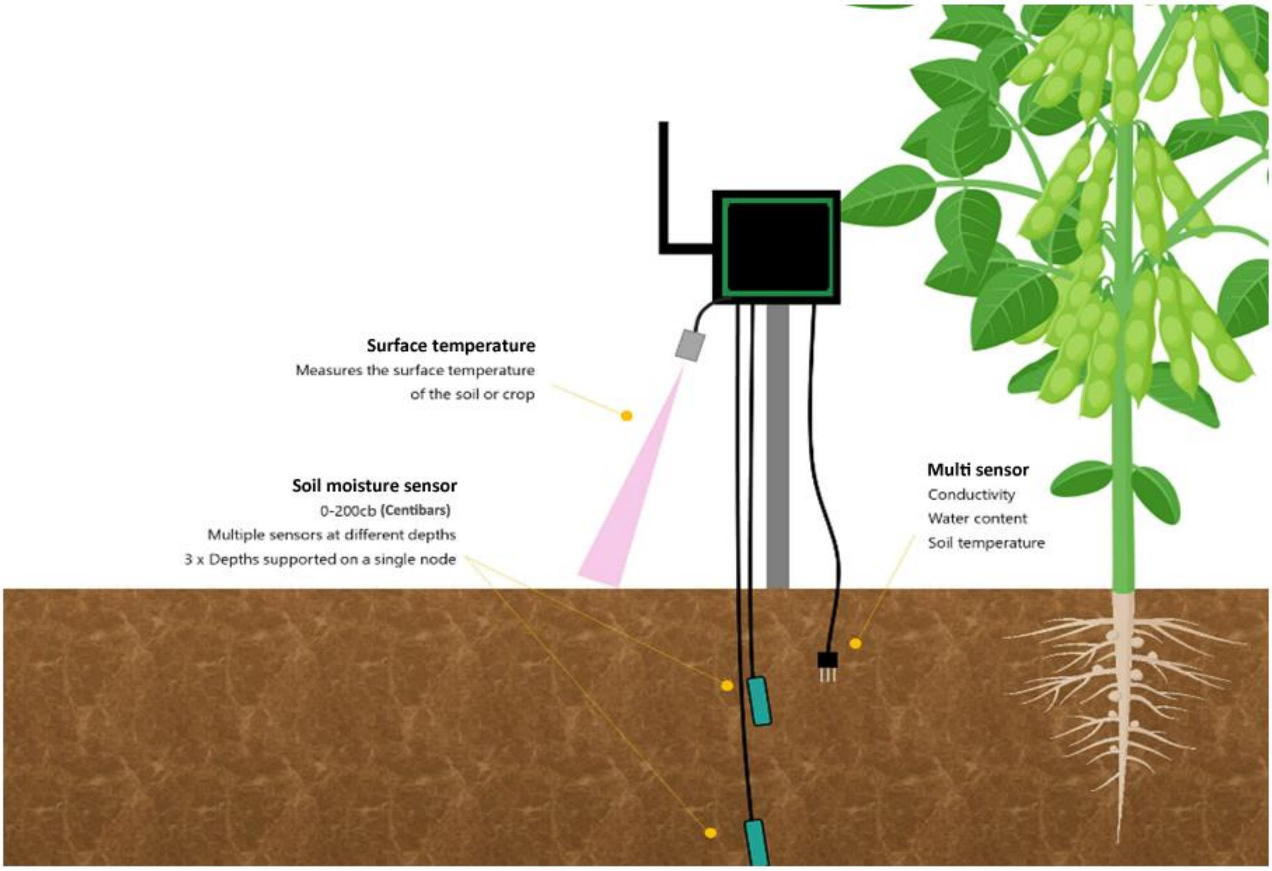

Figure 2. Internet of things (IoT) in agriculture.

Source: Entine (2020).

A large (>70%) proportion of communal farmers in Zimbabwe are located in the semi-arid regions (natural region IV and V) where rainfall is erratic and the soils are infertile, acidic with poor water holding capacity. Therefore, limited soil moisture and low soil nutrient content are major limiting factors of crop and pasture production in these drier regions (Parwada et al., 2022). Basing previously done researches, the IoT technology Figure 2 was successfully used in mitigating crop failure from moisture stress by wisely managing the little available water and increase yield under dry conditions (Amasyali & El-Gohary, 2018). Plants largely depend on water availability, so the agricultural sector constitutes the greatest percentage of consumers of fresh water on a global scale (Vangala et al., 2021). Due to deteriorating rate of soil moisture with negligible charge, there is a need to effectively and efficiently manage water so as to achieving a sustainable crop production (Benos et al., 2021). An improvement of water quality can be a result of effective water management, also including reduction of pollution and health risks (Thilakarathne, Bakar, Abas, & Yassin, 2022).

Precision agriculture is related to digital agriculture (Gorfu & Hiskias, 2001). It offers the possibility of attaining water saving through variable rate irrigation. This was archived through applying irrigation at rates, which were different depending on the field variability, on the basis of exact water requirements of distinct management zones, instead of applying a uniform rate in the entire field (Benos et al., 2021). To achieve both water saving and high yield it calls for the effectiveness and feasibility of the variable rate of water application. The variable rate water application depends on some agronomic factors such as soil properties, topography and the effect on the soil water (Eli-Chukwu, 2019). Efficient irrigation water management can be enhanced by evaluating and monitoring the status of crop growth conditions, soil water, and temporal and spatial patterns in the combination with meteorological monitoring and forecasting. This can be possible through use of the information and communications technology ICTs and remote sensing that provide images and pictures with spatial and temporal variability associated with crop growth parameters. Interestingly, arid areas are a challenging environment for water management, because underground water sources are largely utilized for irrigation, with precipitation only producing a portion of the total crop evapotranspiration (ET) demands (Benos et al., 2021).

The ML technology was applied in crop production and reduced cost of carrying out and monitoring farm work for large-scale farming (Gorfu & Hiskias, 2001). This is possible by combining the IoT and ML e.g tractors and combine harvesters can be deployed to perform highly specific tasks with precise accuracy. These tasks include harvesting or ploughing big farms (Eli-Chukwu, 2019). Harvesting huge quantities of crops and even vegetables faster than human labour can be obtained with the aid of artificial intelligent (AI) implemented tractors and intelligent robots (agribots).

1.3. Weather Forecasting

Unpredictable weather condition has contributed significantly to low crop productivity among the smallholder farmers. The farmers should have clue of the weather condition in order to able to plan crop management practices such as spraying, harvesting and ploughing. Digital agriculture can be used in weather forecasting which is one of the most important aspects in crop management. It is now difficult for farmers to rely on their local knowledge in weather forecasting due to climate change (Parwada et al., 2022). The ML was applied in the prediction of future weather patterns and this information was very useful in farmers' decision making (Gorfu & Hiskias, 2001). The ML uses large sums of data from the past called dataset, analyses the data and learns the weather patterns (Amasyali & El-Gohary, 2018). Once these are predicted, it becomes easier to figure out the best time for planting, fertilising, spraying and harvesting crops. This allows for better decision making to maximise crop yield hence becoming more cost effective. ML through weather predictions, prevents farmers from wasting scarce resources like water and fertiliser through precision farming (Thilakarathne et al., 2022). Predicting the nature of rainfall, for example, can enlighten farmers on the type or variety of crop to farm.

1.4. Yield Prediction

Basically, in modern agriculture, yield prediction is one of the most significant and perplexing topics. Farm owners, for example, can be helped by an accurate model to obtain educated management end decisions on what to grow towards corresponding the crop to the existing market's demands (Benos et al., 2021). The use of predictive analytics, powered by AI and ML is effective in predicting crop yield and future prices for agricultural commodities (Nair, 2019). Crop yield prediction is a very complex task that is determined by multiple factors such as genotype, environment, and their interactions. In turn, identifying such kinds of relationships mandates comprehensive datasets along with powerful algorithms such as ML technique. Data is collected from climate data, satellite images, soil conditions, pest attacks and diseases, to come up with data sets to be used in ML. The ML then uses Neural

Networks like Convolution Neural Network (CNN), Deep Neural Network (DNN) and Artificial Neural Network (ANN) to tackle this complex task (Alzubaidi et al., 2021a). Crop prediction yields before harvest aid farmers to make financial and management decisions. Optimized investments strategies and minimised risk can also be predicated if the prediction of future prices is accurate.

1.5. Disease Detection

Crop diseases are a great threat to agriculture by reducing yield quality and quantity at all levels of production e.g storage and transportation (Gorfu & Hiskias, 2001). Moreover, food security is compromised on a global scale due to risks introduced by crop diseases. A key component of effective and efficient crop management is timely identification of crop disease (Hassan, Maji, Jasiński, Leonowicz, & Jasińska, 2021). In the past, disease detection was piloted by expert field officers or agronomists, through field scouting. Hence, this procedure consumed a lot of time and heavily depended on visual inspection only. Modern technological improvements have enabled commercially accessible sensing systems with the ability to classify diseased plants prior to the symptoms are visible can spray at the affected portions in the field Figure 3. This saves money from crop failure and chemicals because in the traditional pest and disease management practice, the whole field is sprayed if few plants are observed to be affected. Recently computer vision has made impressive progress with the aid of Deep Learning and very Deep learning. As emphasized by Alzubaidi et al. (2021b) who utilised deep learning to identify cucumber leaf diseases. It was important to eliminate background before the model was trained because of the complexity nature of the environmental background. Moreover, for accurate disease diagnosis, there is a need for a large dataset for diseased plants as well as health plants for accurate image classification.

Figure 3. Drone technology.

Source: Entine (2020).

1.6. Soil Management

Soil, a heterogeneous natural resource, involves mechanisms and processes that are very complex. Precise information regarding soil on a regional scale is vital, as it contributes towards better soil management consistent with land potential and, in general, sustainable agriculture (Dixon, Taniguchi, Wattenbach, & Tanyeri Arbur, 2004). Due to problems like Loss of biological productivity, which is part of land degradation, better management of soil has become an area of tremendous interest. Other issues include, soil erosion (due to vegetation over cutting, over grazing of livestock, fallow periods that are unsuitable, and lack of balanced crop rotation) and soil –nutrient imbalance due to over use of compound fertilisers (Nair, 2019). Mentioning just a few components of useful soil properties can mean nutrient content, organic matter and soil texture. Laboratory analysis and soil sampling are traditional means of soil assessment. These methods tend to be time consuming, require a lot of effort and are generally expansive. Effortless and low-cost solutions for the study of soil spatial variability can be ensured by the use of soil mapping sensors and remote sensing. When the use of traditional data analysis methods is employed in data fusion and handling of such heterogeneous "big data", some drawbacks can be witnessed (Torky & Hassanein, 2020). A low cost and trust worthy for this specific task would be ML.

Artificial intelligence (AI) can help farmers monitor potential threats to agricultural productivity, for example, the occurrence of pests and disease which can be a difficult task to do manually, especially in large acreages (Nair, 2019). Satellite images, photographs from cameras, also from drones can be used to generate data that is essential to monitoring crop health. These images can also assist in detection of disease and pests that would harm the crops. Machine Learning (ML) can be used to identify defects and nutrition deficiencies. Internet of things (IoT) can be used to provide and generate data such as moisture levels or pH in soil. IoT sensors can measure soil temperature, NPK, volumetric water content, photosynthetic radiation, soil water potential and soil oxygen levels. This was the genesis of smart farming and precision farming.

1.7. Challenges for Digital Agriculture in Zimbabwe

Regardless of an increase in use and availability of various digital technologies in agriculture, smallholder farming communities in the developing countries are still lagging on use of ICTs. In Zimbabwe, the digital agriculture is mainly centralized on mobile applications but slow in implementing other AI technologies and innovations essential in commercial agriculture (Torky & Hassanein, 2020). There is slight use of high-end technologies that can improve agricultural production and value chain competitiveness among farmer e.g crop protection technology, soil and moisture sensors, drones, geographic information systems (GIS) and the global positioning systems (GPS). Digital agriculture has the potential to transform agricultural production in Zimbabwe but the method is still extremely recent, facts of forthcoming long-term profits are rarely obtainable and cost are high (Musungwini, 2018). That entails that to harness its nationwide adoption will need a consensus and collaboration across the entire value chain on how to win over these challenges. The following are some of the challenges of digital agriculture in Zimbabwe:

1.8. Lack of Region-Specific Datasets

The biggest challenge associated with digital agriculture is the availability of region-specific datasets. Most of the available datasets used may not be specific to Zimbabwe hence it becomes difficult to build, train and test any robust algorithms. Datasets contain a lot of images of data, which are used to train an algorithm. Normally training is done using CNN. The larger the greater the image quality in terms of resolution, the more accurate the training. The lack of specific datasets makes recognition by algorithms challenging hence preventing the effectiveness of datasets in digital agriculture.

1.9. Machine Learning (ML) Training Infrastructure

Computer vision dataset contains huge numbers of images. These images are put in classes so as to be trained on. High Performance Computing (HPC) normally used because the training process is very resource heavy. In Zimbabwe there is only one HPC located in Harare which is only used for academic purposes called (Zimbabwe

Centre for High Performance Computing, 2021). Training with a normal system with a normal computer can take days. The unavailability or restrictions of HPC means that ML operations are limited and crippled.

1.10. Copyright and Privacy Concerns

Images and data obtained from drones tends to give rise to privacy issues especially when training with these images. Already existing laws on copyright, privacy and data protection laws hinder ML from using drones and satellite images for smart farming (Niemitalo et al., 2021). In Zimbabwe one needs a drone license in order to operate a drone. The approval of the drone to a farmer depends on the nature of justification the farmer can produce so as not to infringe on privacy rights. The drones are dependent on the provided dataset. It is difficult to come up with the dataset if the license has not been approved so it is a challenge coming up with the dataset which will not be copyrighted at the moment.

1.11. Digital Literacy

Technology is a very alien concept to most farmers in Zimbabwe both commercial and smallholder communal farmers. Their line of work is generally slow and simple and does not rely on any computers. Most farmers have never even used a computer in their lives (Viatte, 2001). Farmers may not have the knowledge or skill set to use the available AI applications that aid in digital farming. Sustainable farming entails meeting the existing needs for food without comprising environmental health and economic equity (Torky & Hassanein, 2020). Sustainable farming is failing among the Zimbabwean due to the non-use of modern technology. The farmers miss out on the benefits of digital agriculture because of lack of knowledge and or application (Viatte, 2001). Some of the ICT challenges faced by the farmers in Zimbabwe are low digital literacy and high costs of mobile communication. The high costs of mobile internet is causing the mobile technology to be more of a luxury than a necessity (Zimbabwe Centre for High Performance Computing, 2021).

Many smallholder farmers in Zimbabwe do not have time and bandwidth to explore many of the available mobile and digital farming applications. Most of the information disseminating channels have reached their limits and are disintegrated that result in information asymmetry amongst the farmers (Torky & Hassanein, 2020). Therefore, it is imperative to ensure that the technology is cheaply available to many farmers and can be implemented in many ways so as to minimize the undesired effects.

1.12. Security

There exists a variety of key challenges that are increasing due to the nature of dependency on digital systems. If the agriculture sector is heavily dependent on a technology or system that is not secure enough, then an opportunity for coordinated large-scale agriculture warfare has the potential to start (Torky & Hassanein, 2020). Controlled systems could be hacked so as to either contaminate feed and water supplies, damage crop growth, and alter data to conceal issues could be used to damage harvests and negatively affect the ability of people to self-feed (Alzubaidi et al., 2021b). The initial outlay for adoption and development in conglomerate agricultural settings, due to falling costs, could be prohibitively high, discouraging innovation and usage. Understanding, sourcing, deploying, connecting and monitoring technology to create a one-time cost, efficient and effective system and particularly in areas that are not yet generally understood, may prove to be a substantial wall for some years to follow.

2. CONCLUSION AND RECOMMENDATIONS

Digital agriculture has a potential of improving farmers' production outputs in Zimbabwe. If well applied it can mitigate the impact of climate change on crop production by increasing precision of irrigation water management, disease and pest management and accurate weather forecasting. The use of AI enables farmers to quickly analyse and interpret big data e.g weather conditions, temperature, water usage hence making informed decisions. The digitalisation of agriculture is still low in Zimbabwe with very few farmers adopting the technology due to high internet costs and some digital agriculture machinery. In Zimbabwe, it is clear that the appetite for digital agriculture is burgeoning. However, without supportive measures e.g policies and investment there is a potential danger that the digitalization of agriculture will not expand to the poorly resourced farmers. We recommended the need for a well-coordinated implementation and rolling-out of the digital agriculture in Zimbabwe. The best agricultural management practices should be shared hence need for a collaborative approach in the scaling-up of digital innovations with a focus on increasing uptake by farmers.

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