



TOWARD ADOPTION OF DRIP IRRIGATION AND SOIL-MOISTURE SENSORS BY SMALL-SCALE FARMERS

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ABSTRACT

The semi-arid region of the world is occasionally affected by erratic rainfall and drought which threatens agricultural production and food security. This paper presents the outcome obtained from a review to provide proactive measures that will combat the problems of water scarcity through the adoption of sensor-based drip irrigation by small-scale farmers. The small-scale farmers constituted the larger proportion of the farming population in the region. The paper is centred on the general overview of irrigation practices, advances in irrigation systems, modelling irrigation and cropping Systems, coupling soil sensors with drip irrigation and their adoption. Factors that hinder the acceptance and adoption of sensor-based drip irrigation systems were reviewed and synthesized which include initial capital investment, farmers' awareness, risk perception and uncertainties, technical know-how, farm size and capital recovery. A simple framework for adopting a sensor-based drip irrigation system was developed. The building blocks of the framework include the dissemination of sensor-based irrigation to farmers, the creation of awareness among farming communities, and the provision of subsidies and credit. Others include the provision of policies and environmental standards and review of the price of water charges. This study will be useful to farmers, agricultural extension agents and policymakers in making decisions about the water resources planning and farming activities in the region.

Keywords: drip irrigation system, semi-arid, small-scale farmers, soil moisture sensors

INTRODUCTION

The semi-arid region of the world is characterized by high temperatures and low rainfall. The region has continued to experience erratic rainfall and occasional drought caused by climatic change impact (Medugu *et al.*, 2011; Zakari *et al.*, 2019). Also, the rate at which water demand is increasing in the region is frightening due to the ever-increasing human population and competition among water users. Moreover, the dry season farming activities (irrigation) in the region are mostly practised by small-scale farmers with low capital and technical skills. This led the farmers to resort to the conventional surface irrigation method known to have the lowest water use efficiency. These among other reasons further exacerbate the problem of water scarcity in the region. Small-scale farmers as defined by the International Fund for Agricultural Development (IFAD) are farmers with farmland size of less than 2 hectares. These farmers cultivate over 80% of the world's estimated 500 million ha of small farms (IFAD, 2013). Small-scale farmers provide about 50% of food production in the world and more than 70% in Latin America, sub-Saharan Africa, and South and East Asia (Samberg *et al.*, 2016). According to Samberg *et al.*, (2016) small-scale farmers contribute immensely to the economy of the farming communities, rural development and food security. Similarly, in Africa, small-scale farming constitutes about 80% of the farming activities with 33 million fragmented farmlands that are less than 2 hectares and are mostly cultivated by family members (NEPAD, 2013). In Nigeria, small-scale farmers form the majority of the farming population which also make-up about 80% of the Nigerian farmers and produced about 98% of the food consumed in the country except for Wheat (Mgbenka & Mbah, 2016).

Despite their population and contribution to both food security and gross domestic products (GDP), Nigerian small-scale farmers are faced with different problems that include a lack of awareness of technology of the modern farming, high cost of farm inputs, and lack of credit facilities just to mention

but few (Mgbenka & Mbah, 2016). These problems make the majority of the Nigerian small-scale farmers produce crops mainly on rainfed farming which is seasonal and the farmers become idle during the dry seasons (Enete & Amusa, 2010). Rainfed farming exclusively depends on low, erratic and inadequate rain received in the region which resulted in low yield and income for the farmers and hence, low social wellbeing (Sanni *et al.*, 2012). Presently, Nigerian small-scale farmers only irrigate 1% of their croplands which contributed to the ongoing food insecurity and exorbitant cost of farm produce as rainfed farming is affected by erratic rainfall and climatic change impact (Liangzhi *et al.*, 2018). Adoption of micro irrigation systems known to have the highest water use efficiency such as drip irrigation by small-scale farmers in the semi-arid region of northern Nigeria would reduce the risks and uncertainties associated with rainfed farming. Moreover, this will also allow more lands to be put into cultivation thereby, boosting food production and improving the economy of the country. Modelling developed by the International Food Policy Research Institute shows that about 1 million hectares of land can be adopted for irrigation by small-scale farmers in Nigeria and crops like Maize, Rice and Vegetables can generate more than \$600 million increased income for small-scale farmers in the dry season alone (Liangzhi *et al.*, 2018). Adoption of drip irrigation by small-scale farmers in the semi-arid region of northern Nigeria which has been declared a water-stressed region will help farmers to make the best use of the limited available land and water resources. The drip irrigation system coupled with soil sensors (sensor-based drip irrigation system) ensures effective irrigation scheduling and improves the efficiency of the irrigation system through reliable and optimum water application to the crop that can precisely meet the crop water requirement. This paper reports the outcome and knowledge gained from an extensive review of the relevant literature. The primary aim of this review paper was to propose a way forward for the adoption of a sensor-based drip irrigation

system in the semi-arid region of northern Nigeria. In addition, the paper recommended some measures and strategies on how sensor-based drip irrigation systems can be used by small-scale farmers since about 80% of Nigerian farmers are classified as small-scale thereby, addressing water scarcity issues and improving agricultural production and hence, food security in the region.

An Overview of the Irrigation Practices

The development of irrigated agriculture has undoubtedly boosted agricultural productivity and contributed to economic stability and made it possible to feed the world's growing population (Rosegrant *et al.*, 2009; Shanono, *et al.*, 2021). Irrigated crops are usually higher in yields than the crops produced under rainfed agriculture because water is optimally applied by putting climatic conditions into consideration (Li & Troy, 2018). According to Li & Troy, (2018) crop yields obtained through irrigation crop yields are on average 2.3 times higher than the yield produced under rainfed agriculture. Such an increment in yields of irrigated crops compared to rainfed crops demonstrates that irrigated agriculture will continue to play an important role as a significant contributor to the world's food security (Dowgert, 2010). Irrigated agriculture covers 275 million ha of land which is about 20% of cultivated land in the world and irrigation provides about 40% of global food production (UNESCO, 2017). Irrigation in Africa has the potential of providing food security to the entire African countries but food production in the continent is mainly rainfed and the area cultivated under irrigation is about 13 million ha of land which is only about 6% of the total cultivated area in the continent (Liangzhi *et al.*, 2010). According to FAO, (2005) Africa can irrigate up to 42.5 million ha, based on available land and water resources and by far the greatest potential is

found in Nigeria, which accounts for more than 2.5 million ha.

Irrigation development has long been considered essential to the sustainable growth of agricultural production in Nigeria. The country has an estimated 3.1 million ha of potentially irrigable area, of which over 1 million ha is in the Northern part of the country (NINCID, 2021). Out of 624,408 ha planned for irrigation in 2004, only an estimated 293,117 ha (47%) has been equipped for irrigation and only 218,840 ha (35%) has been cropped. The Federal Government of Nigeria recently released a long-term irrigation development strategy for the period of 2016 to 2030 and to be implemented in three phases with a total of 5 million ha by 2030. According to projections, land under irrigation has increased at less than 1% per annum in the last decade or so. It is not foreseen that the situation would change significantly because of many reasons. The harvested irrigated areas are expected to increase from the estimated current figure of 1.17 million ha to about 2.35 million ha in 2025 (NINCID, 2021).

Irrigation is usually practised in arid and semi-arid regions where rainfall is sparsely distributed and could not sustain agricultural production. The arid region receives an average annual precipitation of less than 250 mm per annum with an aridity index of between 0.03 and 0.2 while the semi-arid region receives an average annual precipitation of 250 mm to 500 mm per annum with an aridity index between 0.20 and 0.50 (Whitford & Duval, 2020). Drylands cover almost 54 million km^2 of the total land area of the world and include all the land areas where there are limited and insufficient amount of rainfall which limits the agricultural activities. Semi-arid areas have the largest percentage followed by arid areas and then dry sub-humid lands. These aridity zones spread across all continents, but are predominantly found in Asia and Africa (White & Nackoney, 2003). Figure 1 below shows the map of the dryland in the world.

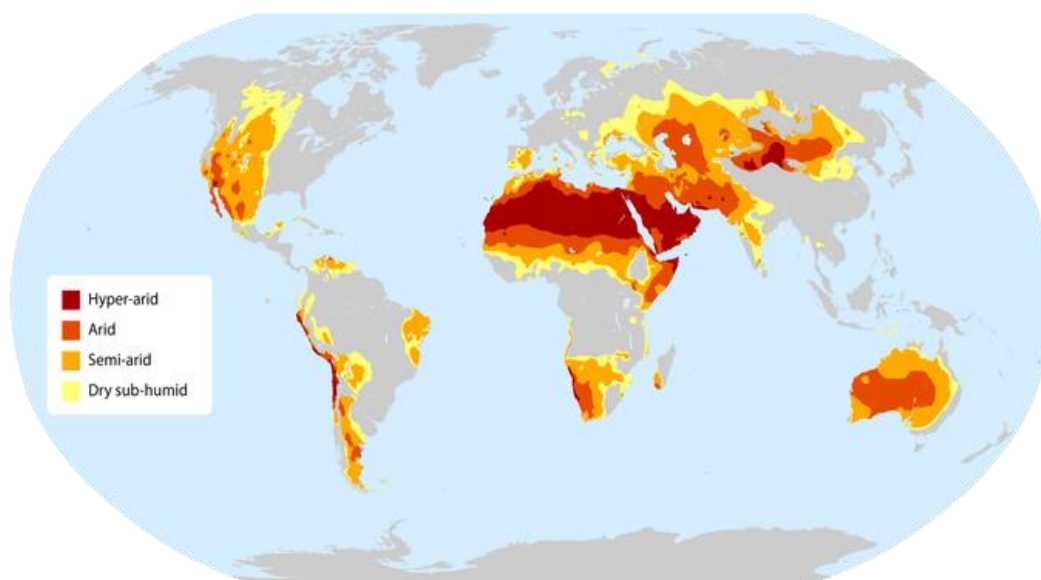


Figure 1: Map of dryland in the world (UNEP-WCMC, 2007)

Table 1 below shows areas equipped for irrigation across different continents of the world as in the 2018 report by World Food and Agriculture - Statistical Yearbook 2020.

Table 1: Area equipped for irrigation across different continents of the world (FAO, 2020)

Continent	Irrigated Area (ha)	Per cent of the world's total area (%)
Asia	238,406,000	70
America	54,819,000	16
Europe	26,219,000	8
Africa	15,959,000	5
Oceania	3,308,000	1
World	338,711,000	100

Irrigation practice is categorized into two, the gravity (surface) and pressurized (micro) irrigation systems. Surface irrigation is the conventional and the most commonly adopted irrigation method in which water is applied and distributed over the soil surface by gravity. Surface irrigation is being practised on about 76 % (255,784,630 ha) of the 338,711,000 ha of irrigated cropped area in the world as of 2018. India as a country, has the largest surface irrigation method in the world with irrigated areas of 68,172,000 ha which accounts for about 27% of the world's surface irrigation. Other five top countries that practice surface irrigation methods in the world are China, Pakistan, the United States of America, and Iran (Knoema, 2021). Although surface irrigation is the most commonly and widely practised by farmers, it is also known to have the lowest water use efficiency (Shanono *et al.*, 2020). About 90% of the freshwater consumed by agriculture is applied through surface irrigation using furrow, basin and border irrigation methods in which a significant amount is lost to conveyance losses, runoff and deep percolation. (Akbari *et al.*, 2018). Water losses in surface irrigation can be minimized by proper land grading, monitoring and controlling the inflow, improving the irrigation scheduling and adopting micro-irrigation systems known to have high water use efficiency.

A pressurized irrigation system otherwise known as a micro-irrigation system is a modern irrigation method in which irrigation water is conveyed and precisely applied to the soil under pressure through a system of pipes. The pressurized system provides improved water distribution and application efficiency, control over the timing of application, reduced wastage reduced labour and efficient use of limited water resources (ICID, 2022). The pressurized irrigation system is categorized into drip and sprinkler irrigation systems. Drip irrigation is a water-saving irrigation method that is typically designed to wet only the soil zone occupied by plant roots and to maintain this at or near an optimum moisture level, using emitters spaced along drip lines. Drip irrigation has improved crop production systems in different parts of the world by increasing yields and water use efficiency in many crops (Zaccaria *et al.*, 2017). Whereas sprinklers use mechanical and hydraulic devices to apply irrigation water to the soil surface and can also apply fertilizer and pesticides together with the correct amount and frequency (Kulkarni, 2011).

Advances Achieved So Far in Irrigation Sector

Advances in the irrigation sector are regularly introduced into irrigated agriculture as this is necessary to overcome the environmental impacts associated with irrigation (Levidow *et al.*, 2014). In addition, an improved irrigation system can help address the problems of the limited water resources, particularly in arid and semi-arid (Ghanisanij *et al.*, 2006; Zakari *et al.*, 2020). Some of the advances introduced recently into irrigated agriculture include modelling, simulation and optimization of irrigation systems. Others include the use of an irrigation controller coupled with soil moisture sensors for optimum irrigation scheduling. These advances are developed to improve high water productivity, increase crop yields, reduce the drudgery, conserve energy and reduce the

leaching of nutrients caused by over-irrigation (Perry *et al.*, 2017). The advances make it possible to automate irrigation systems using soil tension meters incorporated with transducers that can be connected with a solenoid valve or irrigation controller to keep the soil moisture at field capacity (Al-Ghobari *et al.*, 2017).

Irrigation and crop models are promising tools that are now used to support the design of irrigation and cropping systems for sustainable agricultural practice. Crop models are software developed using a set of mathematical equations describing physical system relationships (soil-water-plant-atmosphere). The crop model simulates or imitates the behaviour of a real crop by predicting the growth of its components, such as leaves, roots, stems and yields. Thus, a crop growth simulation model not only predicts the final state of total biomass or harvestable yield but also contains quantitative information about major processes involved in the growth and development of a plant (Jame & Cutforth, 1996). Crop modelling has developed extensively over the past decades in parallel with advances in crop and environmental sciences and computing technologies. Different models have been developed by different researchers encompassing different approaches and levels of complexity and emphasizing different aspects of the soil-water-plant-atmosphere system (Singels *et al.*, 2013) as well as human-water interaction (Shanono & Ndiritu, 2021). Crop models are also used as tools for assessing agricultural management strategies and their interaction with climatic risk.

Thus, crop modelling has greatly contributed to a better understanding of crop performance and yield gaps, better prediction of pest and insect outbreaks, and improving the efficiency of crop management systems and optimization of planting dates (Reynolds *et al.*, 2018). Recent developments in agricultural products include the use of remotely sensed data and mobile phone technology linked to crop management decision support models, data sharing in the new era of big data, and the use of genomic selection and crop simulation models linked to environmental data to help make crop breeding decisions (Antle *et al.*, 2017). Decision Support Systems (DSS) are irrigation models that were developed to improve crop water use efficiency at farm and water basin scales. The application of DSS in irrigated agriculture for irrigation water management has greatly increased across the globe in the last 2 decades. The DSS has been widely used to balance the water use between the field and the district levels, allocation of irrigation water, reduce environmental pollution and improve nutrient-use efficiency (Ara *et al.*, 2021).

Crop simulation models are the act of imitating the processes of plant growth and development. These models are based on equations that describe the processes involved in crop growth and development, amongst others (Wallach *et al.*, 2006; Seidel, 2012). Crop models are nowadays used to evaluate different irrigation and fertilization management or climate scenarios and hence allow generalised predictions of crop production. Moreover, they are powerful tools to test hypotheses and describe as well as understand complex systems and processes. For instance, crop simulation models

are used to understand and establish the relationship between the input and output of the irrigation systems such as the water and Nitrogen applied and the yield (Semenov, 2009; Seidel, 2012). Crop simulation modelling offers an opportunity for exploring cultivar potential for new areas before establishing expensive and time-consuming field experiments in the field which saves time and resources (Kephe *et al.*, 2021). Calibrated and validated simulation models can provide very reliable results in developing agricultural land management strategies. Most simulation models have some forms of limitations and therefore no model applies to every situation, for instance, DSSAT (Decision Support System for Agro-technology Transfer) and EPIC (Environmental Policy Integrated Climate) models can be used in different geographical locations and in various agro-environmental conditions for estimating soil moisture, crop water requirements and crop evapotranspiration. However, these models cannot be used for planning irrigation water management. The CROPWAT for example can be used in estimating water requirements and planning irrigation scheduling (Khan & Walker, 2015). The EPIC simulation model was used by Ko *et al.*, (2009) in South Texas to determine the relationship between the crop yield and crop water use parameters such as crop evapotranspiration (ETc) and water use efficiency (WUE) in the irrigated cotton and maize farms respectively. The researchers also used EPIC to simulate the variability and crop yield response under different irrigation regimes and their findings show that EPIC can be used as a decision support tool for the crops under full and deficit irrigation conditions. Walser *et al.*, (2011) used Soil-Vegetation-Atmosphere Transfer (SVAT) Daisy models to simulate irrigation experiments conducted on a field rain-out shelter for wheat and barley and in a container greenhouse experiment for barley to maximize the water productivity. The researchers concluded that DAISY performed well with simulating lightly drought-stressed crop growth and water balance.

Optimization is the search for the best solution concerning certain criteria from a set of variables and parameters. It involves maximizing or minimizing an objective function by choosing values from an allowed set of decision variables and determining the value of that objective function. Different optimization algorithms are available for the optimization of different processes of different methods of irrigation under different conditions(Li *et al.*, 2020). The general objective for crop growth optimization models is to improve crop water productivity. Through crop optimization models, the optimum amount of water and fertilizer and other farm input can be applied thereby, ensuring little or zero water wastage while at the same time drought-stress crop is avoided (Kloess *et al.*, 2012). The economic and optimization (OPTIMEC) tool developed in Spanish is one of the irrigation optimization models that uses a heuristic technique and the genetic algorithm (GA) to find a quasi-global optimum combination of irrigation events. The model is defined by irrigation date, water cut-off time and inflow rate that maximizes net profit (Akbari *et al.*, 2018). Global Evolutionary Technique for Optimal Irrigation Scheduling (GET-OPTIS) is also another optimization algorithm for optimal irrigation scheduling. The optimization of irrigation scheduling using GET-OPTIS starts with a set of solutions called the population of a random set of schedules. Every member of the set has a fitness value assigned to it which is directly related to the objective function (e.g. crop yield). In sequential steps, the population of schedules is modified by applying four steps, aiming to imitate biological evolution which includes selection, crossover, mutation, and reconstruction. The procedure is

then repeated until a convergence criterion is reached, or the maximum value of steps is exceeded (Schütze & Schmitz, 2010).

The combination of any simulation model with any of the optimization algorithms is known as simulation-based optimization otherwise known as simulation-optimization modelling. Simulation-optimization is a process of finding the best input variable values from among all possibilities without explicitly evaluating each possibility. The objective of simulation- optimization is to minimize the resources spent while maximizing the information obtained in simulation experiments. For instance, the SVAT model can be employed to simulate irrigation experiments for the growth and development of different crops and the simulated values can then be subjected to optimization algorithms to find the optimal values of the simulated results for any performance indicators. Research on the development and application of simulation-optimization Research on the development and application of simulation-optimization models for the management of irrigation systems are still very few (McCarthy *et al.*, 2013; Akbari *et al.*, 2018). Soundharajan & Sudheer (2009) developed an optimal irrigation schedule for rice crops (*Oryza sativa*) under water deficit conditions in southern India. The ORYZA2000 simulation model was used to identify critical periods of growth that are highly sensitive to the reduced crop yield and coupled with a genetic algorithm to develop optimal water allocations during the crop growing period. The study revealed that a significant improvement in total yield can be achieved by the model compared to other water-saving irrigation methods. The results of their study also suggested that employing a calibrated crop growth simulation model combined with an optimization algorithm can lead to achieving maximum water use efficiency. A study was conducted by Saberi *et al.*, (2020) to improve the efficiency of the furrow irrigation method by simulating and optimizing the design parameters (flow rate, furrow length and cut-off time) using the simulation-optimization framework FURDEV. The FURDEV is a combination of SURDEV and AMALGAM shows that the framework plays an effective role in improving irrigation efficiency. Kloss *et al.*, (2014) use a simulation-optimization approach combined with an irrigation experiment to improve water productivity in sensor-based deficit irrigation systems and the results of their study were found to be effective.

Coupling Soil Sensors with Irrigation System

The soil moisture sensors measure the soil or plant water status by either measuring the amount of water or its energy content in the soil. The amount of soil-water contents is measured using a soil moisture meter while the soil-water potential (the energy contents of the water in the soil) is measured using a tensiometer. Measurement of soil-water contents by soil moisture meters only indicates the volume of water in the soil but does not indicate the amount of water available for plants (Thompson & Gallardo, 2005; Kloss *et al.*, 2014; Montesano & Parente, 2015). The measurement of soil matric potential using a tensiometer is used to overcome the problem encountered in measuring soil-water contents by soil moisture meters as it indicates the volume of water available for plants. Moreover, tensiometers are not affected by salinity as they respond purely to moisture tension and thus, measure the force that the plants have to overcome to extract water from the root zone (Lieth & Oki, 2008). A simple tensiometer consists of a tube fitted with a porous ceramic tip on one end and a pressure/suction gauge on the other end. In automated systems, the gauge is supplemented with or replaced by a transducer to convert the tension

(suction) to an electrical signal that can be sensed by a computer or irrigation controller. The basic operation is to have one tensiometer coincide with each irrigation valve. This sensor is usually installed in the root zone of a plant in an experimental plot to represent the whole experimental plot (Lieth & Oki, 2008).

Sensor-based irrigation is an irrigation method that used soil sensors for irrigation scheduling (how much and when to irrigate). Soil moisture sensors (SMS) are widely available and used in full and deficit irrigation systems (Chen *et al.*, 2019). The SMS are devices for monitoring Spatio-temporal variations of soil moisture and hence can be an effective tool for precisely managing irrigation scheduling for various crops. These sensors have the advantage of allowing site-specific crop management which is the most crucial part of precision and smart agriculture (Badewa *et al.*, 2018). Sensor-based irrigation is very conventional, easy to use, and cost-saving less amount of labour is required. With an automated technology of irrigation adopted, human labour and other interventions can be minimized. Sensor nodes enable environment sensing together with data processing, sensors can network with other sensors and can exchange data with external users (Wei *et al.*, 2020). Sensor networks are used for a variety of applications, including wireless data acquisition, environmental monitoring, irrigation management, safety management, and many other areas (Dubey & Dubey, 2018). Irrigation manager who use soil sensors to monitor soil moisture levels in the field greatly increase their ability to conserve water and energy, optimize crop yields, and avoid soil erosion and water wastage and pollution (Chaware *et al.*, 2015). According to the Muñoz-carpena (2004), a sensor-based irrigation system may greatly facilitate the successful employment of low volume-high frequency irrigation systems for commercial vegetable crops. This assumption is in line with the work of Dukes *et al.* (2003) who reported a 50% reduction in water use when using a soil moisture sensor-based automated drip irrigation system for bell pepper as compared to a once-daily manually irrigated system without affecting yield.

In sensor-based irrigation, the water is applied based on maintaining soil water between two limits of the tensiometer. The first limit is the lower limit (drier value) or threshold that indicates when to start an irrigation event whereas the second limit is the upper (wetter value) which indicates when to stop the irrigation event. The difference between the two limits is an indication of the volume of irrigation water required (Thompson & Gallardo, 2005). In practice, threshold soil matric potentials (SMP) values are commonly recommended by extension services, consultants, or suppliers. As general guidelines, Irrrometer Co., a major manufacturer of soil matric potential sensors for commercial use, suggested lower limits of -30 to -60 kPa for most soils and of -60 to -100 kPa for heavy clay soils, and upper limits of -10 to -30 kPa which represent Field Capacity (Thompson & Gallardo, 2005). Recommended SMP values appear to be based on experience and experimental studies conducted with open field crops and show a wide range of threshold SMP values. Thus, some other site-specific factors can also influence results. A study conducted in silty-clay soil by Montesano & Parente, (2015) with a threshold value of -10 kPa for tomato and cucumber shows a water-saving of 35% and 46%, on average, for tomato and cucumber respectively. Also, an earlier study conducted by Wang *et al.*, (2005) compare three irrigation treatments of tomatoes in loamy soil which are irrigated using tensiometer values set at -10 kPa, -20 kPa and -30 kPa shows that irrigation at -30 kPa as a threshold value for tomato crop used 85% less water than that set at -5 kPa and the study

recommended and an optimal value of -30 kPa for tomato crop.

Several researchers and soil sensor suppliers have continued to recommend upper and lower limits of the tensiometer to define adequate soil water matric potential in the crop's root zone. The recommended upper and lower limits differ depending on the soil texture, crop species and evaporative conditions. The most commonly recommended ranges, for high-frequency drip irrigated crops, are between -10 and -20 kPa, -10 and -30 kPa, and -20 and -40 kPa, for coarse, medium and fine-textured soils respectively (Thompson & Gallardo, 2005). Generally, with high-frequency drip irrigated crops, standard Refill Point values are used regardless of crop type and evaporative conditions. Adjustments may be made for crops considered to be very sensitive to over-irrigation (*e.g.* pepper), and to impose controlled moderate water stress to improve fruit quality (*e.g.* melon, fresh tomato) (Thompson & Gallardo, 2005).

The Need to Adopt Sensor-based Drip Irrigation System

Sensor-based drip irrigation can be adopted by small, medium and large-scale farmers, particularly in the semi-arid regions for proper irrigation scheduling, water-saving and the overall water use efficiency. Irrespective of the size of the farms and the types of crops grown, soil sensors can be installed to monitor irrigation and can be coupled with an irrigation controller and /or solenoid valve to automate the system thereby saving time, energy and cost and the overall productivity of the irrigation systems.

Sensor-based drip irrigation systems have been installed in several large-scale farming to improve irrigation water efficiency in different parts of the world and have shown promising results in saving water. A study was conducted by Lea-Cox *et al.*, (2018) at Mellano southern California using sensor-based drip irrigation and achieved a 25% reduction in water use without adversely affecting the yield. Generally, sensor-based drip irrigation can save about 40-60% of water without compromising crop yield or quality. A similar study was also conducted in Commercial Floriculture Production to determine the benefit of sensor-based automated drip irrigation systems in herbaceous ornamental producers. The study tends to compare sensor-based drip irrigation systems with traditional grower-managed irrigation systems for two years growing seasons. Although, the findings of their study show that there is no difference in water consumption between the two systems studied and compared but the number of plants produced under sensor-based drip irrigation was scaled up which indicates the capability of the system for irrigation (Wheeler *et al.*, 2018). According to Wheeler *et al.*, (2018) sensor-based irrigation reduces and facilitates the reallocation of labour from irrigation management, which was especially valuable during peak production and shipping periods. The financial return period calculated from labour savings would be roughly 1.5 years if the sensor-based irrigation system was implemented throughout the facility (Wheeler *et al.*, 2018).

Medium-scale farming is a farming system that produces crops of land size of 5 - 100 ha and is mostly practised by professionals, entrepreneurs or retired civil servants. These types of farmers can easily adopt agricultural innovations and technologies to their farms without any resistance considering their level of education. Sensor-based drip irrigation along with a mulch was adopted on the cotton farm of 18.5 ha in Gujarat, India and the system was able to save about 60% of water when compared to surface irrigation (Mavani & Prajapati, 2019). In another study conducted by Barkunan *et al.*, (2019) a sensor-based automatic drip irrigation system

was adopted for paddy cultivation in Tamilnadu and the results of the study show that the system saves nearly 41.5% and 13% of water compared to the conventional flood and drip irrigation methods respectively. Sensor-based drip irrigation systems can also be incorporated into small-scale farming to improve both irrigation efficiency and the crop productivity of the irrigation systems. Most of the experiments, researches, studies on sensor-based drip irrigation systems were conducted on small experimental plots which indicate that the systems can be easily adopted into a small-scale farming.

Factors Affecting the Adoption of Sensor-based Drip Irrigation

Several factors can affect the adoption of sensor-based drip irrigation systems by small, medium and large-scale farmers. Some of these factors include initial capital investment, farmers' level of awareness, expertise and experience, capital recovery, technical know-how and farm characteristics as well as risk and uncertainties associated with the system. According to the Organization for Economic Cooperation and Development (OECD), the characteristics of technologies such as relative advantage, complexity, divisibility, observability and compatibility affect their diffusion and adoption by the farmers (OECD, 2001). Diffusion is the process by which a new idea, practice or technology (such as sensor-based drip irrigation) spreads in a given population (farming communities in this case).

Initial capital investment, farm size and capital recovery

Capital investment is an expenditure for acquiring, leasing, or improving the property that is used in operating a business and it includes land, buildings, machinery and fixtures. Although sensor-based drip irrigation requires a high initial capital investment but may offer cost savings and higher yields in long run through more precise and proper irrigation scheduling and fertigation (Sharma *et al.*, 2019). A study was conducted to assess the economic performance of a drip irrigation system for growing tomato in Egypt in which 100 tomato farmers were interviewed. The study revealed that investment in the drip irrigation system is profitable, with an increase of 67% in the net return per hectare, compared with results using non-drip irrigation. The benefit-cost ratio amounted to 1.35, the net present value was US\$1720, and the internal rate of return was 44% (Ali *et al.*, 2020). A similar study was conducted by Narayanamoorthy *et al.*, (2018) to assess the techno-economic potential of drip irrigation systems in vegetable crops using survey data from the Indian state of Tamil Nadu. The findings of the study revealed that the drip irrigation system has brought about 54% higher net returns than the conventional method of irrigation. Another study conducted by Kinyangi, (2014) to examine how capital and credit facilities influence the adoption of agricultural technology among small-scale farmers in Kakamega North Sub-County, Kenya shows that both capital and credit facilities had a positive and significant influence on the adoption of agricultural technologies and innovations.

The size of the farm influences the decision of the farmers to adopt sensor-based drip irrigation. The larger farms may have access to higher equity and monetary resources to invest in water-saving equipment (Wang *et al.*, 2010). A field study conducted to determine the major factors influencing farmers' adoption of drip irrigation in two districts in Kerala, India shows that land holding size has a positive influence on drip irrigation adoption index by farmers (Chandran & Surendran, 2016).

Capital recovery is simply the return on an initial investment. It is the earning back of the initial funds put into an investment. The number of years required to recover the capital cost of sensor-based drip irrigation may affect the farmers' decision to adopt or reject the technology (Viswanathan *et al.*, 2016). As against the general perceptions of many farmers that the capital cost recovery of drip irrigation investment takes a long time, a year-wise computation of the net present worth (NPW) for sugarcane, banana, grapes and cotton grown under drip irrigation suggested that farmers could recover the entire capital cost of drip-set from the net profit within one year (Viswanathan *et al.*, 2016).

Farmers' awareness and experience

Farmers' awareness and level of experience are also key determinants of adopting or rejecting agricultural technologies and innovations such as sensor-based drip irrigation systems. Several studies indicate that there is a relationship between the farmers' awareness and their adoption of improved agricultural technologies and innovations (Acheampong *et al.*, 2018; Zakari *et al.*, 2021). Farmers with a high level of education are well-informed about the development and performance of different irrigation technologies and are more likely to accept and adopt these technologies than those with a non or low level of education (Abdulai *et al.*, 2011; Shanono, *et al.*, 2021) This is also supported by the works of Bagheri & Ghorbani, (2011) in which 160 farmers were surveyed for the adoption and non-adoption of micro-irrigation technology in Ardabil Province of Iran. The results of their show that the adopters are farmers with low farming experience but a high level of education (Bagheri & Ghorbani, 2011). A study conducted to find the determinants of Farmers' awareness and adoption of extension recommended Wheat varieties in the rainfed areas of Pakistan shows that there is a strong relationship between the farmers' awareness of a technology (improved Wheat varieties) and its adoption. The study further revealed that the extension contacts of the farmers, income from agriculture, and access to credit positively affected the farmers' awareness, whereas their low level of education and experience, as well as household sizes, negatively affected their awareness (Ullah *et al.*, 2022).

Risk perception and technical expertise

In agriculture, the risk is defined as the probability of occurrence of hazards and shocks that negatively impact agricultural production and other value-chain operations. Farmers in the whole world particularly in Africa, face several interconnected risks (FAO, 2016). These risks discourage farmers to adopt new agricultural technologies on their farms for fear of the possible negative outcome associated with new technology. All agricultural technologies and innovations have some subjective and objective risks associated with them. The adoption and implementation of these technologies are typically influenced by the farmers' individual's perception of risk and uncertainties, and their ability to bear the risk of a new and uncertain endeavour (Parvan, 2011). The capability of sensor-based drip irrigation in increasing the water efficiency of irrigated agriculture is not known to most farmers, particularly small-scale farmers and therefore there is a need to undertake awareness-raising campaigns to enlighten and encourage them to the adoption of the technology.

Technical know-how refers to the information and knowledge relating to the design, development, installation, operation and maintenance of any system. Technical know-how is one

of the impediments affecting the adoption of sensor-based drip irrigation systems by farmers (Dace, 2020). The design, layout, installation, operation and maintenance of sensor-based drip irrigation required technical skills. These skills become barriers for many farmers in adopting the drip irrigation systems despite their excellent performance as water, labour and energy-saving irrigation systems. A study conducted to find out the factors that drive the adoption of drip irrigation in Erode district in Tamil Nadu, India listed technical skill among other factors that hinders the adoption of drip irrigation by the farmers in the study area (Viswanathan *et al.*, 2016; Kaarthikeyan & Suresh, 2019)

Why adopting Sensor-based Drip Irrigation System

The adoption of sensor-based drip irrigation is essential for irrigated agriculture, particularly in arid and semi-arid regions of the world where water is a limiting factor. This emerging technology of sensor-based drip irrigation is environmentally-friendly as all issues associated with over-irrigation such as waterlogging, salinity and soil erosion are eliminated (Ismail *et al.*, 2014; Levidow *et al.*, 2014). The system produces more food with less water making the irrigated agriculture highly profitable through water, energy and labour saving and also minimizing the leaching of fertilizers and other chemicals applied to the soils (Ncube *et al.*, 2018).

In addition, sensor-based drip irrigation is the solution to the problems caused by climatic uncertainty and erratic rainfall that occasionally affect agricultural production. The adoption of sensor-based drip irrigation by farmers is a promising investment that has been found to improve the profitability of their farms (Munoth *et al.*, 2016). The system is also beneficial to the larger society as the pressure on agricultural water demand will be reduced which means more water will be released to the society for domestic and other uses. The adoption of sensor-based drip irrigation will also serve as a guide for policy and decision-makers in the planning of water resources as wide adoption of this system of irrigation will eliminate the need for the construction and development of large dams and reservoirs for surface irrigation.

Framework for the Adoption of Sensor-based Drip Irrigation System

Farmers can easily adopt sensor-based drip irrigation systems despite the major impediments affecting their decisions when the following ideas, suggestions and recommendations are fully implemented.

Dissemination of sensor-based irrigation to farmers

The extension agents can disseminate information on sensor-based drip irrigation to the farming communities and persuade them to adopt the system for efficient water management and the overall productivity of their irrigation systems. Extension workers are usually the middlemen between the research institutes and the farmers. These professionals take and promote any agricultural innovations

developed by the researchers to the farmers. Sensor-based drip irrigation can equally be promoted to the farmers by extension agents and irrigation engineers. The technical know-how associated with the layout, installation, operation and maintenance of sensor-based drip irrigation can be easily explained and demonstrated to the farmers by the extension agents and irrigation engineers. Also, the advantage of sensor-based drip irrigation in comparison to both drip and conventional irrigation systems can be explained to the farmers. The system will be accepted and adopted by the farmers once they are aware of these advantages.

Creation of awareness among farming communities

Awareness-raising campaigns can be created among farming communities and farmers' associations on the importance of the adoption of sensor-based drip irrigation for proper and precise water application. The demonstrations can be done to the farmers on how the systems work. This can be done occasionally to farmers and comparisons can also be made between the sensor-based drip irrigation and conventional irrigation systems for farmers to see practically how the system saves water, energy and labour. The awareness can go a long way in convincing the farmers to adopt the systems on their farms.

Provision of subsidy and credit facilities

Government and other non-governmental agricultural organizations can subsidize drip sets and soil moisture sensors to farmers that are willing to adopt the technology on their farms. This will encourage and motivate the farmers to adopt the systems. The credit facilities can also be made available to the farmers particularly small-scale who are interested in adopting the technology but have no initial capital to invest in the systems.

Provision of policies and environmental standards

Government should enact and implement laws and policies on sustainable agricultural production. Any agricultural activities that result in significant environmental degradation should be banned. Taxes and serious sanctions should be imposed on the defaulters. This will make farmers adopt sensor-based drip irrigation that is environmentally friendly and sustainable.

Review the price of water charges

The current price of water of #5,000.00 which is a charge to the farmers per hectare by the river basin development authority of Nigeria needs to be reviewed. This price is good as free and makes farmers waste water injudiciously. The price of the water needs to be reviewed and should be based on the amount of water consumption by the farmers, not a fixed rate. The flow meters can be installed at various farms to measure the actual quantity of water consumed by the farmers. This will change the perceptions of the farmers and will look for the adoption of water-saving irrigation systems such as sensor-based drip irrigation systems.

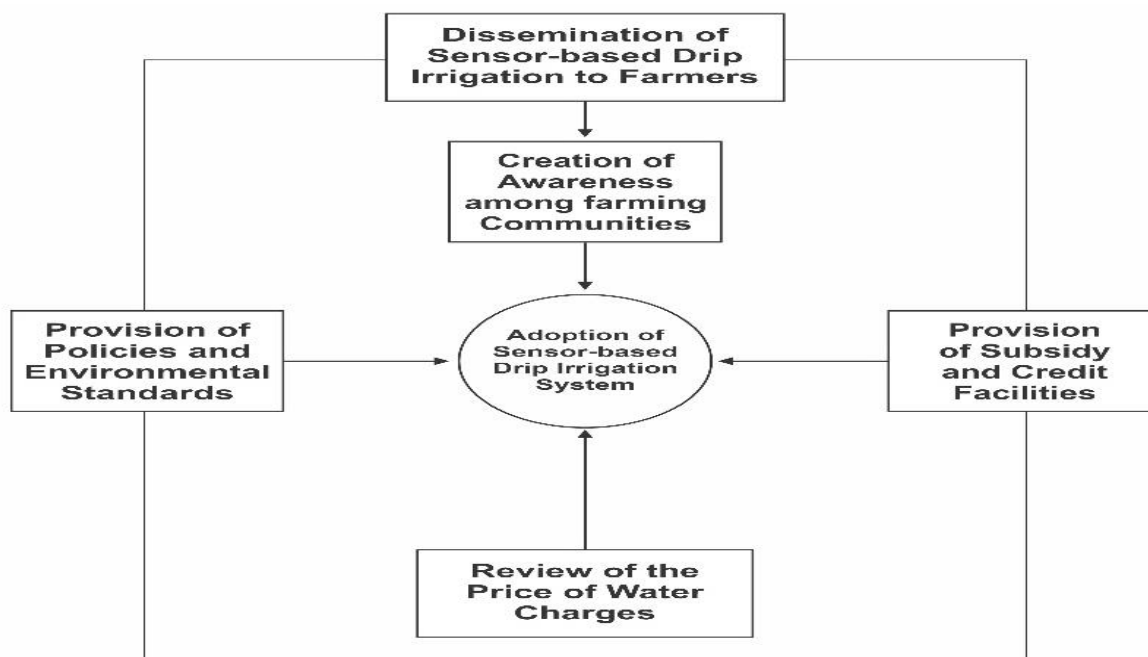


Figure 2: Framework for the adoption of sensor-based drip irrigation

CONCLUSION

The adoption of sensor-based drip irrigation by small-scale farmers in the semi-arid region of Nigeria will boost agricultural production and food security in the region through precise and proper irrigation scheduling. The adoption of the system can also help in addressing the problems of water scarcity that are being experienced occasionally due to erratic rainfall and climatic change impact. As the water resources in the region are reducing gradually while their demand is rapidly increasing, thus, the adoption of sensor-based drip irrigation to ensure efficient water application while maintaining high crop yield is no longer an option but a necessity. The factors identified to hinder the adoption of sensor-based drip irrigation systems by small-scale farmers include initial capital investment, farmers' awareness, risk perception and uncertainties and capital recovery. Others include technical know-how and farm characteristics. These issues can be overcome by dissemination of sensor-based irrigation to farmers, creation of awareness among farming communities, provision of subsidy and credit facilities, provision of policies and environmental standards and review of the price of water charged to the farmers among others.

REFERENCE

Abdulai, A., John-Eudes, V. O., and Bakang, A. (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, 70(7), 1415–1423. <https://doi.org/https://doi.org/10.1016/j.ecolecon.2011.03.004> Get rights and content

Acheampong, P. P., Amengor, N. E., Nimo-Wiredu, A., Adogoba, D., Frimpong, B. N., Haleegoah, J., and Adu-Appiah, A. (2018). Does Awareness influence Adoption of agricultural technologies? The case of Improved Sweet potato varieties in Ghana. *Ghana Association of Agricultural Economists (GAAE) 2nd GAEE Conference 9-11th August, 2018 Ghana's Agriculture, Food Security and Job Creation Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, August.*

Akbari, M., Gheysari, M., Mostafazadeh-Fard, B., and Shayannejad, M. (2018). Surface irrigation simulation-optimization model based on meta-heuristic algorithms. *Agricultural Water Management*, 201(January), 46–57. <https://doi.org/10.1016/j.agwat.2018.01.015>

Al-Ghobari, H. M., Mohammad, F. S., Al-Marazky, M. S., and Dewidar, A. Z. (2017). Automated irrigation systems for wheat and tomato crops in arid regions. *Water SA*, 43(2), 354–364. <https://doi.org/http://dx.doi.org/10.4314/wsa.v43i1.12>

Ali, A., Xia, C., Jia, C., and Faisal, M. (2020). Investment profitability and economic efficiency of the drip irrigation system: Evidence from Egypt. *Irrigation and Drainage*, 69(5), 1033–1050. <https://doi.org/https://doi.org/10.1002/ird.2511>

Antle, J. M., Basso, B., Conant, R. T., Godfray, H. C. J., Jones, J. W., Herrero, M., Howitt, R. E., Keating, B. A., Munoz-Carpena, R., Rosenzweig, C., Tittonell, P., and Wheeler, T. R. (2017). Towards a new generation of agricultural system data, models and knowledge products: Design and improvement. *Agricultural Systems*, 155, 255–268. <https://doi.org/10.1016/j.agry.2016.10.002>

Ara, I., Turner, L., Harrison, M. T., Monjardino, M., deVoil, P., and Rodriguez, D. (2021). Application, adoption and opportunities for improving decision support systems in irrigated agriculture: A review. *Agricultural Water Management*, 257(June), 107161. <https://doi.org/10.1016/j.agwat.2021.107161>

Badewa, E., Unc, A., Cheema, M., Kavanagh, V., and Lakshman Galagedara. (2018). Soil Moisture Mapping Using Multi-Frequency and Multi-Coil Electromagnetic Induction Sensors on Managed Podzols. *Agronomy*, 8(10). <https://doi.org/https://doi.org/10.3390/agronomy8100224>

Bagheri, A., and Ghorbani, A. (2011). Adoption and non-adoption of sprinkler irrigation technology in Ardabil

- Province of Iran. *African Journal of Agricultural Research*, 6(5), 1085–1089. <https://doi.org/10.4236/ajar.2017.65108>
<http://www.academicjournals.org/AJAR>
- Barkunan, S. R., Bhanumathi, V., and Sethuram, J. (2019). Smart sensor for automatic drip irrigation system for paddy cultivation. *Journal of Computer and Electrical Engineering*, 73(January), 180–193. <https://doi.org/10.1016/j.compeleceng.2018.11.013>
- Chandran, K. M., and Surendran, U. (2016). Study on factors influencing the adoption of drip irrigation by farmers in humid tropical Kerala, India. *International Journal of Plant Production*, 10(3), 1–10. <https://doi.org/10.1016/j.ijpp.2016.03.001>
- Chaware, D., Panse, M., Raut, A., and Koparkar, A. (2015). Sensor-based Automated Irrigation System. *International Journal of Engineering Research & Technology (IJERT)*, 4(05), 33–37. <https://doi.org/10.17993/IJERTV4IS050076.pdf>
- Chen, X., Qi, Z., Gui, D., Gu, Z., Ma, L., Zeng, F., Li, L., and Sima, M. W. (2019). A model-based real-time decision support system for irrigation scheduling to improve water productivity. *Agronomy*, 9(11), 1–10. <https://doi.org/10.3390/agronomy9110686>
- Dace, H. (2020). Technology to Feed the World. In *Tony Blair Institute for Global Change*. <https://institute.global/sites/default/files/articles/Technology-to-Food-the-World.pdf>
- Dowgert, M. (2010). The Impact of Irrigated Agriculture on a Stable Food Supply. *Proceedings of the 22nd Annual Central Plains Irrigation Conference*, 1–11. <https://doi.org/10.1016/j.procs.2010.08.001>
- Dubey, A., and Dubey, K. (2018). Sensor Based Drip Irrigation. *International Journal of Scientific and Engineering Research*, 9(2), 11–14. <https://www.ijser.org/>
- Dukes, M. D., Simonne, E. H., Davis, W. E., Studstill, D. W., and Hochmuth, R. (2003). effect of sensor-based high frequency irrigation on bell pepper yield and water use. *Proceedings 2nd International Conference on Irrigation and Drainage, Phoenix, AZ*, 665–674. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.455.495F70238DF8438F52BE9A5024F178FD?doi=10.1.1.455.495F70238DF8438F52BE9A5024F178FD>
- Enete, A. A., and Amusa, T. A. (2010). Challenges of Agricultural Adaptation to Climate Change in Nigeria: A synthesis from the literature. *Open Edition Journal*, 4(December), 1–11. <http://www.mendeley.com/research/challenges-agricultural-adaptation-climate-change-nigeria-synthesis-literature/>
- FAO. (2005). Irrigation in Africa in figures AQUASTAT Survey – 2005. In *Irrigation in Africa in figures*. <https://www.fao.org/3/a0232e/A0232E.pdf>
- FAO. (2020). *World Food and Agriculture - Statistical Yearbook 2020*. Food and Agricultural Organisation. <https://doi.org/10.4060/cb1329en>
- Food and Agriculture Organisation. (2016). *Agriculture And Food Insecurity Risk Management in Africa Concepts, lessons learned and review guidelines*.
- Ghanisani, H. D., Oweis, T., and Qureshi, A. S. (2006). Agricultural water use and management in arid and semi-arid areas: Current situation and measures for improvement. *Annals of Arid Zone*, 45(2r), 1–24. <https://doi.org/10.1007/s11662-006-9092-1>
- IFAD. (2013). *Smallholders, food security, and the environment*. https://www.ifad.org/documents/38714170/39135645/smallholders_report.pdf/133e8903-0204-4e7d-a780-bca847933f2e
- International Commission on Irrigation and Drainage. (2022). *Application of Irrigation water > Pressurized Irrigation*. <https://doi.org/10.1016/j.icid.2022.100001>
- Ismail, H., Abubakar, S. Z., Oyebode, M. ., Halilu, A. G., and Shanono, N. J. (2014). Effect of Irrigation Regimes on Growth and Yield of Tomato under High Water-table Conditions. *Nigerian Journal of Science and Environmental Research*, 12, 43–57.
- Jame, Y. W., and Cutforth, H. W. (1996). Crop growth models for decision support systems. *Plant Science*, 76, 9–19. [https://doi.org/10.1016/0168-1263\(96\)00117-2](https://doi.org/10.1016/0168-1263(96)00117-2)
- Kaarthikeyan, G. M., and Suresh, A. (2019). A Study on Understanding the Adoption of Water Saving Technology : A Case Study of Drip Irrigation. *International Journal of Recent Technology and Engineering*, 7(6), 1123–1130. <https://doi.org/10.17993/IJRTV7IS06001123-1130>
- Kephe, P. N., Ayisi, K. K., and Petja, B. M. (2021). Challenges and opportunities in crop simulation modelling under seasonal and projected climate change scenarios for crop production in South Africa. *Agriculture and Food Security*, 10(1), 1–24. <https://doi.org/10.1186/s40066-020-00283-5>
- Khan, M. I., and Walker, D. (2015). Application of Crop Growth Simulation Models in Agriculture with special reference to Water Management Planning. *International Journal Of Core Engineering & Management (IJCEM)*, 2(5), 9510. <https://pdfs.semanticscholar.org/2be8/1e0c2be83f681147a52ab1b412106c440499.pdf>
- Kinyangi, A. A. (2014). Factors Influencing the Adoption of Agricultural Technology Among Smallholder Farmers in Kakamega North Sub-County, Kenya. In *MSc Thesis*. <https://doi.org/10.1016/j.ijert.2014.03.001>
- Kloess, S., Schütze, N., Walser, S., Kloss, S., and Walser, S. (2012). Evaluation of Different Crop Models for Estimating the Potentials To Increase the Water Use Efficiency Under Climate Variability. *Water Resources Management*, 26(4), 1–12. <https://doi.org/10.1007/s11269-011-9906-y>

- Kloss, S., Schütze, N., and Schmidhalter, U. (2014). Evaluation of Very High Soil-Water Tension Threshold Values in Sensor-Based Deficit Irrigation Systems. *Journal of Irrigation and Drainage Engineering*, 140(9). [https://doi.org/10.1061/\(asce\)ir.1943-4774.0000722](https://doi.org/10.1061/(asce)ir.1943-4774.0000722)
- Knoema. (2021). *World Data Atlas ; Water Irrigation » Area Equipped For Full Control IRRIGATION*. Knoema. <https://doi.org/https://knoema.com/atlas/topics/Water/Irrigation-Area-Equipped-for-Full-Control-Irrigation/Surface-irrigation>
- Ko, J., Piccinni, G., Guo, W., and Steglich, E. (2009). Parameterization of EPIC crop model for simulation of cotton growth in South Texas. *Journal of Agricultural Science*, 147, 169–178. <https://doi.org/10.1017/S0021859608008356>
- Kulkarni, S. (2011). Innovative Technologies for Water Saving in Irrigated Agriculture. *International Journal of Water Resources and Arid Environments*, 1(3), 226–231.
- Lea-Cox, J. D., Williams, J., and Mellano, M. A. (2018). Optimising a sensor-based irrigation protocol for a large-scale cut-flower operation in southern California. *Acta Horticulturae*, 1197, 219–225. <https://doi.org/10.17660/ActaHortic.2018.1197.29>
- Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., and Scardigno, A. (2014a). Improving water-efficient irrigation : Prospects and difficulties of innovative practices. *Agricultural Water Management*, 146, 84–94. <https://doi.org/10.1016/j.agwat.2014.07.012>
- Li, J., Jiao, X., Jiang, H., Song, J., and Chen, L. (2020). Optimization of irrigation scheduling for maize in an arid oasis based on simulation-optimization model. *Agronomy*, 10(7). <https://doi.org/10.3390/agronomy10070935>
- Li, X., and Troy, T. J. (2018). Changes in rainfed and irrigated crop yield response to climate in the western US. *Environmental Research Letters*, 13(6). <https://doi.org/10.1088/1748-9326/aac4b1>
- Liangzhi, Y., Ringler, C., Nelson, G., Wood-Sichra, U., Robertson, R., Wood, S., Guo, Z., Zhu, T., and Sun, Y. (2010). What Is the Irrigation Potential for Africa? a Combined. *Sustainable Solution for Ending Hunger and Poverty Discussion Paper 00993*, June. <http://ageconsearch.umn.edu/bitstream/93736/2/ifpridp00993.pdf>
- Liangzhi, Y., Takeshima, H., and Xie, H. (2018). *Cultivating growth in Nigerian agriculture with small-scale irrigation*. International Food Policy Research Institute. <https://www.ifpri.org/blog/cultivating-growth-nigerian-agriculture-small-scale-irrigation>
- Lieth, H., and Oki, L. (2008). *Irrigation in Soilless Production* (J. H. L. Michael Raviv (ed.)). Elsevier. <https://doi.org/https://doi.org/10.1016/B978-044452975-6.50006-X>
- Mavani, D., and Prajapati, G. (2019). Sensor-based Drip Irrigation Using Solar Pump. *Global Sci. J.* 7(6), 388–392. https://doi.org/https://www.globalscientificjournal.com/researchpaper/Sensor_Based_Drip_Irrigation_Using_Solar_Pump.pdf
- McCarthy, A. C., Hancock, N. H., and Raine, S. R. (2013). Advanced process control of irrigation: the current state and an analysis to aid future development. *Irrigation Science*, 31, 183–192. <https://doi.org/dx.doi.org/10.1007/s00271-011-0313-1>
- Medugu, N. I., Majid, M. R., and Johar, F. (2011). Drought and desertification management in arid and semi-arid zones of Northern Nigeria. *Management of Environmental Quality: An International Journal*, 22(5), 595–611. <https://doi.org/10.1108/14777831111159725>
- Mgbenka, R. N., and Mbah, E. N. (2016). A Review of smallholder farming in Nigeria: need for transformation. *International Journal of Agricultural Extension and Rural Development Studies*, 3(2), 43–54. <https://www.eajournals.org/journals/international-journal-agricultural-extension-rural-development-studies-ijaerds/vol-3-issue-2-may-2016/review-smallholder-farming-nigeria-need-transformation/#:~:text=More than 80%25 of farmers, production resources avail>
- Montesano, F., and Parente, A. (2015). Irrigation Management of Greenhouse Tomato and Cucumber Using Tensiometer : Effects on Yield, Quality and Water Use. *Agriculture and Agricultural Science Procedia*, 4, 440–444. <https://doi.org/10.1016/j.aaspro.2015.03.050>
- Munoth, P., Goyal, R., and Tiwari, K. (2016). Sensor-based irrigation system: A review. *Int. J. Engg. Res. Tech.*, 4(23), 86–90. <http://www.ijert.org>
- Muñoz-carpena, R. (2004). *Field Devices For Monitoring Soil Water Content 1*. IFAS Extension University of Colorado. <https://doi.org/10.1201/9781420032086.ch5>
- Narayanamoorthy, A., Bhattarai, M., and Jothi, P. (2018). An assessment of the economic impact of drip irrigation in vegetable production in India. *Agricultural Economics Research Review*, 31(1), 105. <https://doi.org/10.5958/0974-0279.2018.00010.1>
- Ncube, B., Mupangwa, W., and French, A. (2018). Precision Agriculture and Food Security in Africa. In *Systems Analysis Approach for Complex Global Challenges*. Springer International Publishing AG, part of Springer Nature 2018. <https://doi.org/10.1007/978-3-319-71486-8>
- NEPAD. (2013). *African Agriculture, Transformation and Outlook*. <https://www.tralac.org/images/docs/6460/agriculture-in-africa-transformation-and-outlook.pdf>
- Nigerian National Committee on Irrigation and Drainage. (2021). *Country profile on Irrigation and Drainage*. https://doi.org/https://icid-ciid.org/member/country_profile1/71_A
- OECD. (2001). Adoption of Technologies for Sustainable Farming Systems. *Wageningen Workshop Proceedings*, 149. <https://doi.org/https://www.oecd.org/greengrowth/sustainable-agriculture/2739771.pdf>
- Parvan, A. (2011). Agricultural technology adoption: Issues for consideration when scaling-Up. *The Cornell Policy Review*, 5–31.

<https://doi.org/https://blogs.cornell.edu/policyreview/2011/07/01/agricultural-technology-adoption-issues-for-consideration-when-scaling-up/>

Perry, C. S., Steduto, P., and Karajeh, F. (2017). *Does improved irrigation technology save water? A review of evidence: Discussion paper on irrigation and sustainable water resources management in the Near East and North Africa* (C. Perry, P. Steduto, & F. Karajeh (eds.)). Food and agriculture organization of the united nations, cairo. <https://doi.org/https://www.fao.org/3/I7090EN/i7090en.pdf>

Reynolds, M., Kropff, M., Crossa, J., Koo, J., Kruseman, G., Molero Milan, A., Rutkoski, J., Schulthess, U., Singh, B., Sonder, K., Tonnang, H., and Vadez, V. (2018). Role of modelling in international crop research: Overview and some case studies. *Agronomy*, 8(12). <https://doi.org/10.3390/agronomy8120291>

Rosegrant, M. W., Ringler, C., and Zhu, T. (2009). Water for agriculture: Maintaining food security under growing scarcity. *Annual Review of Environment and Resources*, 34, 205–222. <https://doi.org/10.1146/annurev.enviro.030308.090351>

Saberi, E., Khashei Siuki, A., Pourreza-Bilondi, M., and Shahidi, A. (2020). Development of a simulation-optimization model with a multi-objective framework for automatic design of a furrow irrigation system. *Irrigation and Drainage*, 69(4), 603–617. <https://doi.org/10.1002/ird.2460>

Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M., and West, P. C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11.

Sanni, S. A., Oluwasemire, K. O., and Nnoli, N. O. (2012). Traditional capacity for weather prediction, variability and coping strategies in the front line states of nigeria. *Agricultural Sciences*, 03(04), 625–630. <https://doi.org/10.4236/as.2012.34075>

Sawa, B. A., Ati, O. F., Jaiyeoba, I. A., and Oladipo, E. O. (2015). Trends in Aridity of the Arid and Semi-Arid Regions of Northern Nigeria. *Journal of Environment and Earth Science*, 5(10), 61–69. <https://core.ac.uk/download/pdf/234664246.pdf>

Schütze, N., and Schmitz, G. H. (2010). OCCASION: New Planning Tool for Optimal Climate Change Adaption Strategies in Irrigation. *Journal of Irrigation and Drainage Engineering*, 136(12), 2010. [https://doi.org/https://doi.org/10.1061/\(ASCE\)IR.1943-4774.0000266](https://doi.org/https://doi.org/10.1061/(ASCE)IR.1943-4774.0000266)

Seidel, S. (2012). *Optimal Simulation Based Design Dresdner Schriften zur Hydrologie*.

Semenov, M. A. (2009). Impacts of climate change on wheat in England and Wales. *Journal of the Royal Society Interface*, 6(33), 343–350. <https://doi.org/10.1098/rsif.2008.0285>

Shanono, N. J., Bello, M. M., Zakari, M. D., Ibrahim, A., Usman, I. M., Nasidi, N. M., and Maina, M. (2020). Stakeholders Conflict And Infrastructural Decay In Nigerian Irrigation Schemes: A Review. *Nigerian Journal of Engineering Science and Technology*, 6(1), 78–90. http://www.njestr.com.ng/article.php?_open&_eid=NJE-866376

Shanono, N. J., Isma'i, H., Nasidi, N. M., Yahya, M. N., Umar, S. I., Nuradeen, A. Y., Musa, A. M., Mustapha, Z., Dantala, M. Z., and 1D. (2021). Assessing the Operational Performance and Stakeholders' Perceptions on the Management of Irrigation Projects in Kano, Nigeria. *COMU J. Agric. Fac.*, 9(2), 317–325. <https://doi.org/10.33202/comuagri.936306>

Shanono, N. J., Nasidi, N. M., and Isma'il, H. (2021). Framework for Quantitative Incorporation of Human Behaviour into Irrigation Schemes Performance Assessment. *Academia Letters*, Article 43(December), 1–6. <https://doi.org/https://doi.org/10.20935/AL4302>

Shanono, N. J., and Ndiritu, J. (2021). Modelling and assessing the impact of illegal water abstractions by upstream farmers on reservoir performance. *Turkish Journal of Geoscience*, 2(2), 47–54. <https://doi.org/10.48053/turkgeo.1011374>

Sharma, V., Singh, P. K., Bhakar, S., and Yadav, K. K. (2019). Integration of Soil Moisture Sensor Based Automated Drip Irrigation System for Okra Crop Integration of Soil Moisture Sensor Based Automated Drip Irrigation System for Okra Crop. *Indian Journal of Pure and Applied Biosciences*, 7(4r), 277–282. <https://doi.org/10.18782/2320-7051.7642>

Singels, A., Annandale, J. G., Jager, J. M. De, Schulze, R. E., Durand, W., Rensburg, L. D. Van, Heerden, P. S. Van, Crosby, C. T., Green, G. C., and Steyn, J. M. (2013). *Modelling crop growth and crop water relations in South Africa: Past achievements and lessons for the future*. 1862. <https://doi.org/10.1080/02571862.2010.10639970>

Soundharajan, B., and Sudheer, K. P. (2009). Deficit irrigation management for rice using crop growth simulation model in an optimization framework. *Paddy and Water Environment*, 7(2), 135–149. <https://doi.org/10.1007/s10333-009-0156-z>

Thompson, R. B., and Gallardo, M. (2005). Use of Soil Moisture Sensors for Irrigation Scheduling. *Improvement of Water Use Efficiency in Protected Crops*, January, 1–6. https://doi.org/https://www.researchgate.net/publication/285422793_Use_of_soil_sensors_for_irrigation_scheduling/link/566481dc08ae418a786d6a93/download

Ullah, A., Saqib, S. E., and Kächele, H. (2022). Determinants of Farmers' Awareness and Adoption of Extension Recommended Wheat Varieties in the Rainfed Areas of Pakistan. *Sustainability*, 14(3194), 1–18. <https://doi.org/https://doi.org/10.3390/su14063194>

Umar, D. A., Umar, H. A., and Tukur, A. I. (2017). Climate variability and water supply: a review of rural water planning techniques for semi-arid region of nigeria. *Dutse Journal of Pure and Applied Sciences*, 3(2). https://www.researchgate.net/publication/323737877_climate_variability_and_water_supply_a_review_of_rural_water_planning_techniques_for_semi-arid_region_of_nigeria

UNEP-WCMC. (2007). *A spatial analysis approach to the global delineation of drylands areas of relevance to the CBD Programme of Work on Dry and Subhumid Lands. Dataset based on spatial analysis between WWF terrestrial ecoregion*

- (Vol. 7, Issue 3). https://doi.org/https://www.unep-wcmc.org/system/dataset_file_fields/files/000/000/091/original/Global-Drylands-FINAL-LR.pdf?1398440625
- UNESCO. (2017). *World Water Assessment Programme (UNESCO WWAP): Facts and Figures*. <http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/all-facts-wwdr3/fact-24-irrigated-land/>
- Viswanathan, P. K., Kumar, M. D., and Narayanamoorthy, A. (2016). *Micro Irrigation Systems in India: Emergence, Status and Impacts (India Studies in Business and Economics)*. Springer International Publishing Switzerland 2016. <https://doi.org/10.1007/978-981-10-0348-6>
- Wallach, D., Makowsk, D., Jones, J., and Brun, F. (2006). *Working with Dynamic Crop Models Evaluation, Analysis, Parameterization, and Applications* (D. M. and J. J. Daniel Wallach (ed.); first). Academic press. <https://www.elsevier.com/books/working-with-dynamic-crop-models/wallach/978-0-444-52135-4>
- Walser, S., Schütze, N., Marcus, G., Susanne, L., and Schmidhalter, U. (2011). Evaluation of the transferability of a SVAT model—results from field and greenhouse applications. *Irrigation and Drainage*, 60(SUPPL. 1), 59–70. <https://doi.org/10.1002/ird.669>
- Wang, J., Mendelsohn, R., Dinar, A., and Huang, J. (2010). How Chinese Farmers Change Crop Choice to Adapt to Climate Change. *Climate Change Economics*, 1(3), 167–185. <https://doi.org/10.1142/S2010007810000145>
- Wang, Q., Klassen, W., Li, Y., Codallo, M., and Abdul-Baki, A. A. (2005). Influence of cover crops and irrigation rates on tomato yields and quality in a subtropical region. *HortScience*, 40(7), 2125–2131. <https://doi.org/10.21273/hortsci.40.7.2125>
- Wei, L., Awais, M., Ru, W., Shi, W., Ajmal, M., Uddin, S., and Liu, C. (2020). Review of Sensor Network-Based Irrigation Systems Using IoT and Remote Sensing. *Advances in Meteorology*, 2020. <https://doi.org/10.1155/2020/8396164>
- Wheeler, W. D., Thomas, P., van Iersel, M., and Chappell, M. (2018). Implementation of sensor-based automated irrigation in commercial floriculture production: A case study. *HortTechnology*, 28(6), 719–727. <https://doi.org/10.21273/HORTTECH04114-18>
- White, R. P., and Nackoney, J. (2003). DRYLANDS , P EOPLE, AND ECOSYSTEM GOODS AND SERVICES : A Web-Based Geospatial Analysis. *World Resources Institute, February*, 1–58. <http://www.wri.org/>
- Whitford, G. W., and Duval, D. B. (2020). *Ecology of the Desert System; Chapter 1 - Conceptual Framework, Paradigms, and Models* (second). Imprint Academic Press. <http://dx.doi.org/10.1016/j.jss.2014.12.010><http://dx.doi.org/10.1016/j.sbspro.2013.03.034><https://www.iiste.org/Journals/index.php/JPID/article/viewFile/19288/19711><http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.678.6911&rep=rep1&type=pdf>
- Zaccaria, D., Carrillo-Cobo, M. T., Montazar, A., Putnam, D. H., and Bali, K. (2017). Assessing the viability of sub-surface drip irrigation for resource-efficient alfalfa production in central and Southern California. *Water (Switzerland)*, 9(11), 1–21. <https://doi.org/10.3390/w9110837>
- Zakari, M. D., Audu, I., Igbadun, E., Shanono, N. J., Maina, M. M., Nasidi, N. M., and Shitu, A. (2020). *Yield and Water-Use of Tomato under Deficit-Irrigation and Mulch Practices at Kano River Irrigation Project*. 6(1), 78–90.
- Zakari, M. D., Audu, I., Igbadun, H. E., Nasidi, N. M., Shanono, N. J., Ibrahim, A., Mohammed, D., A.A. Sabo, and Usman, I. M. T. (2019). effects of deficit irrigation and mulch practices on yield and yield response factors of tomato (*lycopersicon esculentum*) at kano. *bayero journal of engineering and technology*, 14(2), 209–225. <https://www.bayerojet.com>
- Zakari, M. D., Dalhat, H. N., Ohiudi, I. S., Shamsu, S., Mohammed, D., Ahmadu, S. E., Ibrahim, A., Nasidi, N. M., Shanono, N. J., and Sabo, A. A. (2021). Assessing the farmers' awareness and practices of irrigation water conservation techniques in Kano – Nigeria. *Algerian Journal of Engineering and Technology*, 05, 14–18. <https://jetjournal.org/index.php/ajet>



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