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Performance evaluation of portable sprinkler irrigation system in Ilorin, Nigeria

Isiguzo E. Ahaneku

Dept. of Agricultural & Bioresources Engg., Federal University of Technology, P. M. B. 65, Minna, Nigeria
drahaneku@yahoo.com

Abstract

The global climate change and its attendant effect on scarce water resources have further reduced the amount of water available for agriculture. Under this circumstance, the use of pressurized irrigation systems can be an option of enhancing the efficiency of water consumption. This study was therefore conducted to evaluate the performance of a new portable sprinkler system purchased by the lower Niger river basin development authority, Ilorin, Nigeria. Catch can test were carried out to determine the performance of irrigation applied with the portable sprinkler irrigation systems under field conditions. The tests were carried out using ASABE (2009) standard procedures. The coefficient of uniformity (CU) was used to compute the uniformity of sprinkler water application on the field; while the delivery performance ratio (DPR) was used to quantify the efficiency of the management inputs of the sprinkler system. Results of the field evaluation indicated that the average CU and DPR of the system were 86% and 87%, respectively, indicating satisfactory performance of the sprinkler system. Emanating from the study were a set of performance guidelines and recommendations for the design and management of sprinkler irrigation systems necessary for the achievement of optimum performance.

Keywords: Sprinkler irrigation, performance, evaluation, water, Nigeria

Introduction

Nigeria has a population of 140 million with an average population growth rate of about 2.7% based on the 2006 general census. It occupies a land area of 923,968 km^2 situated between longitude 3^o and 15^o east and latitude 4^o and 14^o north. Two major seasons abound in Nigeria: rainy and dry seasons. The total annual rainfall decreases from 3,800 mm at the Forcados on the south coast to below 650 mm at Maiduguri in the northeast of the country. The length of the rainy season also decreases from nearly 12 months in the south to below 5 months in the north. Nigeria has relatively high temperatures throughout the year which is very necessary for photosynthesis. Agriculture remains the largest sector of the Nigerian economy. It generates employment for about 70% of the country's population and contributes about 40% to the gross domestic product (GDP) (Nigeria National Report, 2006). With the large expanse of land, good temperatures but high variability of rainfall, Nigeria needs irrigated agriculture to feed her teeming population.

Irrigation is the process of applying water to the soil to meet crop water demands. The role of irrigation is to improve production and input efficiency in areas where the climate limits production potential. Nigeria belongs to such areas by virtue of its climatic variability and disproportionate rainfall distribution in time and space. With improvements in irrigation technology, irrigation methods have changed dramatically in recent items. The number of surface-irrigated area has declined by more than 1 million hectares, while the number of sprinkler-irrigated areas has increased from less than 1.5 million hectares to about 6 million hectares (Scherer *et al*., 1999). This is as a result of some surface systems being converted to sprinkler systems. This trend is expected to continue due to improvements in water application efficiency and labour reduction associated with sprinkler systems.

Irrigation performance assessment has been given the highest priority in irrigation research among other research priorities needed to solve the problems of irrigation development and management in Nigeria (Nwa & Pradhan, 1993). Performance of irrigated agriculture which includes irrigation methods or system must improve in order to have additional food per unit area for a growing population like Nigeria. This improvement becomes very imperative because of the serious constraint faced by irrigators due to water scarcity and the ensuing competition for water by other higher-valued industrial concerns and urban uses. No doubt, irrigation development has contributed immensely to national food security; to economic development and to poverty reduction, yet much more is expected from irrigated agriculture as a result of the increasing population. It is obvious that many irrigation systems are performing below their capacities. This situation may lead to non-uniform and unreliable water distribution. Therefore, a good starting point as identified by experts (Nwa & Pradhan, 1993) is to assess the performance of available irrigation systems in order to identify areas of lapses in the system design and make amends. An ideal irrigation system should apply the correct amount of water, minimize the losses, and apply the water uniformly.

Sprinklers can be a good investment when properly designed, installed, maintained and managed. Sprinklers apply water more efficiently and uniformly than typical surface irrigation systems, thus they produce more yields for each quantity applied per unit area (Hill & Heaton, 2001). An indispensable tool in irrigation project management is evaluation. This entails the measurement and analysis of key aspects of irrigation system performance and management. Evaluation will enable irrigation managers measure and determine actual performance; identify which factors are responsible for less than ideal performance and determine the relative impact of these factors and how they may be addressed. Nasab *et al*. (2007) in their evaluation of sprinkler systems in Iran, concluded that the main problems of sprinkler irrigation systems are deficient design and implementation, low distribution uniformity, low water pressure, deficient distribution of pressure, insufficient lengths of lateral pipelines in addition to poor quality equipment and deficient management and maintenance processes. According to Keller and Bleisner (2000) the uniformity of sprinkler irrigation is a central design goal. Uniformity relates to how evenly water is applied over a given area. Since no irrigation system can apply water precisely to all areas of the field, it becomes necessary to estimate the uniformity of water application in order to assess the performance of the system. Uniformity of water application is also sought to minimize variability of crop yield or plant quality in the case of turf grass and landscapes (Dukes *et al*., 2006). The two most common methods of expressing uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU). CU calculates the average deviation of the catch compared to the depth of the catch, while DU compares the driest quarter of the field to the rest. For a typical overhead system with a statistically normal distribution and CU > 70%; CU and DU are approximately related (Keller & Bleisner, 1990):

$$CU = 100 - 0.63\,(100 - DU) \quad (1)$$

Li and Rao (2004) studied spatial variation of water in the soil and the response of crop growth and yield to non-uniform water application. The results showed that the coefficients of uniformity for water storage in the soil were always greater than those of the sprinkler uniformities. They therefore concluded that reduced sprinkler uniformity may not necessarily result in a lower yield. Mateos *et al*. (1997) found that the coefficient of variation (CV) of infiltrated water was one-third of the applied water measured by catch cans under sprinkler irrigation. This indicates that variability in catch can data does not adequately represent soil moisture variability. Several works have been reported on the evaluation of sprinkler systems with emphasis on irrigation uniformity (Ramazan *et al*., 2005; Dukes *et al*., 2006; Nasab *et al*., 2007). However, these studies were conducted outside the shores of Nigeria with different climatic and environmental conditions. This study was therefore aimed at assessing the principal specifications of a portable sprinkler irrigation system in relation to those given by the manufacturer and to evaluate the performance characteristics of the sprinkler system.

Materials and methods

Sprinkler equipment description

The portable sprinkler irrigation equipment was manufactured by economical combine for agricultural machine building, Jambol, Bulgaria. The equipment consists of a diesel-motor system coupled to a pump with a shield. The motor and pump are fixed together on a frame, equipped with a wheel-carrier. The suction-flange of the pump is connected by a quick-clutch to the suction pipeline, while the delivery-flange is connected to the mainline. From the mainline, laterals are connected with control valves. On to the laterals, sprinklers and risers are connected. The nozzle size is 8 x 6 mm.

Evaluation of sprinkler performance

The goal of any sprinkler irrigation system is to apply the desired amount of irrigation water to the crop's root zone as efficiently and uniformly as possible. The factors that determine sprinkler performance characteristics include wetted diameter (swath radius), droplet size, which is a function of the operating pressure, the flow rate or discharge, the application rate, and uniformity of water application among others.

Experimental field

The study was conducted at the experimental field of the lower Niger river basin development authority, Ilorin, Nigeria. Ilorin is entirely within the Southern Guinea Savannah ecology and on longitude 4^0 30' East and Latitude 8^0 26' north. The experimental field is a relatively flat land well developed for irrigation purposes. All the tests were carried out under moderate environmental conditions while the average wind speed was less than 5.5 km/hr in the northeast direction. The soil type is sandy loam.

Swath radius determination

The sprinkler head of a system can only distribute the water over a given area. The farthest distance covered by water droplets (throw) from the irrigation system centre line at which the sprinkler deposits water over the inlet surface area of the collector was measured. The detection of the farthest distance of throw was possible due to the fact that the assessment was carried out during the dry season. The test was conducted on the irrigation system at full pressure and throttle of the irrigation equipment drive mechanism.

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System operating pressure

The output of a nozzle, the droplet sizes and distance that the sprinkler throws water is highly dependent on pressure. Due to the malfunction of the pressure gauge on the system pump, the pressure at the sprinkler head was estimated using the water spread area formula (eqn. 2) as suggested by Cavazza (Sivanappan, 1987):

$$R = 1.3\sqrt{dh} \qquad (2)$$

Where, R = swath radius, m
d = diameter of nozzle, mm
h = pressure head at the nozzle, m.

Uniformity of water distribution

The test procedure according to ASABE S436.1 (2009) standards was utilized for the determination of the uniformity of water distribution of the sprinkler system. The test was conducted on a square plot measuring 25 m x 25 m and bounded by four sprinklers. The sprinkler nozzle sizes are 8 and 6 mm, while the sprinkler spacing is 17.73 x 18.83 m. The test time was 30 min. for each run. The test procedure consisted of setting up a pattern of identical metallic catch cans 6.5 cm diameter and 6.3 cm high. The sprinkler system was operated for a period of time and the rate of discharge and the wind speed direction were recorded. The distribution data was obtained by measuring the volume of water caught in each collector at the end of the test period. The cans were located along lines parallel to the pipeline and placed 1.5 m apart since the sprinkler radius of throw was more than 12 m in accord with ASABE S398.1 (2009) standards. Based on the cross-sectional area of the catch cans, the water volume was converted to depth of water in millimeters (mm). No evaporation suppressant was used.

Table 1. Parameters for computation of uniformity coefficient

Observation (mm)	Frequency	Application rate × Frequency	Numerical deviations	Frequency × Deviations
7.4	1	7.4	1.5	1.5
7.2	1	7.2	1.3	1.3
7.1	3	21.3	1.2	3.6
6.9	1	6.9	1.0	1.0
6.7	2	13.4	0.8	1.6
6.4	3	19.2	0.5	1.5
6.0	1	6.0	0.1	0.1
5.9	1	5.9	0.0	0.0
5.7	3	17.1	0.2	0.6
5.3	1	5.3	0.6	0.6
5.2	5	26.0	0.7	3.5
4.8	5	24.0	1.1	5.5
4.7	1	4.7	1.2	1.2
4.5	1	4.5	1.4	1.4
4.3	1	4.3	1.6	1.6
	30	mn =173.2		∑X= 25

Christiansen's coefficient (ASABE, 2009) being the most widely understood and easier to calculate by hand than functions like standard deviation was used to evaluate uniformity in this assessment. Table 1 shows the observed parameters used in evaluating the coefficient of uniformity. The coefficient of uniformity was computed using the Christiansen's equation (Schwab, 1993) as:

$$CU = 100\left[1 - \frac{\sum x}{mn}\right] \qquad (3)$$

Where,

m = Average value of all observations (average application rate), mm

n = Total number of observation points.

x = Numerical deviation of individual observation from average application rate, mm.

Sprinkler discharge test

The sprinkler discharge among others determines to a large extent, the selection of a sprinkler system. The required discharge of an individual sprinkler is a function of the water application rate and the two-way spacing of the sprinklers. The sprinkler discharge test was carried out by both direct measurement of actual flow of water from the nozzles over a given time frame, and by computation to determine the intended or expected flow rate of the sprinklers based on their spacing. Sprinkler discharge was evaluated using eqn. 4 (Schwab *et al.*, 1993).

$$Q = \frac{S_1 \, x \, S_m \, x \, I}{360} \qquad (4)$$

Where,

Q = Required discharge of individual sprinkler, l/sec
S_1 = Spacing of sprinklers along laterals, m
S_m = Spacing of laterals along the main, m
I = Optimum application rate, cm/hr.

Delivery performance ratio

The data generated from the discharge tests was used to compute the delivery performance ratio (DPR) of the sprinkler system which is a measure of the system performance. The DPR was computed using the relation (Molden & Gates, 1990):

$$DPR = \frac{\text{Actual discharge}}{\text{Required discharge}} = \frac{Q_A}{Q_R} \qquad (5)$$

and DPR = 1 when $Q_A \geq Q_R$

Application rate

The average rate of water application for a single sprinkler was estimated using the relation (Smajstria *et al.*, 2005):

$$Ra = \frac{q}{360} \times A \quad (6)$$

Where,

Ra = water application rate, cm/h

q = rate of discharge of sprinkler, l/sec

A = wetted area of sprinkler, m^2

Fuel consumption

Saving energy in irrigation represents a means of reduction in production costs and also contributes to the conservation of valuable resources. Therefore, the sprinkler equipment was evaluated in this regard. In this test, a known quantity of fuel was poured into a container and the suction pipe of the irrigation sprinkler engine inserted into it. The engine was run for a definite time interval for two consecutive times and the quantity of fuel used up noted. The average of the two runs was taken as the fuel consumption rate.

Table 2. Comparison of key specifications of the irrigation system

Item	Manufacturer's specification	Evaluated value
Water pressure	25 m	22.2 m
Swath radius	21-26 m	18 m
Fuel consumption rate	7.23 l/hr	7.8 l/h
Operation personnel	1 man	1 man

Results

Table 2 shows the comparison of the key specifications for the portable irrigation system. The specifications of the manufacturer were virtually in tandem with the observed values within the limits of experimental error. Table 3 presents the evaluation parameters of the sprinkler system with values calculated and the standard or expected value for each evaluated parameter.

Table 3. Results of evaluation parameters of the sprinkler system

Parameter evaluated	Value obtained	Standard/expected value
CU of the system	86%	85% & above
Average discharge of the sprinklers	0.85 l/sec	0.98 l/sec
Average application rate of a sprinkler	2.40 cm/h	2-3 cm/h (Basic infiltration of the test soil)
Delivery performance ratio (DPR) of the system	0.87	1.00

Discussion

The evaluated coefficient of uniformity of the portable irrigation system was 86%. This indicates a deviation of only 14% from perfect uniformity. The CU obtained falls within the acceptable range for both high value crops CU > 84% and for general field and forage crops: CU > 75% (Michael, 1999; Keller & Bleisner, 1990). The value of CU obtained in this study is in agreement with that obtained elsewhere by Ramazan *et al*. (2005). The high coefficient of uniformity recorded could be ascribed to the appropriate selection of the types of sprinklers, spacing, efficient functional pressures of the sprinkler and favourable weather conditions (Nasab *et al*., 2007).

Higher uniformity could have been achieved if there were no leakage losses. These losses were observed from the coupling joints of the mains and the laterals. The losses invariably led to small pressure differential between the main and the laterals and hence a little less than normal pressure uniformity in the field. With the high coefficient of uniformity attained by the irrigation system, the irrigator will have to devote more time in perfecting the system's scheduling to achieve higher crop yield usually associated with higher sprinkler uniformity (Li & Rao, 2004).

As reflected in Table 3, the average application rate of the sprinkler was within the basic infiltration rate of the tested sandy loam soil (Ahaneku, 2010). The system application rate is a measure of how fast water is being applied to the soil. Since no runoff was observed during the irrigation period, it can be inferred that the raining intensity of the sprinkler system is satisfactory. The efficiency of an irrigation system is associated with the correct selection of design factors, namely sprinkler nozzles, pressures and spacing. Delivery performance ratio (DPR) is the simplest indicator that could be used by irrigation managers to assess performance of operation. It could be used to assess adequacy as it gives information on the amount of water delivered in comparison with the amount of water intended to be delivered at a given location in the field. DPR can also be used as an indicator of dependability/reliability of an irrigation system at a given location if it remains constant or fluctuates within the permissible limits (Rust & Snellen, 1993). The portable irrigation system recorded a DPR of 0.87 (Table 3). The value falls within the DPR performance class of Good (Molden & Gates, 1990).

The result of DPR obtained in this study is in agreement with those obtained from similar studies elsewhere (Rust and Halsema, 1998; Tariq *et al.,* 2004). This shows that the management input associated with the system is effective. The DPR of 0.87 implies a system efficiency of 87% which is satisfactory. Therefore, if the sprinkler system is maintained at the designed efficiency and uniformity, it should achieve optimum performance.

Conclusion

Efficient irrigation systems are cost-effective. However, many systems are not efficient resulting in water wastage, increased energy use and reduced profits. A well designed sprinkler system applies water uniformly to the soil surface, without exceeding the basic infiltration capacity of the soil. A good system design considers such factors as pressure; nozzle size and spacing; weather conditions; soil infiltration rate; and crop water use rate. Leakage losses are observed to reduce irrigation system efficiency and therefore should be prevented as much as possible. A CU and DPR of 86% and 87%, respectively achieved in this evaluation were seen as satisfactory enough to recommend the system to irrigators. Proper operation and maintenance of the sprinkler system is necessary to achieving optimum system performance.

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