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SMART TECHNIQUES FOR IMPROVING WATER USE UNDER THE CONDITIONS OF ARID AND SEMI-ARID ENVIRONMENTAL AREAS: A REVIEW

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Abstract

Climate change will have a negative impact on the elements of agricultural devel-opment, especially in developing countries. Water plays a role as one of the most im-portant elements of social and agricultural development, including food security, indus-trial development, housing, urbanization and all other aspects of human life activities. In light of this, water scarcity appears to be a real big problem for the global economy in the near future.Egypt is one of those countries that may be exposed to the effects of climate change. Due to the limited water resources in Egypt, agriculture sector is the main con-sumer of water in Egypt (85%). It is one of the imperatives that the agricultural policy must adopt in Egypt to work in all directions and by all means to rationalize the water use and raise the water use efficiency in all aspects of uses, especially agricultural. For these reasons, there is a possibility to reduce the amount of water used in agri-culture and to maximize the water use to achieve water security through integrated management, as well as developing irrigation systems and using modern and smart tech-niques and technologies in agriculture. Therefore, there are some methods and techniques that can be used to maximize and improve water use in the agricultural sector: 1) Development of surface irrigation using self-compensating gated pipe irrigation technique for improving water use and yield compared to traditional gated pipe. 2) Using surge flow to increase distribution efficiency and reduce deep percolation compared to continuous irrigation. 3) The use of on-farm real-time technologies for surface irrigation systems reduces irrigation labor and plays a role in improving water use. 4) Applying IoT technologies and smart irrigation as a good tool to control everything in agriculture and make the right decision at the right time, especially irrigation water management. 5) Using ground image processing to measure the percentage of green cover (PGC) in order to estimate crop water requirements. 6) Reuse of agricultural drainage water, subsurface irrigation as one of the effective techniques that can be used in irrigation water management.

Keywords: Water use, Farm real-time, IoT technologies,Smart irrigation, Image processing, Agricultural drainage.

1. Introduction

Water is the most important element for social and agricultural development including food security, industrial development, housing and urban expansion and all other aspects of human life activities. In this light, water scarcity appears to be a real big problem for the global economy in the near future. Therefore, water consumption must be improved, in all life activities, and water treated as a rare and important commodity (Marwa et al., 2018 and Abdelraouf et al., 2020 a,b). Saving irrigation water is one of the most important objectives of agricultural policies for sustainable development, climatic changes and facing the increasing population requirements against the constant or probable decrease of water resources of Egypt (Marwa et al., 2017 and Eid and Negm 2019). The main goals of irrigation development are optimizing the water use in agriculture and increasing the irrigation efficiency. To achieve these goals, ideal design irrigation systems must be developed (El-Shafie et al., 2018). El-Shafie et al., (2017) and Dewedar et al., (2021 a,b) indicated that, the modified irrigation using a regulated gated outlet as a new technique leads to an increase in soil moisture and thus

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an increase in the yield compared to traditional irrigation. Therefore, the use of most effective methods to maximize the irrigation water use efficiency is one of the most important goals today, so there are many smart irrigation techniques that are used in farms today for this purpose (Dieter et al., 2018). Also, In the Egyptian agricultural sector, according to the strategy for sustainable agricultural development until 2030, there are six main strategic goals (MALR, 2014): 1) Using natural resources in a more sustainable way by enhancing irrigation water use in the agricultural sector. 2) Increasing and improving water productivity and land units. 3) Increasing the degree of awareness and food security for strategic commodities. 4) Supporting the competitiveness of agricultural products. 5) Increase and support agricultural investments by providing a good economic climate. 6) Providing job opportunities, especially for rural youth, in order to help them overcome poverty. Increasing and maximizing water use is one of the priorities of agricultural strategies. Koech and Langat, (2018), Marwa et al., (2020) and Abdelraouf et al., (2012). mentioned that, a major goal in many countries is to improve water use for integrated water and land management. This can be achieved through a lot of procedures that can all lead to lessen water consumption by plant and improve irrigation water use. In other words, obtain the best productivity from a water unit.

Therefore, the main goal of this review article is to present some smart techniques for improving water use in the agricultural sector under arid regions conditions.

1- Definition of water use

Water use can be defined as total water that is applied by irrigation systems to preservation of plant growth in agricultural procedures. In order the water that is used for initial -irrigation, rime protection, chemigation, weed control, field organization, crop cooling, harvesting and leaching requirements (Dieter et al., 2018). Estimates of irrigation withdrawals are generally calculated from the difference between the point of water supply (wells, springs, streams, and ponds) and on field water application point as shown in Fig. 1 the flowchart of water use definition. It includes water that was lost in conveyance prior to application on fields, as well as water that may return to the surface of as runoff after application, also, water is consumed through evapotranspiration (ET) from plants and evaporated from the soil, or water that recharges aquifers as it leaks through the root zone (Templin et al., 2016). From an engineering point of view, water use is defined simply, that it is the ratio between the water that is provided through irrigation and that is used dynamically for growth by the plant; it can be measured by application Eq. (1 and 2),

$$AE = \frac{\text{volume of water stored in the root zone}}{\text{total volume of water applied}} \quad (1)$$

$$RE = \frac{\text{volume of water stored in the root zone}}{\text{water deficit prior to irrigation}} \quad (2)$$

Where: AE is application efficiency and RE is requirement efficiency.

While, water use performance analysis, AE and RE are only applicable in the field case and this definition is used on-farm irrigation management. Moreover, there are water losses through the water conveyance and delivery channels before reaching the field. Further losses may occur due to evaporation and leakage from the canals sides. Performance measures used in these cases include transport, distribution, and storage efficiency. So, the assessment can be done at the level of a catchment or a basin (Koech and Langat, 2018).

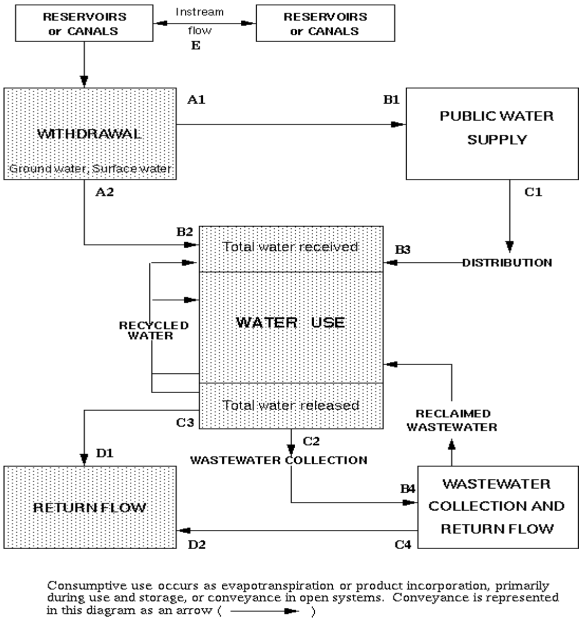

Fig. 1. Flowchart of water use definition.

2- How to improve water use?

It is important to know that global freshwater resources are finite and non-renewable. So, it is very important to approach water management for sustainable agriculture in a more meaningful way (Nair, 2019 and Abdelraouf et al., 2021).

Whereas if runoff and evaporation are controlled from free direct water surfaces, if evaporation losses from the soil surface are reduced and effective weed control is carried out. Moreover, using irrigation scheduling in quantities that suit crop requirements to avoid deep percolation, all losses can be reduced to less than 20% of the water used. Then the irrigation water use efficiency can reach 80% or more (El-Naggar, 2020; Sakthivadivel, 2017).

Nair, (2019) and Hozayn et al., (2016) recommended some points to improve water use. 1) Reducing conveyance losses and evaporation from free surfaces by using large water conveyance pipes. 2) Irrigation in the early morning or at night to reduce evaporation during irrigation. 3) Reducing excessive irrigation of plants to control losses by runoff and deep percolation. 4) Use of various methods to cover the soil surface to reduce evaporation from the soil surface. 5) Integrated weed control to reduce water consumption from weeds. 6) Use zero or minimum tillage, the use of effective organic and biological fertilization and the use of fertilizer injection methods during the irrigation system. 7) Periodically measure soil salinity, monitor the water table, design and choose the optimal drainage system. 8) Carrying out irrigation operations in accurate and appropriate amounts without reaching water shortages, taking into account climate changes and the of crop growth stages. Also, there are matters, as it is no less important than the above, as water use can be improved through the selection of crops and varieties that consume lesswater, fertilization methods, agricultural operations, and the appropriate timing for planting and harvesting. Novel irrigation methods and applications can improve water use, while achieving economic expansion while also reducing environmental impacts (Levidow, 2014 and Youssef et al., 2017).

From the above, the importance of improving water use for integrated water management was defined. Therefore, in the following, some methods and techniques used to maximize and improve water use in the agricultural sector will be presented.

3- Development of surface irrigation

3.1. Self- compensating gated pipe irrigation technique

Surface irrigation is one of the major methods of irrigation in Egypt (El-Shafie et al., 2018). In Australia, surface irrigation is accounts for 59% of the total irrigated land (ABS, 2018). Ali and Mohammed, (2015) noted that waterlogging and low application efficiency are the main problems inherent with surface irrigation in the Nile Delta. So, surface irrigation development using gated pipes (GP) provides an important new tool to improve its performance according to agricultural policies. Also, mentioned that, the improving Surface Irrigation Efficiency in Maize Hybrids used gated pipe irrigation. Use of gated pipes technique as compared to traditional irrigation reduced water use by 5.7% and increases in yields by 3.4%. It is concluded that the gated pipes technique is better than traditional irrigation for improving water and maize productivity under Nile Delta conditions.

El-Shafie et al., (2017) designed a self-compensating gated outlet to improve water use under a surface irrigation system. The field results concluded that, there are homogeneity in soil moisture distribution and improvement of water use, due to the regularity of water distribution under surface irrigation system use of pressure compensating gated pipe, thus an increase in water use and yield compared to traditional gated pipe. The increase in the uniformity of distribution along the pipeline is due to the gated outlet is designed and supplied with silicone rubber in the direction of the water outlet as shown in Fig. 2. When the pressure increases, the gate partially closes. This leads to reduce the outflow and this will increase the uniformity of distribution along the pipeline.

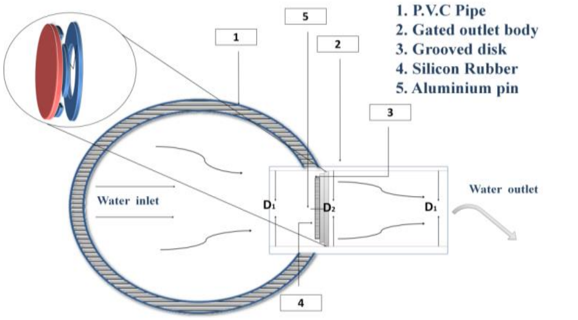

Fig.2.Gate outlet operation mechanism with side view.

3.2. Automatic surge flow

Due to the runoff losses in continuous irrigation under surface irrigation methods, surge flow irrigation is preferable to reduce these losses. In surge flow irrigation, the water is opened and closed at intervals, and the soil surface is significantly saturated, so the soil becomes smooth for the flow of water to the end of the field compared to continuous irrigation. This reduces losses due to runoff and deep percolation (Mostafazadeh-fard et al., 2006).

Surge flow irrigation is a discontinuous application of water and is thorough by on and off the water between two irrigation sets. The use of surge flow increased distribution efficiency and reduced deep percolation compared to continuous irrigation (Bayush, 2020).

Amer and Attafy, (2017) studied two methods of irrigation, surge flow irrigation, continuous irrigation, and two different discharges. The highest values of water saving were obtained under the surge flow irrigation treatment and on and off cycles. Performance technology of surge flow indicators have been improved such as, water required for each irrigation, seasonal irrigation water requirement, runoff, application efficiency, storage efficiency, and uniformity of distribution. The surge flow method is better compared to continuous irrigation.

Mostafazadeh-fard et al., (2006) made an automatic valve to control the operation of the surge flow with gated pipe irrigation Fig. 3. The system includes an automatic valve that the farmer can easily adjust according to field conditions such as changing soil infiltration characteristics during the irrigation season. The system was a furrow irrigation that was irrigated by automatic surge flow with an irrigation cycle of 10 min on and 10 min off. The results indicated that the system is easy to accurately irrigate by automatic surge under furrow irrigation. There is a better advance time with surge flow compared to the continuous flow with used the same discharge of applied water.

Abdullah and Abdullah, (2017) designed and evaluated a simple Automatic surge flow for improving water use under furrow irrigation system using solar energy as shown in Fig. 3. The data indicated that that the innovative technology is able to give high efficiency with a coefficient of variation (CV) less than 10%. Also the results showed that the system could generate enough power to control of opening and closing on the perforator outside the machine and open a lot of time and synchronize the closing time. Finally, the new automatic surge flow irrigation is economical and easy to move. Finally, the automatic surge flow system can reduce water loss and improve irrigation performance and easy to use.

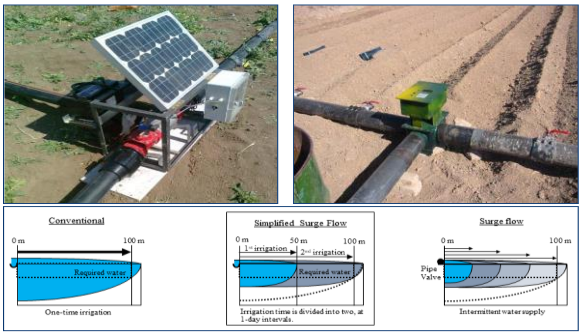

Fig. 3.Automatic surge flow.

3.2. Real time management systems for surface irrigation

Real time farm technologies for surface irrigation systems are focused on reducing irrigation labor and play a role in improving water use. Due to this, water losses are less under automatic surface irrigation systems due to less human intervention. Smith et al., (2016) developed an automatic system for surface irrigation that based on moisture sensors to determine the advanced and recession time. The results showed that the application efficiencies were improved in the fields in which the system was applied. The irrigation system was working well in northern Victoria .

At the same trend (Koech et al., 2014) used the same technology and recommended that this system be used as it led to an improvement in water use efficiency on the farm and to save labor. Also, recommended that this system be used as it led to an improvement in water use efficiency on the farm and to save labor Fig. 4 shows the FloodTech sensor diagram.

4. IoT and smart irrigation

The Internet of Things (IoT) is a good tool for controlling everything in agriculture, especially irrigation water management. Several researchers have studied the role of the Internet of Things in improving water use (Ramachandran et al., 2018). Ryu et al., (2015) mentioned that, the Internet of Things (IoT) uses new technologies, for example, sensor, network, and computing technologies to enable new applications and services. Smart farming technologies using Internet of Things (IoT) have enabled farmers to solve their big problems. The system taking the right decision at the right time, the system also gave those appropriate solutions and various treatments (Saha et al., 2021).

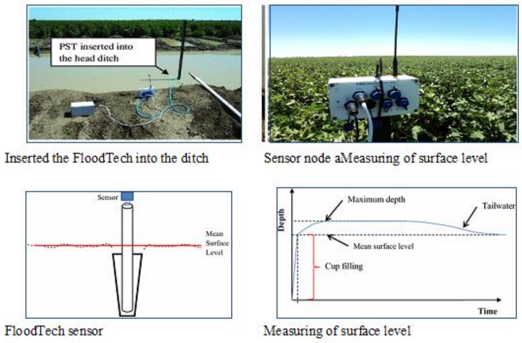

Fig. 4. Install the FloodTech control system in the field.

On the other hand precision agriculture using the Internet of Things is a broad class of related technologies that will maintain precise control over farm decisions. This method of planting decisions is intended for specific crops and not for an entire region. Precision farming combines agricultural machinery and efficient agricultural operations to meet the specific needs of farmers. For example, making the best decision to manage irrigation systems by automatic scheduling irrigation, and knowing the plants' need for water in actual amount and in real time (Mentsiev et al., 2020). Nawandar and Satpute, (2019) developed a low cost system used IoT technology for irrigation management. The Internet of Things has been used to make devices used to communicate on their own. An irrigation scheduling system was also put in place to improve water use efficiency, as this resulted in smart support and remote data monitoring. Through the results, it became clear that the system has a great benefit as it is characterized by its intelligence, low cost and easy transport, which makes it suitable for different crops under of climatic changes conditions .

IoT technology is a good tool for tracking and observing all around conditions of crops such as climate data, ambient humidity, temperature and soil moisture. Also, the monitoring and observation of crops using IoT technology gives the right decision at the right time, such as scheduling and managing irrigation water (Balakrishna and Rao, 2019).

Balamurali and Kathiravan, (2015) recommended a design for a remote sensor system for water control and monitoring that is made up of various sensor hubs with a systems administration capability that is delivered on the fly for the purpose of continuous testing. Sensor data will be transmitted to the base station. In light of the results, the future system provides a lower amount of power consumption with high unwavering efficiency. The use of high-power wireless sensor networks is suitable for tasks in industries such as manufacturing, irrigation technology growth, and so on .

Nigussie et al., (2020) developed An IoT platform for smallholders that monitor soil, climate and water parameters for good irrigation system management. It provided information on local agriculture, expert knowledge, region's climate information, crop characteristics, and soil and water analyses. This is so that the system can make accurate decisions to manage irrigation systems in order to maximize water use. Moreover, the use of renewable energy sources and the intelligent data analysis algorithm for the various elements are investigated. The study recommended that IoT platforms are a smart framework for processing data that can be used to make appropriate decisions and help more agricultural knowledge. Increased crop production is supported by the IoT irrigation management system, which maximises the use of available resources while minimising environmental effects Fig. 5 shows irrigation control system building style at the system level.

Smart irrigation based on ARDUINO controller is the process of taking the easy appropriate decisions and that is the answers to two key questions: When to irrigate? What is the amount of water needed for irrigation? The main goal of smart irrigation is to codify and rationalize the use of water for irrigation to ensure reducing losses to a minimum and raise the efficiency of its use to the maximum, and get the highest return of production (Nandhini et al., 2017).

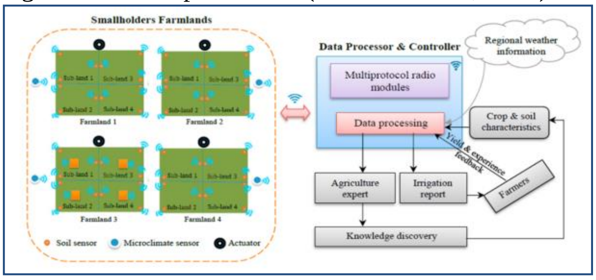

Fig. 5.Irrigation control system building style at the system level

The modern advances in the fields of “automatic control and modern communication technologies as well as computer applications” made it possible to compose a low cost electronic system to control the irrigation process from A-Z. Recently, during the last three years, some scientific articles concerning automatic control systems or smart system for irrigation, started to be shown up in some electronic engineering journals and conferences. Most of these papers based on using ARDUINO micro-controller system and moisture sensors to carry out their proposals. Nearly, all their findings came to the same conclusion that, the micro-irrigation ARDUINO implemented system was found to be feasible and cost effective for optimizing water resources for agricultural production, Parameswaran and Sivaprasath, (2016); Abhishek and Magesh, (2017); Asadullah and Ullah, (2017); Đuzić and Đumić, (2017); Taneja and Bhatia, (2017) and Nandhini et al., (2017).

The concept of using the ARDUINO microcontroller to control automatic irrigation can be illustrated in the block flow chart, Fig. 6.ARDUINO system uses soil moisture sensors to record the decrease of soil moisture to the critical limit for the plant growth. Then it alerts an electronic board based on, pre-programmed to pass the appropriate quantity of water to reach the field capacity or to the saturation capacity of the soil with automatic on/off the valves (Wahba, 2019).

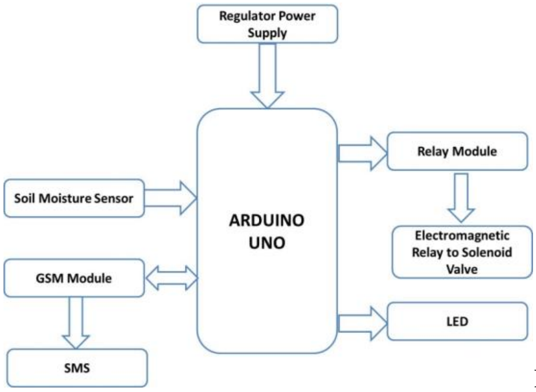

Fig. 6. Flowchart of automatic irrigation operating system with an ARDUINO system

Wahba, (2019) concluded that the control system consists of the following: (Fig. 7). 1) Main control unit: It is a microcontroller part which can read the soil moisture content by mean of the soil moisture sensors. The sensors give order to the automatic water valves to open to pass the required water to the crop area. The valve will be closed according to the moisture sensor reading sent to the micro controller. 2) Moisture sensors: This can read the moisture contents in the soil during the irrigation cycle and send it to the microcontroller. 3) Solenoid valves: to pass the required water to each crop. 4) Communication unit (SIM 900): This unit communicates with the microcontroller by mobile ships. It can send the soil moisture data to a certain mobile number on calling. 5) Intermediate unit: Relays circuit that transmits the signal from the microcontroller to the automatic solenoid valves to be able to open or close safely without impairing the control unit. 6) Power supply unit: to provide the microcontroller, moisture sensors, electric valves with electricity, necessary for running. Also, reported that with respect to the ARDUINO approach, which depends mainly on recording soil moisture sensors connected to ARDUINO control system, the system was configured, modified, calibrated and primary tested in the lab and the field to determine the opening and closing points of the irrigation system.

Fig. 7.The components of automatic irrigation with an ARDUINO system.

1- Image processing for irrigation management

Due to a scarcity of water supplies, a framework for evaluating systems and the implementation of requirements to reduce water use have been established. Information technology integration in sensor networks and field stations (Bogena et al., 2007, Díaz et al., 2011), Water management is made much easier with this tool, which allows for precise control and tracking of water use. (Coates et al., 2013, Hernández-Hernández et al., 2016).The use of photographs is a specific technique for controlling water in crops and soils. (Segovia-Cardozo et al., 2019). The crop green or canopy cover photos provide an indication of how much water the crop is lost due to evapotranspiration (Li et al., 2018).

One of the most important technologies used in irrigation management applications and measuring crop water requirements is satellite image or aerial photography analysis. Due to the limitations of drones and satellites in obtaining real-time aerial images of crops, flight delay time, problems caused by adverse weather conditions, and other issues, fixed cameras installed in areas of interest are required to capture close-ups and choppy images, and photos upon request. One of the most important uses of these images is water management in agriculture (Molina-Martínez and García-Mateos, 2020). Images may provide useful information on the percentage of ground cover, which is essential for assessing crop irrigation requirements. Color analysis techniques allow for accurate and efficient classification of soil/plant regions in photographs (García-Mateos et al., 2015).

Fernández-Pacheco et al. (2014) in the southeast of Spain, researchers investigated a new approach based on computer vision for estimating the crop coefficient (Kc) of lettuce crops from the percentage of ground cover (PGC) derived from digital images .

Mateo-Aroca et al., (2019) created a remote image capture device for a lettuce crop application. The device is made up of several capture nodes and a local processing base station that uses image processing algorithms to extract key features for irrigation and harvesting strategy decision-making Fig. 8.

Using multiple image capture nodes, various observation zones indicative of the entire crop can be obtained. This station makes irrigation and harvesting decisions based on the effects of image processing by the nodes and information from other nearby sensors. The system's ultimate goal is to measure the percentage of green cover (PGC) in order to estimate the crop's water requirements.

2- Riser board for drainage water management

Due to high water table levels and seasonal water saturation conditions, some soils can hinder crop production due to irregular land or heavy clay soil types, as well as increased salinity (Jia et al., 2017).

One of the most important methods used to manage irrigation water is the reuse of agricultural drainage water below the soil surface as one of the effective techniques used in irrigation. The reuse of subsurface wastewater is done by using buried perforated tubes to drain the excess water and lowering the water table through the soil layers (Wang et al., 2004).

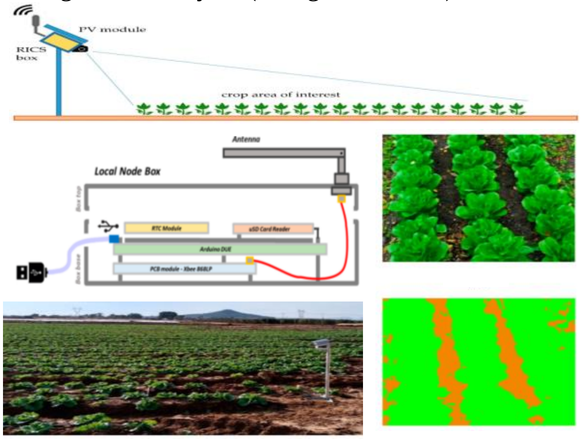

Fig. 8. Remote image capture system.

Developing groundwater management systems for on farms water level control systems by adding structures that can control agricultural drainage water and groundwater level. This may also include an aspect of sub-irrigation. Through a barrier to control the water outlet, in terms of time and the amount of drainage flow, as it maintains the depths of the groundwater at the required level. Therefore, the subsurface irrigation system is defined here as “the use of wastewater under the soil surface for irrigation by raising the level of the groundwater within the root zone or near of which (ASABE Standards, 2015).

The USDA has developed a technique to control the volume and timing of water discharges from agricultural drainage systems known as drainage water management. This approach is based on the idea that drainage rate does not have to be constant throughout the year. Under this technique, water quality and development benefits can be improved. The high water quality is obtained by reducing the amount of nitrate that leaves farm fields by eliminating excessive tile drainage. This technique can also be used to keep water in fields that will be used for crop production later in the season (Schott et al., 2017). Fig. 9 shows the riser board and how to work for drainage water management?

On the other hand Kolars et al., (2019) modified the method for managing agricultural drainage water. This method uses a model to calculate irrigation scheduling for drainage water, using the daily water balance due to the approximate flow from the groundwater table. The results indicated that a modified portable plate could be used for groundwater management.

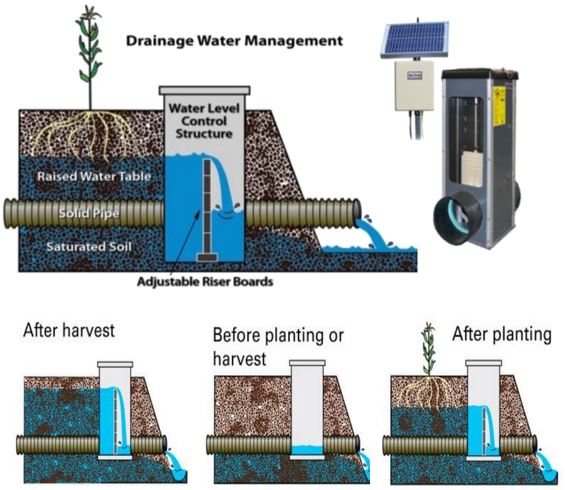

Fig. 9**.** Riser board for drainage water management.

CONCLUSION AND RECOMMENDATIONS

Due to the limited water resources,agriculture sector is the main consumer of water. It is one of the imperatives that the agricultural policy must adopt to work in all directions and by all means to rationalize the water use and raise the water use efficiency in all aspects of uses, especially agricultural.For these reasons, the use of water must be maximized to achieve water security through integrated management, as well as the development of irrigation systems and the use of modern and smart technologies and techniques in agriculture.

Therefore, there are some methods and techniques that can be used to maximize and improve water use in the agricultural sector: 1) Development of surface irrigation using self- compensating gated pipe irrigation technique for improving water use and yield compared to traditional gated pipe. 2) Using surge flow to increase distribution efficiency and reduce deep percolation compared to continuous irrigation. 3) The use of on-farm real-time technologies for surface irrigation systems reduces irrigation labor and plays a role in improving water use. 4) Applying IoT technologies and smart irrigation as a good tool to control everything in agriculture and make the right decision at the right time, especially irrigation water management. 5) Using ground image processing to measure the percentage of green cover (PGC) in order to estimate crop water requirements. 6) Reuse of agricultural drainage water, subsurface irrigation as one of the effective techniques that can be used in irrigation water management.

Finally, these previous approaches and techniques will save a significant amount of irrigation water, as well as have other practical and economic benefits.

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