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Performance of a self-propelled traveler gun sprinkler based on sensor technology

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Abstract

In Egypt, surface irrigation methods are predominantly used for crop cultivation to meet the rising water demand. However, traditional irrigation techniques result in significant water loss. Sprinkler irrigation systems offer a modern alternative that improves water use efficiency by delivering larger amounts of water compared to conventional methods such as flood irrigation. This study evaluated the performance of a traveler gun sprinkler at Aswan University. Field experiments were conducted using nozzle sizes of 8 mm and 10 mm, at a constant pressure of 3 bar, and three forward speeds (25, 50, and 75 m/h). Results showed that the 10 mm nozzle achieved a higher flow rate (6.9 m^3/h) and a longer wetted radius (18 m) than the 8 mm nozzle, which had a flow rate of 5.4 m^3/h and a radius of 16.25 m. A clear relationship was observed between forward speed and average collected water depth at constant pressure for the two nozzles, with the 10 mm nozzle consistently recording greater values. Shows at 25 m/h, the collected depth was 6.61 mm for the 10 mm nozzle compared to 5.1 mm for the 8 mm nozzle.

Keywords: traveler gun sprinkler; sensor technology; irrigation design; Remote control.

1. Introduction

Egypt's economy mainly depends on agriculture, with water being the key factor in improving crop production. Traditional irrigation methods in Egypt have low efficiency, leading to low productivity. Using a hose-reel sprinkler irrigation system offers advantages over other methods, such as cooling crops and not interfering with farming operations. In sprinkler irrigation, water is sprayed at high speed and breaks into droplets due to air resistance, falling on the soil like rain. Droplet distribution depends on nozzle size, sprinkler height, operating pressure, and other factors. Wind speed and direction also affect droplet size and distribution patterns **[1]**. Self-propelled traveler gun sprinkler systems are specialized irrigation technologies combining mobility with precise water application. These systems consist of a large water gun mounted on a trailer or cart that can project water up to 200 feet through a single nozzle, with movement options including fixed speeds, self-propulsion via separate engines, or continuous hydraulic movement **[2]**. The adoption of self-propelled sprinkler irrigation has made these systems highly efficient, currently irrigating over 12.5 million hectares worldwide and increasingly replacing conventional methods like flood **[3]**.

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Recent commercial developments in sprinkler irrigation have focused on integrating GPS-based controllers for motion control, along with wireless communication and sensor technologies to monitor soil and ambient conditions, as well as operational parameters like flow and pressure, to achieve higher water application efficiency **[4]**. Modern systems use multiple sensor types for intelligent control, including soil moisture, temperature, and humidity sensors that continuously monitor environmental conditions and transmit real-time data to central control units **[5]**. The integration of soil moisture sensors has proven particularly effective, with systems designed to measure soil moisture content and automatically controls irrigation sprinklers based on actual soil needs **[6, 7].** These sensor-equipped systems show significant water conservation benefits, achieving 80-90% water efficiency compared to 40-45% in surface irrigation methods, and enabling up to 70% water savings in agriculture **[6, 7].** Advanced self-propelled systems now incorporate comprehensive sensor arrays, including infrared tracking, obstacle avoidance sensors, and speed measurement systems controlled by microcomputers like Arduino UNOR3, enabling precise irrigation patterns **[8]**. Field tests confirm that soil moisture sensors accurately measure soil water content and control sprinklers based on needs, reducing water use by up to 70% compared to conventional methods **[6].** These systems modulate irrigation rates from 0 to 25 mm and adjust travel speeds between 0 and 3 m/min while maintaining application uniformity of 90% or higher **[9].** Variable-rate irrigation (VRI), integrated with sensor technology, significantly advances self-propelled sprinkler performance, increasing crop water productivity by up to 20% and reducing energy use by about 18% **[9]**. VRI achieves water savings by avoiding irrigation of uncultivated areas, matching rates to soil infiltration, and optimizing for crop needs through varied ground speed, nozzle pulsing, or individual nozzle control **[3, 10, 11].**

2. Materials and Methods

To achieve the objectives of this research, an experimental traveler gun sprinkler was designed using SolidWorks software. This prototype is intended for use in open fields and football fields. The design accommodates a wide range of flow rates, forward speeds, and application heights. The assembled unit is shown in Fig. 1.

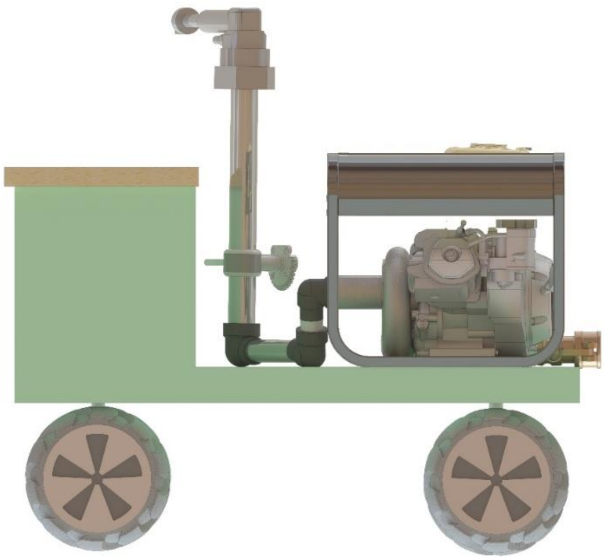

Fig. (1): the traveler gun sprinkler shows main components.

2.1. Description of the experimental traveler gun sprinkler

The entire experimental field traveler gun sprinkler was designed following standard design methodology. The traveler gun sprinkler consists of five main parts as follows:

2.1.1. Frame

The traveler gun sprinkler structure consists of a set of parts designed and manufactured using rectangular iron pipes in dimensions (40 × 40 × 2) mm. The structure has been coated with 1mm thick galvanized metal sheets, ensuring the structure's traveler gun sprinkler and protection against corrosion. The sprinkler is characterized by its ability to move above the soil surface thanks to four firmly installed wheels, making it easier to move during the irrigation process. The ground wheel is 40 cm in diameter, while the spray is 120 cm long and 90 cm wide, making it suitable for use in various agricultural conditions. The height of the sprinkler from the earth's surface is about 55 cm, which is suitable for most plants, ensuring effective water distribution without impeding the movement of the sprinkler or causing damage to crops. This design combines traveler gun sprinkler and flexibility, making the sprinkler ideal for use in varied farmland.

2.1.2. Power Source

The traveler gun sprinkler Machine consists of four continuous current (DC) engines, each motor is installed inside the ground wheels to become an integrated part of it. The electric power of each motor is 350W, and each two engines are connected together to work simultaneously; The two engines associated with the front wheels work together, while the two engines associated with the rear wheels also work simultaneously. During the irrigation process, the front wheels can be operated only to move the machine, but if the machine has difficulty moving or needs additional thrust, the four motors are operated together to ensure smooth and efficient movement. These automated wheels are characterized by their ability to control the front speed of the machine, as their speed is adjusted according to the needs of the crop to be irrigated. Speed can be increased or reduced based on the type of plants and the amount of water required, providing high flexibility in the irrigation process. This system ensures energy efficiency and facilitates the process of control of machine gun movement, making it suitable for use in various agricultural conditions.

2.1.3. Power supply system

The power supply system is one of the key elements of the traveler gun sprinkler, where a special control box is installed on the traveler gun sprinkler structure, containing electronic circuits responsible for managing the irrigation process and controlling the operation of the traveler gun sprinkler. This box includes three batteries to save the power needed to power the system: two 36V and 4,400mAh lithium batteries, used as the main power source for running DC engines that move the wheels and manage the irrigation process. In addition, the circuit has a third battery with 12V voltage and 2200mAh capacity, dedicated to the operation of electronic circuits and control subsystems. To ensure continuity of operation and energy efficiency, these batteries can be recharged in three different ways home charging or charging by a generator or using solar panels, providing a renewable source of energy and enhancing the sustainability of the system, especially in remote or electricity-deficient areas. This design ensures stable and effective machine-gun operation while reducing reliance on conventional energy sources.

2.1.4. Sprinkler Irrigation System

The traveler gun sprinkler consists of a 2 inch water pump, capable of pumping up to 23 m^3/h. This pump is directly installed on the traveler gun sprinkler structure, operated by a 7 hp petrol engine, ensuring the energy needed to efficiently pump water. The pump pulls irrigation water from the water source through a flexible hose that pulls behind the sprinkler as it moves, ensuring a constant flow of water during the irrigation process. The pump connects to the 1.5 "diameter gun sprinkler, through pipes made of galvanized iron, providing high durability and corrosion resistance. These connections allow the height of the spray gun to be adjusted from the ground surface, giving flexibility in directing the flow of water according to crop needs and the nature of the terrain. The traveler gun sprinkler has a set of interchangeable nozzles (10 and 8 mm), allowing control of water distribution pattern, wetness diameter and water disposal amount, ensuring perfect coverage of planted space and reducing water waste. This carefully designed system provides high efficiency in irrigation process, taking into account the ease of operation and maintenance.

2.1.5. Control system.

The traveler gun sprinkler features an intelligent remote-managed control system via a web-connected smartphone app, providing integrated solutions for controlling the operation and stop of DC engines, adjusting their speed, and managing the power valve work of the irrigation process. This sophisticated electronic system relies on accurate programming that controls the operation of key components (engines and irrigation appointments) based on soil moisture readings, ensuring automated operation consistent with the actual water needs of each plot. The system consists of several main modules including MCU (Wi-Fi) node for wireless connectivity, motor operating unit, DC engines, and battery system. This integrated electronic system designed with a range of smart electrical circuits has been specifically developed to meet the needs of traveler gun sprinkler, enabling careful control of irrigation equipment and adjusting the amount of water distributed according to soil moisture levels, thereby significantly enhancing water efficiency. One of the most important features of this system is its simple design and easy programming, relying on locally available components at an economical cost. It is worth mentioning that the programming of the electronic circuits of this system took place at Aswan University in Egypt, where the Table (1) shows the basic components of the electronic system.

Table (1): Components of the electronic circuit.

	Parameter
1	Node MCU Based ESP8266 Development Kit
2	UNO R4- WIFI
3	Soil Moisture Sensor
4	Drushless Dc Motor Controller
5	Brushless DC Motor
6	Solenoid valve

2.2. Experimental Variables

Several key engineering factors that directly affect the traveler gun sprinkler's performance were identified. The experimental variables are as follows:

2.2.1. Gun Nozzles

It is essential to select nozzles that match the operating pressure of the sprinkler irrigation system. Therefore, equipping the sprinkler with a large nozzle at low operating pressure is not recommended. Nozzles differ in discharge rates and wetted diameters (width). To suit an operating pressure of 3 bars, experiments were conducted using 8 mm and 10 mm nozzle sizes.

2.2.2. Forward Speed

Three forward speeds of 25, 50, and 75 meters per hour were used in the field experiments.

3. Results

The traveler gun sprinkler was manufactured at the Faculty of Agriculture and Nature Resources of the University of Aswan and is located approximately 85 meters above sea level, at 24.088 degrees north latitude and 32.899 degrees east longitude.

3.1. Mechanical Design for Gasoline Engine Pump.

The power required for water pumping (kW) can be calculated using equation (1), which incorporates the following parameters:

$$Pr = \frac{\mathrm{Q} \times \mathrm{H} \times \mathrm{SG}}{k \times \eta} \dots\dots\dots\dots\dots\dots\dots\dots \dots\dots\dots\dots\dots\dots (1)$$

Where:

Q is the required flow rate, m^3/h.
H is the total dynamic head, m.
η is the pump efficiency, %.
SG is the specific gravity of water
k is a constant conversion factor

It was found that the required discharge is 23 m^3/h, the total accumulative head (including suction, delivery, and friction losses) is 55 m, pump efficiency is 75%, the specific gravity of water is 1, and the constant factor is 367.

$$Pr = \frac{23 \times 55 \times 1}{367 \times .75} = 4.59\ KW(6.15\ hp)$$

Based on a detailed engineering analysis, the actual power required to operate the pump motor was found to be 6.15 hp (4.59 kW). However, a 7 hp motor was selected to ensure efficient operation, providing a 27% safety margin over the calculated power to accommodate sudden loads during start-up and compensate for any efficiency decline over time. This selection also considers standard specifications of commercially available motors, offers flexibility for unforeseen conditions, reduces the risk of motor overload, and meets potential future requirements without equipment upgrades. This approach aligns with standard engineering practices, which recommend increasing equipment power by 20 – 30% over calculated values to guarantee optimal and stable operation.

3.2. Performance of traveller gun sprinkler

Through experiments, the flow rate of water from the traveller gun sprinkler is demonstrated by applying various factors such as 10 and 8 diameters of the gun nozzle (mm), cross-section area of nozzle (m^2), length of wetness diameter, at constant pressure, operational pressure at nozzles was (3 bar) Plus cover area in case of irrigation at 360 ° as shown in Fig.2.

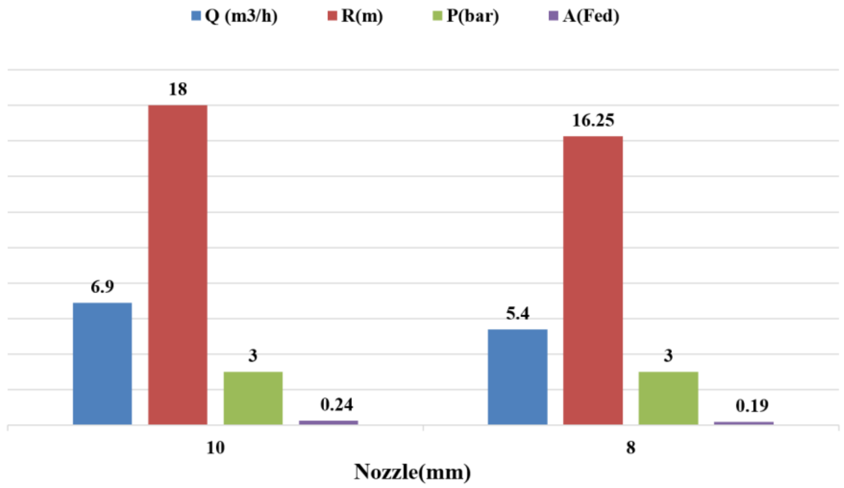

Fig.(2): Performance of a traveller gun sprinkler using different nozzles.

Fig. 2 shows that the 10 mm nozzle achieves a higher flow rate (6.9 m^3/h) and longer wetted radius (18 m) than the 8 mm nozzle, which has a flow rate of 5.4 m^3/h and radius of 16.25 m, both at an operational pressure of 3 bars. Despite having the same pressure, the larger nozzle size results in greater water discharge and coverage area, which could enhance irrigation efficiency for larger fields. It was found that the coverage area for irrigation with the 10 mm nozzle (0.24 Fed) compared to (0.19) Fed for the 8 mm nozzle.

3.3. The Average Collected Water Depth

Fig.(4.21) shows the average collected water depths as a function of forward velocity using nozzles (8 and 10 mm) at a spray pressure of 3 bar. The results show a relationship between forward velocity (m/h) and average collected water depth (mm) when using different nozzles (8 mm and 10 mm) at a constant spray pressure (3 bar). It can be seen that increasing the nozzle diameter leads to an increase in the collected water depth at all velocities, with the 10 mm nozzle recording higher values compared to the 8 mm nozzle. At a velocity of 25 m/h, the depth was 6.61 mm for the 10 mm nozzle compared to 5.1 mm for the 8 mm nozzle, reflecting the effect of increasing flow rate with larger nozzle size. We note that forward velocity negatively affects the collected water depth, as the depth decreases with increasing velocity for both nozzles. When the advance speed increased from 25 to 75 m/h, the depth decreased for the 8 mm nozzle from 5.1 mm to 1.62 mm, and for the 10 mm nozzle from 6.61 mm to 2.2 mm. This decrease is attributed to the reduction in irrigation time. The rate of decrease was more pronounced at lower speeds (25–50 m/h) than at higher speeds (50–75 m/h), indicating a nonlinear relationship between speed and depth, potentially related to factors such as droplet distribution and spray pattern. A larger nozzle is preferred to achieve higher coverage, considering that increasing advance speed reduces the amount of water collected.

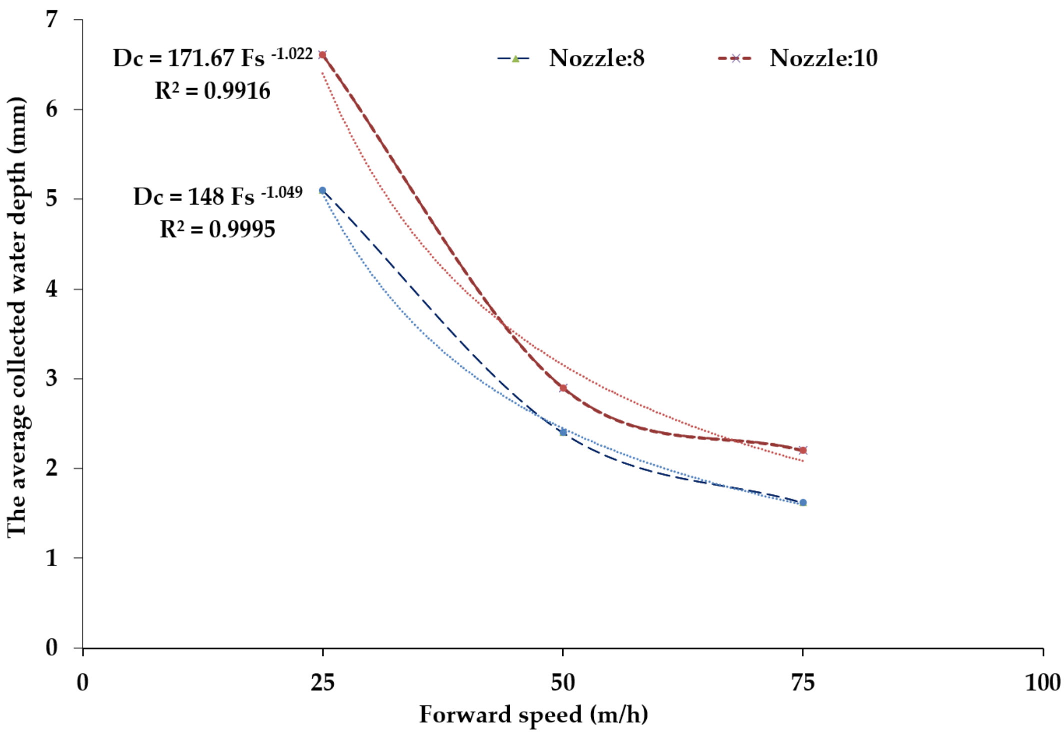

Fig.(3): The average collected water depth as a function of forward speed using nozzles (8 and10mm) at a sprinkler pressure of 3 bar.

Fig.3 shows multiple mathematical models were developed, and the optimal model for each case was selected based on the highest value of the regression coefficient (R^2). Curve fitting was used to derive the following equations:

$$D_C = 148\ F_S^{-1.049} \qquad \text{Equation for nozzle 10 and 3bar gun pressure} \qquad (2)$$

$$D_C = 171.67\ F_S^{-1.022} \qquad \text{Equation for nozzle 8 and 3bar gun pressure} \qquad (3)$$

4. Conclusion

This paper presents results from testing two nozzle sizes under a constant pressure of 3 bar, confirming that the actual spray rates increase proportionally with nozzle size. Conversely, spray rates decrease as the forward speed of the sprinkler increases at these nozzle sizes. The throw radius of the moving sprinkler was found to vary with different sprinkler models. The irrigation system's goal is to achieve an optimal watering depth by carefully planning the irrigation process and adjusting engineering parameters. Understanding how these engineering factors influence sprinkler performance is crucial and forms the foundation for advancing sprinkler irrigation technologies. Notably, developing advanced sprinkler systems will enhance their adaptability to various soil types, thereby improving practical irrigation effectiveness. Overall, this study provides valuable insights into innovating sensor-integrated, next-generation sprinkler irrigation systems.

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