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Field evaluation of a prototype self-drawn sprinkler irrigation

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Abstract

In Egypt, surface irrigation methods are commonly used to grow crops to meet the demand of the ever-increasing population. A big share of water is lost in agriculture during conventional means of irrigation. A sprinkler is one of the methods of irrigation water applications that can bring more efficiency. The main aim of this research was to field evaluation of a prototype self-drawn sprinkler irrigation to fit the conditions of the Egyptian agriculture. The field experiments were conducted in Aswan University Stadium, Egypt. The sprinkler was tested by using a nozzle that has rated discharge of 11.3 m^3/h under three forward speed 0.02, 0.03 and 0.04 km/hr. The results indicated that the percentage increase in moisture content was 43, 32 and 24% for travel speeds S1, S2 and S3, respectively. The uniformity and distribution coefficients as well as depth of water application were lower at the end, the highest and lowest values of Cu were 72.45 % and 56.16% and the highest and lowest values of Du were 60.40% and 40.66 % for nozzle for different speeds, the throw range 48 m for nozzle 12 mm at 4 bars. Non-uniform water application leads to over or under irrigation in various parts of the field which can result in wasted water and energy.

Keywords: sprinkler gun, irrigation prototypes, evaluation, distribution uniformity.

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1. Introduction

Water is necessary to live. Where there is no water, there is no life. The total volume of water on the planet is around 1.4 billion km^3. Water accounts for around 35 million km^3 of the entire volume, or 2.5% volume (Aguiar, 2012). In most parts of worldwide, traditional surface flood irrigation is widely practiced, resulting in low efficiency and significant loss of water resources (Yan *et al*., 2020). Because of the growing awareness of worldwide water, the governments have designated the development of water-saving irrigation as a core national policy. Since then, countries have invested much in research and promotion, to develop a new level of sprinkler irrigation. In the scientist's opinion, the automatic irrigation is the most popular type of irrigation. Robot irrigation will continue to play an important part in these industries for the foreseeable future, despite the fact that few new machines are currently being purchased (Smith *et al*., 2008). In the sprinkler technique of irrigation, water is sprinkled into the air and allowed to fall on the ground surface just like rainfall. The spray is done by the flow of water under pressure through small orifices or nozzles (Khadke, 2020). In recent years, the shift to sprinkler and drip irrigation has been increasingly considered a major opportunity for improving the performance of surface irrigation schemes. This shift to pressurized irrigation techniques arguably helps increase water productivity and farm incomes, stated that the main factors in evaluating the quality of sprinkler irrigation systems are sprinkler irrigation uniformity, water application rate and degree of mist, which are required to meet the Technical Code for Sprinkler Engineering. Egypt scholars have carried out a lot of basic research on these main factors, which provides powerful technical support for the development of sprinkler irrigation technology in Egypt (Namara *et al*., 2007; Shah *et al*., 2005). Irrigation uniformity (the variation in irrigation depths over an irrigated area) is a central goal of the sprinkler irrigation system design. It is an important performance characteristic of the sprinkler irrigation system (Darko *et al*., 2017). The distribution uniformity values help to identify the magnitude of under-irrigated areas (Dwomoh *et al*., 2013). The distribution uniformity values help to identify the magnitude of under-irrigated areas. Effects of operating speeds on distribution uniformity (DU) classes are as follows: Excellent > 80, Very good = 70-80, Good = 60-69, Fair = 50-59 and Poor < 50 (Li *et al*., 2021). The present study was undertaken to study evaluation of the sprinkler irrigation prototype system with different speeds and to evaluate the performance of sprinkler irrigation prototype system.

2. Materials and methods

Sprinkler irrigation prototype was developed to increase the efficiency of irrigation water use. Design feature includes major characteristics are a simple design and ease of use, its parts are locally available materials and ease of construction, suitable for irrigation of fields and stadiums in addition to the possibility of remote control of the field operation. The field experiments were conducted in Aswan University Stadium, Egypt, located at 24.08889 N latitude, 32.89972 E longitude and at an altitude of about 85 m above mean sea level. The detailed descriptions of the essential parts of the sprinkler irrigation prototype are shown in Table (1) and Figures (1 and 2).

Table (1): The detailed descriptions of the essential parts of the prototype.

The components	Descriptions
Frame	Consisting of main frame and pivot frame the majority of which are made of: rectangular tube (40 * 70 * 2 mm), square tube (30 * 30 * 1 mm), square tube (16 * 16 * 1 mm), angle (30 * 30 * 1.5 mm) and sheet metal of 1 mm thickness was used to cover the frame. The prototype frame contact with the soil surface using four wheels [550 * 12], couple of tires. They are installed in the pivot frame and the other wheels They are installed in the main frame; the robot is dragged by the pull frame to the field to be irrigated.
Power transmission system	The pull winch takes the power from the gasoline engine by using belts and pulleys. As it works to withdraw the wire, which works to move the prototype. The driving motor power for 16 hp (11.936 kW), the rotational speed of the motor power = 3600 rpm and the sprinkler irrigation prototype at a maximum forward speed of 0.02, 0.03 and 0.04 km/h.
Power supply system	Two battery 12 V was used as alternative power source for the electronic circuits, electric valve, motor. The battery was charged from the gasoline engine by dynamo, the batteries were connected in such a way to provide both 12 and 24 V.
Sprinkler irrigation system	Sprinkler irrigation system frame consists of several parts most of them made of galvanized iron pipes, sprinkler gun (D= 1.5 in, W= 47 and Q= 11.3 m^3/hr), water pipes (2 in, 1.5 in), hose (2 in), solenoid valve (1.5 in) and manual valve (2 in).

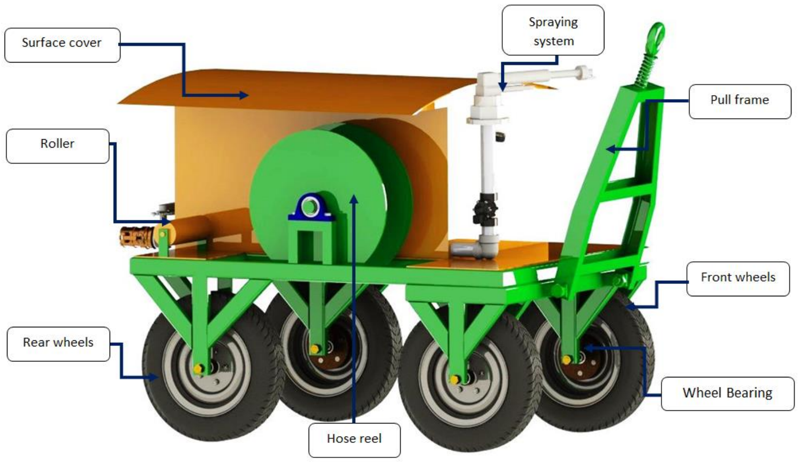

Figure (1): The detailed descriptions of the essential parts of the prototype self-drawn sprinkler irrigation.

Figure (2): A photo of the prototype self-drawn sprinkler irrigation with opening door.

2.1 Variables of field experiments

Soil moisture, depth of water application, operating pressure, width of wetted strip, gun discharge and speed of prototype were measured during the study:

1- Speed of the prototype: wooden stakes were placed at 10 m intervals along the irrigation path of the prototype and the time of prototype was recorded with the help of a stopwatch to estimate the speed of advance of the model.

2- Soil moisture: been measured for moisture content were taken Using a sensor to measure the moisture content via Arduino, before irrigation and after irrigation at a depth of 15 cm from the surface of the soil.

3- Depth of water application: A total of 44 catch cans were used at a grid spacing of 4 × 4 m to collect and determine the depth of water application.

4- Width of wetted strip: The width of the wetted strip was measured at the three locations, *i.e*., beginning, middle and end of the prototype irrigation path, with the help of a measuring tape.

5- Gun discharge: Capacity measuring cylinder, a hosepipe and a stopwatch were used to determine the flow rate at selected locations. The gun arc angle was kept at 210°.

2.2 Indicators of irrigation uniformity evaluation

2.2.1 Coefficient of uniformity

Sprinkler irrigation prototype was operated at different speeds of nozzle 12 and constant pressure 4 bar. In the real field conditions sprinkled water from prototype was received in collecting pots which were placed with same inter distance in an array along the line of water throw. Volume of water was measured from each area of catchment after certain time and number of turns by prototype. Through this the coefficient of uniformity for sprinkler irrigation prototype using following equations (Christiansen equation) (Yaseen *et al*., 2019):

$$Cu = 100 \times \left(1 - \frac{\sum|x|}{nm}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where: X= numerical deviation of individual observations from the average application depth (mm). m= average application depth based on all observations (mm). n= total number of observations.

2.2.2 Distribution uniformity

The low quarter distribution uniformity (DU) was computed as descripted by Li *et al*. (2021):

$$Du = 100 \times \left(\frac{\text{Xlq}}{\text{Xt}}\right) \ldots\ldots\ldots\ldots.\ldots\ldots..2$$

Where: Xlq = average of the lowest one-fourth of the application depths (mm). Xt = average of all application depths (mm).

3. Results and discussion

3.1 Speed of the trolley

The speed of prototype as measured during the operation of sprinkler irrigation prototype system in the stadium is given in Table (2).

3.2 Width of wetted strip and Gun discharge

The average width of wetted strip and Gun discharge during different test speeds sprinkler irrigation prototype, as measured during the experimentation, is given in Table (3).

Table (2): Average speed of prototype (m h^{-1}) during the operation of sprinkler irrigation prototype system.

Prototype speed (m/h)			
Tests	Speed 1	Speed 2	Speed 3
Test 1	21	32	40
Test 2	20	29	40.5
Test 3	20	30	40
Mean	20	30	40

Table (3): Average width (m) of wetted strip and gun discharge for different test speeds of sprinkler irrigation prototype.

Speed of sprinkler irrigation robot		
Speeds (m/h)	Width (m)	Q (m^3/hr)
20	48	11.2
30	47	11.3
40	49	11.4
Mean	48	11.3

3.3 Depth of water application

The depth of water application is an important consideration for any irrigation event. Considering the prototype nature of the tested system, it is important to study the average depth of water application as well as its variation along and across the prototype path of the system up to 22 m of the travel path at three speeds of the gun prototype is shown in Figure (3).

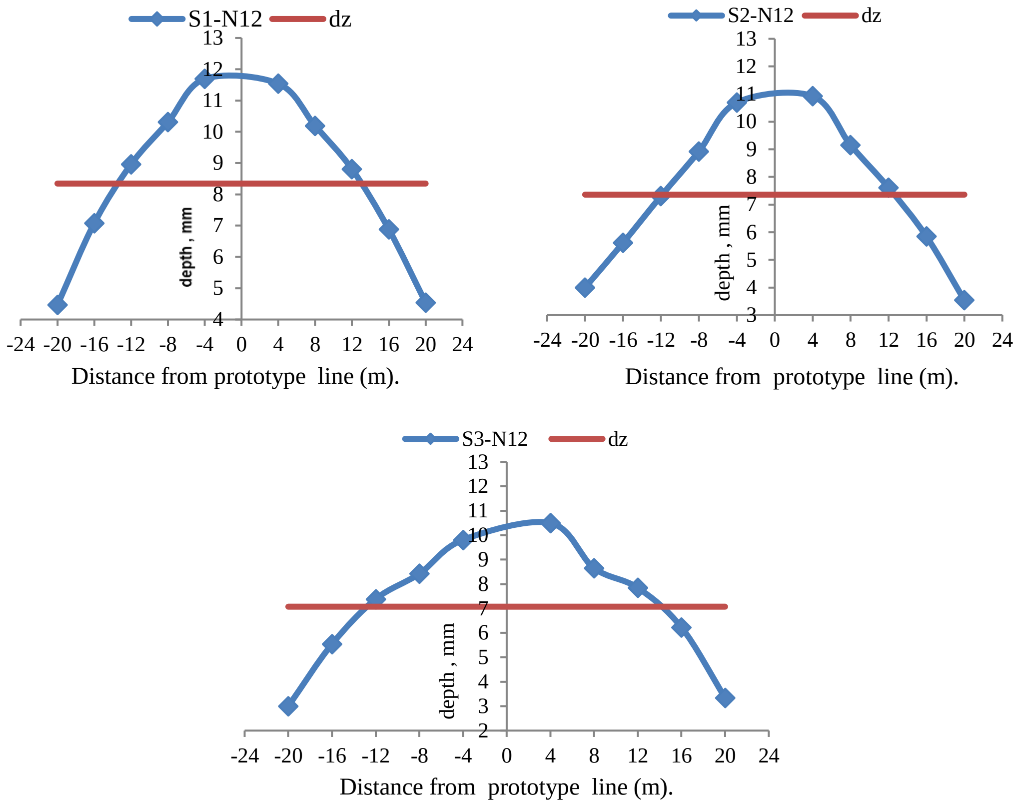

Figure (3): Depth of water application across the prototype path for S1, S2 and S3.

It can be seen from Figure (3) that the depth of water application, at a speed 20 m/h, nozzle 12 on either side of the prototype line, along the prototype path becomes almost ideal. The depth of application is lower than the average depth of application at the start of the prototype path. For instance, for speed 20 m/h, at the depth of water application at the centre of the wetted strip increased to more than 11.69 mm after a certain distance of prototype. The depth of water application, particularly in the middle area of the wetted strip, is almost uniform from the centre line up to a certain distance and then decreases towards the extreme end of the wetted strip. This represents a different type of water distribution/precipitation pattern of a prototype gun as compared to a fixed medium-size double-nozzle sprinkler.

3.4 Average depth of water application

As the speed of sprinkler irrigation prototype increased, the depth of water application decreased. When the speed 20 m h^{-1}, 30 m h^{-1} and 40 m h^{-1}, the average depth of water application was observed as 8.75, 7.2 and 6.4 mm, respectively. This is one of the special features of sprinkler irrigation prototype system in which the depth of water application can be changed easily by varying the speed of the prototype. The depth of water application can also be changed in other types of sprinkler irrigation system such as portable and permanent by reducing the duration of water application. However, if shallow depth of water application is required, such as for frost protection, the portable system would require lot of labour for frequent shifting of the system. On the other hand, permanent type of sprinkler irrigation system would be only able to irrigate in the fields where the system is fixed. The sprinkler irrigation prototype system can be transported to any location and can be used to apply any desired depth of application. Therefore, this type of system is very suitable where light irrigation is to be applied over a large area in a short period of time. Depth of water application with sprinkler irrigation prototype system as a function of speed of robot is shown in Figure (4) following form of relationship was fitted between the depth of water application, speed of prototype for nozzle.

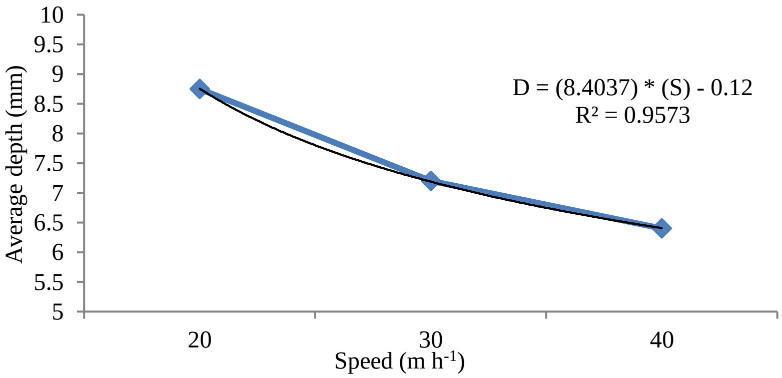

Figure (4): Depth of water application with respect to prototype speed.

3.5 Soil moisture

Results presented in Table (4) shows the average soil moisture different areas at the test site. The moisture content was measured before and after irrigation. The average moisture content on a dry basis was estimated before and after irrigation.

Table (4): Average moisture content (%) in different soil layers before and after irrigation for different test speeds.

Average moisture content (%)					
Speeds	Before irrigation	After irrigation			
20	7.23	10.42	10.54	10.19	10.24
30	7.32	9.71	9.65	8.87	9.42
40	7.18	8.89	8.97	9.03	8.58

With an increase in speed of the prototype, soil moisture content increased at a decreasing rate (Figure 5). On average, the percentage increase in moisture content above the initial value was 36.03, 30.98 and 22.84% for travel speeds S1, S2 and S3, respectively. The following relationship was fitted between the percentage increase in moisture content (IMC) and prototype speed of the gun (m/hr).

3.6 Effects of operating different speed on Cu and Du

3.6.1 Uniformity of water application

Figure (6) and Table (5) indicates the values of water coefficient uniformity (DU), coefficient uniformity (CU) namely Cu and Du values. The highest and lowest values of Cu were 72.45 % and 56.16% for nozzle 12 for different speeds 20, 30, 40 m/hr. Also, results of performance evaluation of prototype were showed that CU for the systems were within acceptable standards the results indicated that the distribution uniformity decrease as prototype speed increased. Speed 20 m/hr has given high Cu value, and this was due to the use of the low speed. speed 40 m/hr has given little Cu value, and this was due to the use of the high speed. Also, results of performance evaluation of prototype were showed that DU for the systems were within acceptable standards the results indicated that the distribution uniformity decrease as prototype speed increased.

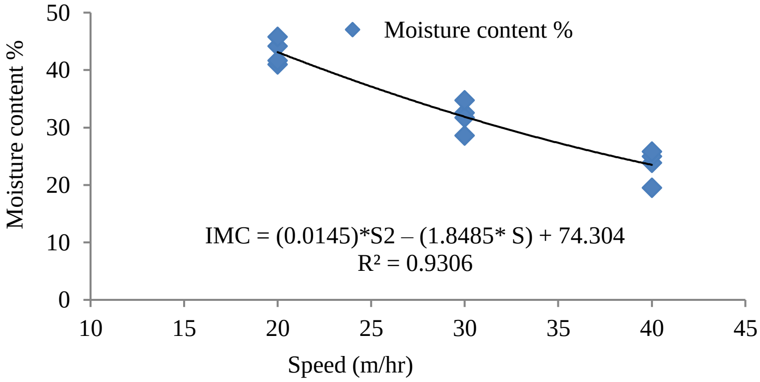

Figure (5): Percentage increase in moisture content with travel speed of prototype.

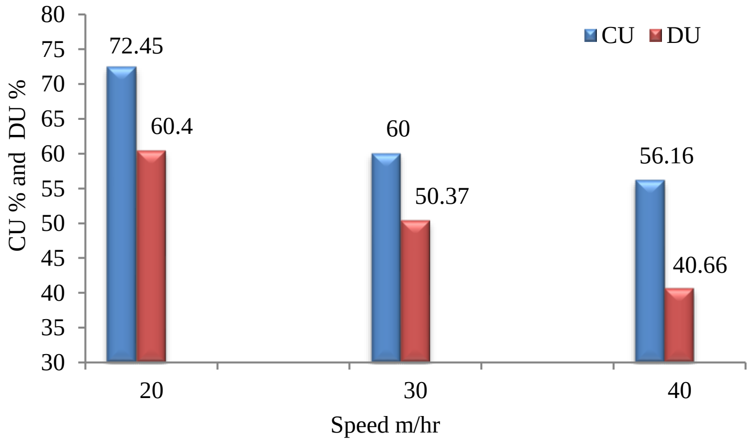

Figure (6): Comparison between values of performance coefficients for various of speeds.

Table (5): Uniformity of water application with different operating speed and scale of evaluation.

Speed of sprinkler irrigation prototype			
Value	Speed 1	Speed 2	Speed 3
Cu	72.45%	60%	56.15%
Du	61%	50.37%	40.66%
Dz	8.75 mm	7.2 mm	6.4 mm

Speed 20 m/hr has given high Du value, and this was due to the use of the low speed, the highest and lowest values of Du were 60.40% and 40.66% for nozzle for different speeds. The present study was undertaken to evaluate the performance sprinkler irrigation prototype under Egypt farming conditions. The ease with which the depth of irrigation can be increased or decreased by changing the prototype speed makes it particularly suitable if light irrigation is to be applied over large areas in a short time. The sprinkler irrigation prototype works at minimum 4 bar pressure. The following salient observations can be made based on the present study: The speed of prototype is inversely correlated with the depth of water application and percentage increase in moisture content, confirming reduction in water application with an increase in speed. Quantification, of depth of water application with prototype speed is useful to decide the operational speed for the intended purpose. For instance, for frost protection, light irrigation with sprinklers may be required over a large area in a short time. One of the major problems occur during the sprinkler irrigation is evaporation loss of spraying water. It is depended upon the things like pressure, climatic condition, wind speed, wind direction and the temperature.

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