Effect of Solar Powered Irrigation System on Crop Growth

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Abstract-

The solar powered irrigation system is an adaptive plants and crops irrigation system. The purposes of the irrigation system are to provide water delivering schedule to the crops to ensure all the crops have enough water for their healthy growth, to reduce the amount of water waste in irrigation, and to minimize the economic cost for the users. The system takes in real time data of the water content of the plant as input value, combines it with other parameters such as water cost schedule and precipitation on the crop field, runs the designed linear optimization system periodically and outputs the most efficient amount of water the plants need, which is translated by a specific actuation time of the water pumps. The linear optimization system, is able to make decisions for the users when to distribute water into the crops fields and how much water should be delivered. Given the number of factors to be considered and the different crop requirements to take into account for each type of plant, this problem became too complex to solve through simple management methods and has to be supported by automated systems such as the one provided in this work.

***Keywords*:** Irrigation system, water content, linear optimization, water pump, soil sensor.

1.0 Introduction

Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic generation is an efficient approach for using the solar energy. Solar panels (an array of photovoltaic cells) are nowadays extensively used for running street lights, for powering water heaters and to meet domestic loads. One of the applications of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in Nigeria. This is a green way for energy production which provides free energy once an initial investment is made.

Nowadays, one of the greatest problems faced by the world is water scarcity and agriculture being a demanding occupation consumes plenty of water. Therefore a system is required that uses water appropriately. Automated irrigation systems estimate and measure the diminution of existing plant moisture in order to operate an irrigation system and also restore water as needed while minimizing excess water usage.

Technological advancement is required to provide farmers with tools and resources to make farming more convenient and sustainable. Concepts of modern technologies in agricultural systems have given an important role for the improvement of agricultural productions e.g. crop yield, livestock production, aquaculture production, and sustainable agriculture, in order to maintain food security.

2.0 Literature Review

The world population is increasing at exponential rate. Therefore, managing agricultural production systems on a sustainable basis is one of the most critical challenges for the future of humanity. Technological advancements must be used to provide farmers with tools and resources to make farming more convenient and sustainable.

2.1 Theory of Solar Powered Irrigation System

Automated irrigation system is a form of dripping irrigation, in which a required amount of water is applied to crops at specific time intervals. A typical automatic irrigation system consists of a pump, mainline, laterals (spans) laid along ridges, emitting devices (sprinklers and end-guns) and accessories such as control switches, pressure gauges, a water meter and solenoid valves.

Automated irrigation system is a project which was developed to automate the usage of water based on the water requirement of crops in place of conventional irrigation system that allow water wastage.

2.2Centre Pivot Irrigation System

Is a form of sprinkler irrigation, in which a small amount of water is applied at frequent intervals (Ruffino 2009). A typical center pivot irrigation system consists of a pump, motor, mainline, laterals (spans) mounted on wheeled towers and equipped with a driving system, emitting devices (sprinklers and end-guns) and accessories such as control switches, pressure gauges, a water meter and safety valves. In this system the lateral is fixed at one end (the center of the field) and rotated around the field at some specified rotational speed (Jarrett and Graves, 2010). Water is generally supplied to the lateral through a buried pipe (mainline). Pivots are available as low, medium and high pressure units based on sprinkler or spray nozzle operating pressure (Evans and Sneed, 1996).

3.0 Methodology

In this irrigation system, solar energy generated from the solar panels is used for operating the automatic irrigation system. The automatic irrigation system was designed to continuously sense the moisture level of the soil and apply water when necessary. The system responds appropriately by sensing and watering the soil with the exact required quantity of water and then shuts down the water supply when the required level of soil moisture is achieved.

3.1IrrigationSystem Description

The irrigation system mainly consists of two modules, solar pumping module and automatic irrigation module. In solar pumping module a solar panel of required specification is mounted near the pump set.

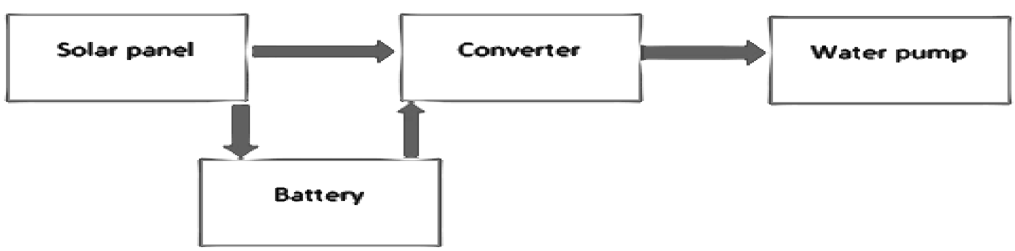

Figure 3.1.SolarPumpingModuleBlock Diagram

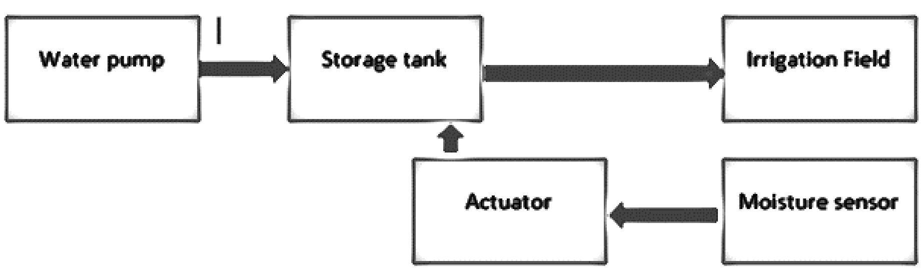

Figure 3.2.Automatic Irrigation Module Block Diagram

In automatic irrigation module the water outlet valve of the tank is electronically controlled by a soil moisture sensing circuit. The sensor is placed in the field where the crop is being cultivated. The sensor converts the moisture content in the soil into equivalent electrical voltage. This is used as input to sensing circuit which has a reference voltage that can be adjusted by the farmer for setting different moisture levels for different crops. The amount of water needed for soil is proportional to the difference of these two voltages.

3.2 Soil Moisture Content

This is a crucial factor in determining required irrigation amount and irrigation schedule. Soil water availability refers to the capacity of a soil to retain water available to plants. The total available water in the root zone can be expressed as follows.

$$TAW = 1000(\theta_{FC} - \theta_{WP})\ Z_r \qquad (3.1)$$

where TAW is the total available soil water in the root zone [mm], θ_{FC} is the water

content at field capacity [$m^3\ m^{-3}$], θ_{WP} is the water content at wilting point [$m^3\ m^{-3}$], Zr is the rooting depth [m].

Readily available water is that portion of the available water that is relatively easy for a plant to use. It is common to consider about 50% of the available water as readily available water [Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998].

$$RAW = p\ TAW \qquad (3.2)$$

where RAW is the readily available soil water in the root zone [mm], p represents average fraction of total available soil water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs.

Real time monitoring for soil moisture content could be achieved through simultaneously calculation for depletion ratio in soil moisture. This ratio should be prohibited from exceeding RAW amount, so as to avoid water stress occurrence. The percentage value of depletion in soil moisture could be calculated according to the formula:

$$d\ \% = ((\theta_{FC} - \theta_{Cm}) / (\theta_{FC} - \theta_{WP})) * 100\%\quad d < RAW \qquad (3.3)$$

where d is the percentage soil moisture depletion ratio, θ_{FC} is the water content at field capacity [$m^3\ m^{-3}$], θ_{WP} is the water content at wilting point [$m^3\ m^{-3}$], θ_{Cm} is current soil moisture [$m^3\ m^{-3}$].

3.3 Irrigation Quantity

Irrigation quantity is crucial issue in precision agriculture, since it affects a crop yield and quality.

Required irrigation amount depends on several vital parameters. One of these factors is a crop water requirements (ETc), which could be estimated according to equation 3.4 [Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998].

$$ETc = ET_0 \times Kc \qquad (3.4)$$

Where ETc the crop water requirements [mm day^{-1}], ET_0 the reference evapo-transpiration [mm day^{-1}], Kc the crop coefficient. The required net irrigation amount is estimated using equation below [Ketema Tilahun Zeleke and Leonard John Wade].

$$d_n = (\theta_{FC} - \theta_{Cm}) * Z_r \qquad (3.5)$$

Where d_n is current net irrigation amount [mm], θ_{FC} is the water content at field capacity [$m^3\ m^{-3}$], θ_{Cm} is current soil moisture [$m^3\ m^{-3}$], Zr is the rooting depth [m].

Additional, irrigation interval was calculated as [Iraqi Agribusiness Program, Irrigation Guidelines. 2012].

$$\Pi = d_n / ETc \qquad (3.6)$$

where Π is irrigation interval (day), d_n is net irrigation [mm], ETc crop water requirements [mm day^{-1}].

3.4 Irrigation Time (T)

Irrigation time is the time that it takes to apply the amount of irrigation water.

For drip irrigation system, time of irrigation on a management unit is calculated according to the equation below.

$$\boldsymbol{T} = \frac{\boldsymbol{d_n}}{\boldsymbol{q*N*E}} \quad (3.7)$$

where **T** is irrigation time [minute], d_n is net irrigation [mm], **E** is system efficiency %, **q** is nozzle discharge rate [1/s], **N** is number of nozzles.

Since q, N and E are constants which depend on the irrigation equipment information, the previous equation can be re-written as:

$$T = k * d_n \quad (3.8)$$

where $$k = \left(\frac{1}{q*N*E}\right) \quad (3.9)$$

4.0 Modelling of Crop Growth of Maize in Response to Irrigation

Maize has been a fruitful model organism for research in genetics for many years,

Barbara McClintock. Maize grain yield varies highly with water availability as well as with fertilization and relevant agricultural management practices.

The effective area of each experimental plot was approximately 21 m^2. The average fresh ear weight (G_1, kg) of each treatment was estimated and the average grain yield, Y ($kg \cdot ha^{-1}$), was computed as:

$$Y = k\ x\ \frac{G1}{20} x\ 10000 \quad (4.1)$$

where *k* is the ratio of grain dry weight to fresh ear weight for each treatment. To estimate the values of *k*, ten medium-sized ears were sampled from each experimental plot and their average fresh ear weight (G_2, kg) and average fresh grain weight (G_3, kg) were measured for each treatment.

Extra moisture in maize grain should be removed before estimating the average maize grain yield. The average moisture content of fresh grain for each treatment (*A*%) was therefore determined using a PM-8188 Grain Moisture Tester (Japan). Then *k* was calculated as:

$$k = \frac{G3}{G2}\ x\ \frac{(100-A)}{(100-18)} \quad (4.2)$$

4.1 Effect of Irrigation Scheduling and Rate on Plant Height

Plant height was significantly influenced by irrigation schedule as well as by level of irrigation applied. When water was applied either in split irrigations or as single applications, at two weeks after sowing (2WAS), the tallest plants were observed when water was given in three split portions in the morning, afternoon and evening (MAE), followed by single application of water in the morning (M). The least plant height at 2WAS was observed when water was given in two equal split applications in the afternoon and evening (AE). Subsequently, the tallest plants were observed in single application of water in the morning at 4, 6, 8WAS as well as final plant height. While application of water as split irrigation in the afternoon and evening (AE) consistently gave the shortest crops throughout the period of data collection.

4.2 Effect of Irrigation Scheduling and Rate on Plant Girth

Stem girth, which is a measure of a plant's stem width, is an indication of the stem ability to resist lodging resulting from wind or cob bearing. The assumption is that the thicker the girth the less breakable the stem would be either due to wind effect or as a result of cob bearing. Although plant girth was not significantly influenced by irrigation schedule at 2, 4, 6, 8WAS as well as final plant girth taken prior to crop harvest, the stem girth actually responded positively to irrigation application though not significant. The widest girth was obtained with split application of irrigation given in the morning and evening (ME), while the least result was seen in a single application of irrigation in the afternoon (A).

4.3 Determination of IWR for Maize (*Zea-mays)* Plant

Maize irrigation requirement for each month was computed using equation in accordance with James (1988), expressed as:

$IWR_{maize} = ET_{maize} - R_e$

Where: IWR_{maize}= Maize irrigation water requirement (mm/day)

R_e= Effective rain fall (mm/day)

Table 4.1. Effect of irrigation scheduling and rate on plant height and girth in maize with application of water

Irrigation Schedule	Mean Plant Height (cm)					Mean Stem Girth (cm)				
	2WAS	4WAS	6WAS	8WAS	Final Height	2WAS	4WAS	6WAS	8WAS	Final Girth
MAE	32.47	52.20	90.00	107.00	240.01	1.10	1.33	1.55	1.56	1.66
MA	29.00	42.53	89.13	99.83	225.30	0.93	1.07	1.20	1.30	1.52
ME	27.37	39.33	84.60	99.63	234.50	0.97	1.13	1.67	1.79	2.07
AE	16.17	31.10	51.60	71.67	203.07	0.70	0.73	0.76	0.91	1.17
M	29.93	53.30	112.00	123.57	241.07	1.13	1.20	1.27	1.28	1.47
A	17.23	33.43	62.90	93.50	221.40	0.70	0.72	0.79	0.82	1.23
E	28.33	33.40	73.67	88.67	219.10	0.61	0.83	1.08	1.10	1.17

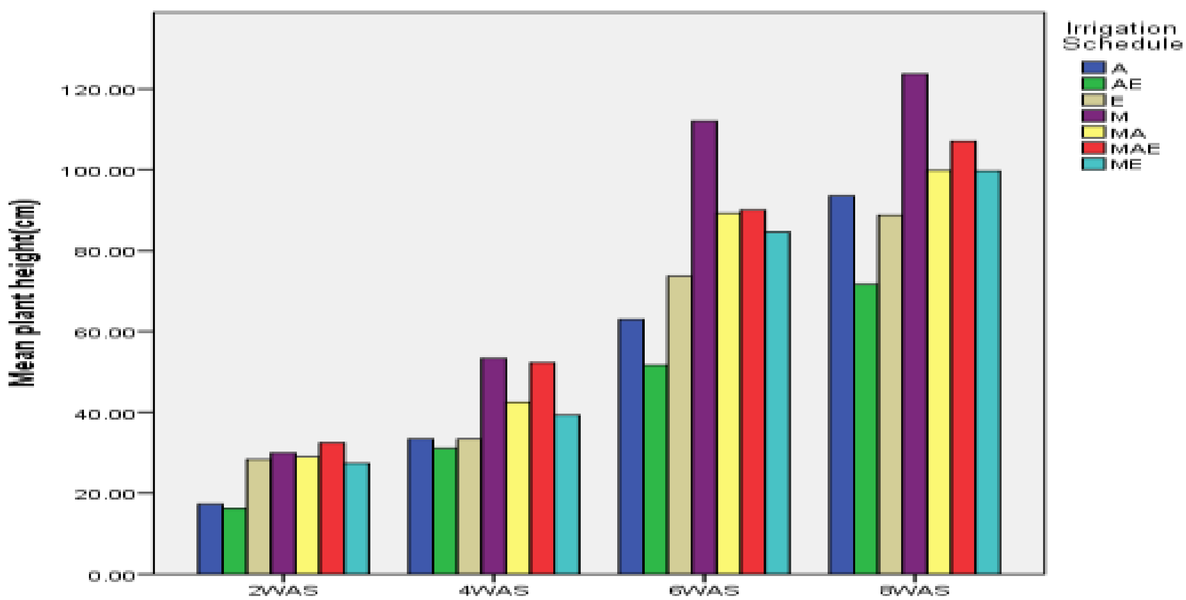

Figure 4.1. Comparison of Maize Mean Plant Height

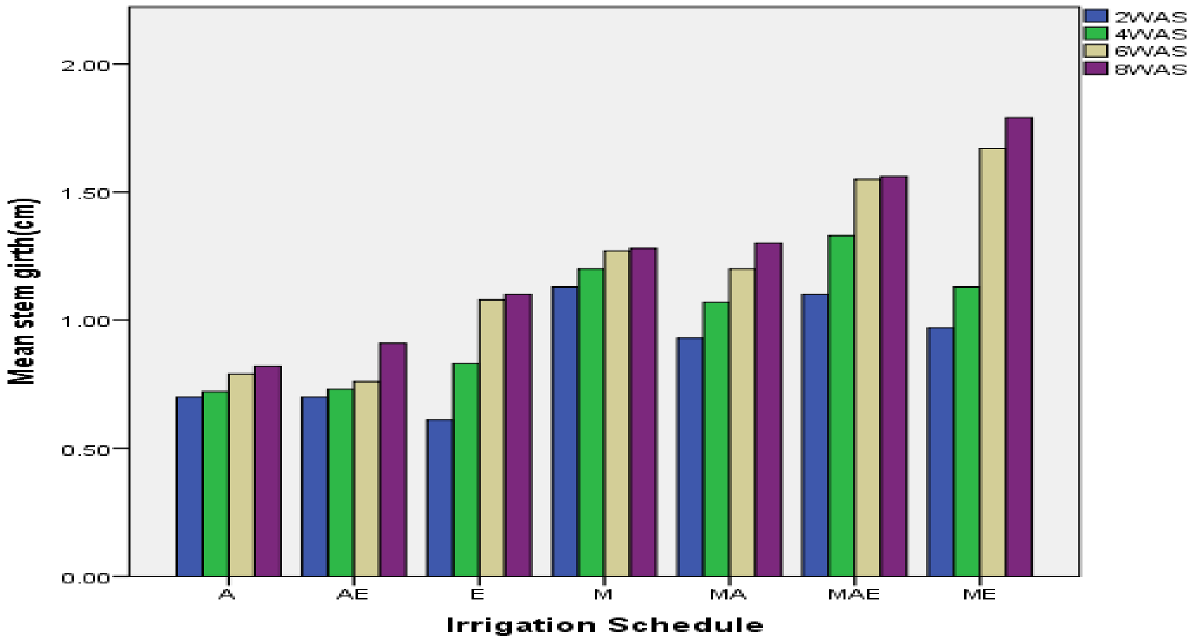

Figure 4.2. Comparison of Maize Mean Stem Girth

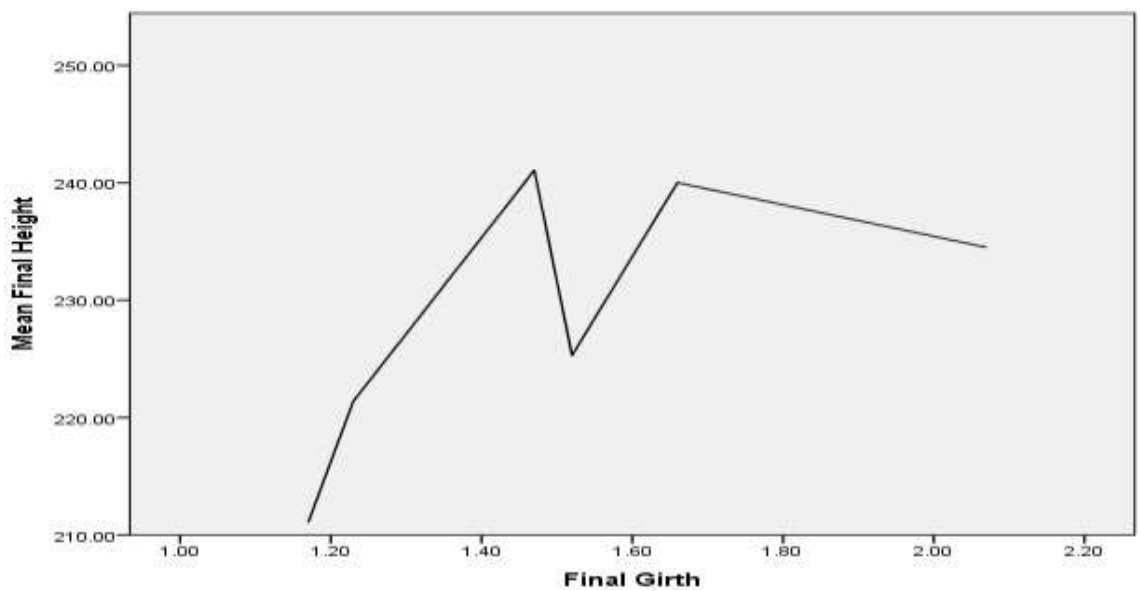

Figure 4.3. Maize Growth Performance against Time

Plant height was significantly influenced by irrigation schedule as well as by level of irrigation applied. When water was applied either in split irrigations or as single applications, at two weeks after sowing (2WAS), the tallest plants were observed when water was given in three split portions in the morning, afternoon and evening (MAE), followed by single application of water in the morning (M). The least plant height at 2WAS was observed when water was given in two equal split applications in the afternoon and evening (AE). Subsequently, the tallest plants were observed in single application of water in the morning (M) at 4, 6, 8WAS as well as final plant height. The application of water as split irrigation in the afternoon and evening (AE) consistently gave the shortest crops throughout the period of data collection.

Although plant girth was not significantly influenced by irrigation schedule at 2, 4, 6, 8WAS as well as final plant girth taken prior to crop harvest, the stem girth actually responded positively to irrigation application though not significant. The widest girth was obtained with split application of irrigation given in the morning and evening (ME), while the least result was seen in a single application of irrigation in the afternoon (A).

Yield of cob (undehusked and dehusked), grain yield per plant as well as grain yield per plot responded significantly to irrigation application. When irrigation water was applied, the highest grain yield was observed in single application of water in the morning. The least grain response was observed when irrigation water was given in the afternoon.

Yield responses to water stress have been reported by Rucker *et. al*. (1995), Farooq *et. al* (2009), Jamileh and Moghadam (2015), noting that prevailing water stress reduces plant growth and development, leading to hampered flower production and grain filling and thus smaller and fewer grains.

5.0 Conclusion

In this research work, we successfully develop a system that can help in an automated irrigation system by analyzing the moisture level of the ground. The grounded sensors all around the farming land will give notification about the need of water and accordingly it will be supplied.

Automatic irrigation control system was modelled, constructed and operated. The prototype of the system worked according to specification satisfactorily. The system components are readily available, relatively affordable and they operate quite reliably. The system helps to eliminate the stress of manual irrigation (watering can), conventional irrigation (FADAMA) and irrigation control while at the same time conserving the available water supply. Improving irrigation efficiency can contribute greatly to bumper harvest and reduce production costs of agricultural products, thereby making the industry to be more competitive and sustainable.

Irrigation farming is a profitable and sustainable venture for farmers during the off peak period.

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