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ORIGINAL RESEARCH ARTICLE

EFFECT OF DIFFERENT RISER HEIGHTS ON SPRINKLER IRRIGATION PERFORMANCE UNDER CONSTANT OPERATING PRESSURE

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ABSTRACT
The study assessed the effect of different riser heights on the sprinkler irrigation performance to cater for the cultivation of taller crops and reduce water losses. A layout of 144 m2 was designed according to the length of mainline and lateral lines, and 36 catch cans were positioned in a grid of 2 m apart. The water caught in Cans were subjected to One-way ANOVA using the Tukey method in Minitab 17 Environment. The risers 4m, 3m and 2m, were significantly different because the means without any letter in common and concluded that some of the riser height have the different mean value of water caught in the catch cans. The results showed that as the riser height increased the mean application rate decreased. Also, the Coefficient of Uniformity (%) for riser height 2 m and 3 m were rated excellent. The Distribution of Uniformity (%) for 2 m and 3 m were rated excellent and fair. The study concluded that riser heights 2 m and 3 m had the optimum CU and DU at 1.6 bar (operating pressure) reduce water losses. The study suggested that sprinkler irrigation should be carried out in Gidan Kwano campus between 5:06 pm and 11:35 am. Also, wind direction should be established before the installation of sprinkler irrigation.

1.0 Introduction

Irrigation is viewed as the application of water to the soil to supply moisture for plant development and crop production (Yahaya, 2002). The need for irrigation arises when the frequency and amount of rainfall are insufficient to replenish the water required by the crop. In more arid regions, drought periods last longer in a year, and the seasonal rainfall is unable to meet crop needs during their growth period (Onwualu et al., 2006). Irrigation systems are classified as surface, sub-surface, sprinkler and drip irrigation (Onwualu et al., 2006). Sprinkler irrigation method is a pressurised irrigation system that consumes water from a different source and sprays it to the cultivated ground or earth as in the shape of rain using an enclosed system and under pressure (Nakayama and Bucks, 2012). Sprinkler irrigation is an adaptable means of supplying crops with common and uniform application of water over a broad range of topography and ground conditions (Nakayama and Bucks, 2012; Fanadzo et al., 2010; Evans and Sadler, 2008). Water distribution application in a sprinkler system is rich and more coherent than surface irrigation system (Yazar et al., 1999). A riser is one of the essential elements of a solid set sprinkler system that influence the performance indicators of the Coefficient of Uniformity (CU) and Distribution Uniformity (DU) under specified environmental conditions. The CU has either a positive or negative effect on crop production (Okasha and Pibars, 2016). In summation, the weak CU and DU reduce the efficiency of sprinkler irrigation system. Water losses in sprinkler irrigation system occur due to evaporation and wind movement. Thus, there is a need to improve the functioning of the sprinkler irrigation system to bring down the cost of irrigation and water losses (Okasha and Pibars, 2016).

Various surveys have indicated that the two common methods of determining sprinkler water uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU). CU is the average deviation of the catch compared to the depth of the catch can, while DU compares the driest quarter of the field to the rest (Kara, 2008). Magagula (2013) reported that a catch-can test is a safe method of assessing the efficiencies of the existing sprinkler irrigation system. Bishaw and Olumana (2015) said that increase in riser heights between 2.5 m and 4.0 m lead to increase in sprinkler water uniformity and riser height 4 m produced optimum CU and DU at low wind speed. In view of this, the study aims at assessing the effect of different riser heights on the sprinkler irrigation performance to cater for taller crops and reduce water losses.

2 Materials and Methods

2.1 Study Area

The study area is located within the Federal University of Technology, Minna, Gidan Kwano, Minna, Nigeria. It lies on latitude 9°32'04.1 N and longitude 6°26'53 E. The study was carried out on the land adjacent to the Department of Agricultural and Bio-resources Engineering Laboratory of the University. Gidan Kwano has two seasons namely rainy and dry. The annual maximum and minimum rainfall in the area is 1086 mm and 1309 mm, respectively, which occurs in May and ends in October. The yearly maximum and minimum temperature in the area is 37 °C and 19.3 °C respectively (Galadima, 2014).

2.2 Materials and Equipment

2.2.1 Water Pump

The water pump moves water by pressure or suction from the reservoir to field, and its specification was presented in Table 1.

Table 1: Water Pump Specifications

Item	Description
Water pump model	WP20X
Type	DF1
Connection diameter	50 mm
Delivered volume	600 L/min
Total head	26 m
Power speed	3600 rpm

2.2.2 Sprinkler Irrigation system

The sprinkler irrigation system has a main line of 6 m long with 50 mm diameter. Two lateral lines have 25 mm diameter with 3 m long each. It has different riser heights such as 1.5 m, 2 m, 3

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m, and 4 m with 2.5 mm diameter. Sprinkler irrigation system conveys water from the reservoir through the main and lateral line to the nozzle which sprays the water in the form of rain to the field.

2.2.3 Sprinkler Heads

The sprinkler head sprays the water in the form of raindrops to the area. The specifications, characteristics and manufacturers details of the pressure, spraying radius, nozzle diameter and discharge of the four sprinkler heads were shown in Table 2.

Table 2: Sprinkler Head Manufacturers' Specifications

Specification	Comments/remarks
Pressure	0.5 – 4.0 Bar
Spraying Radius	3.0 – 16.5 m
Nozzle Diameter	5.0+2.5 mm (7.5 mm)
Flux/ Discharge	6.8-32.4 L/min
Size	¾ inches
Operation Capacity	360° full circle coverage
Model	RC130 zinc/brass

2.2.4 Catch Cans

The diameter, height and volume of the catch cans were 84 mm, 130 mm and one litre respectively.

2.2.5 Water Hose and Siphon Tube

Siphon tube sucks water from the tank to the pump impeller. Water hose conveys water from the pump to the mainline. The hose connected at the other end of the impeller to the main line which was held firmly by a clip to prevent leakages.

2.2.5 Tape

A 50 m tape was used to measure the layout and the spacing of the catch cans.

2.2.6 Volumetric cylinder

The cylinder was used to measure the water caught in the catch cans. It has a capacity of 500 cm^3.

2.2.7 Marking pegs

Pegs were used to map out the area and grid system.

2.2.8 Stopwatch

A stopwatch was used to measure the time it takes the sprinkler head to fill the container.

2.2.9 Pipe Wrenches

Pipe Wrenches was used to screw in the laterals into the main line and the risers into the laterals.

2.2.9 Cup Anemometer

Cup anemometer was used to measure wind speed and direction.

2.2.9 Portable Thermo-hygrometer

Portable Thermo-hygrometer was used to measure the temperature and humidity of the area

2.3 Methods

2.3.1 Experimental description and Design Layout

Field evaluation was carried out at Agricultural and Bio-resources Department, Federal University of Technology, Minna. The field had an area of 144 m^2 (12 m by 12 m). The vegetation of the field was cleared in line with Osie (2009) and mapped out with pegs to form a grid as shown in Figure 1. Sprinkler compositions used were different riser height (such as 1.5 m, 2.0 m, 3.0 m and 4.0 m), pump, siphon tube, rubber hose, 36 catch cans, four sprinkler nozzles (model RC130), one main line (6 m in distance and 50 mm in diameter) and two laterals (6 m in length and 25 mm in diameter). The water pump has two impeller hoses which included a siphon tube and a rubber hose. The rubber hose was attached or connected to the mainline while the siphon tube was attached water tank as shown in Figure 1. These components assembled such that the laterals were spaced 3 m apart on the main line. In summation, the catch cans were spaced 2 m apart along the grid. The 36 Catch Cans estimated according to the area of the field

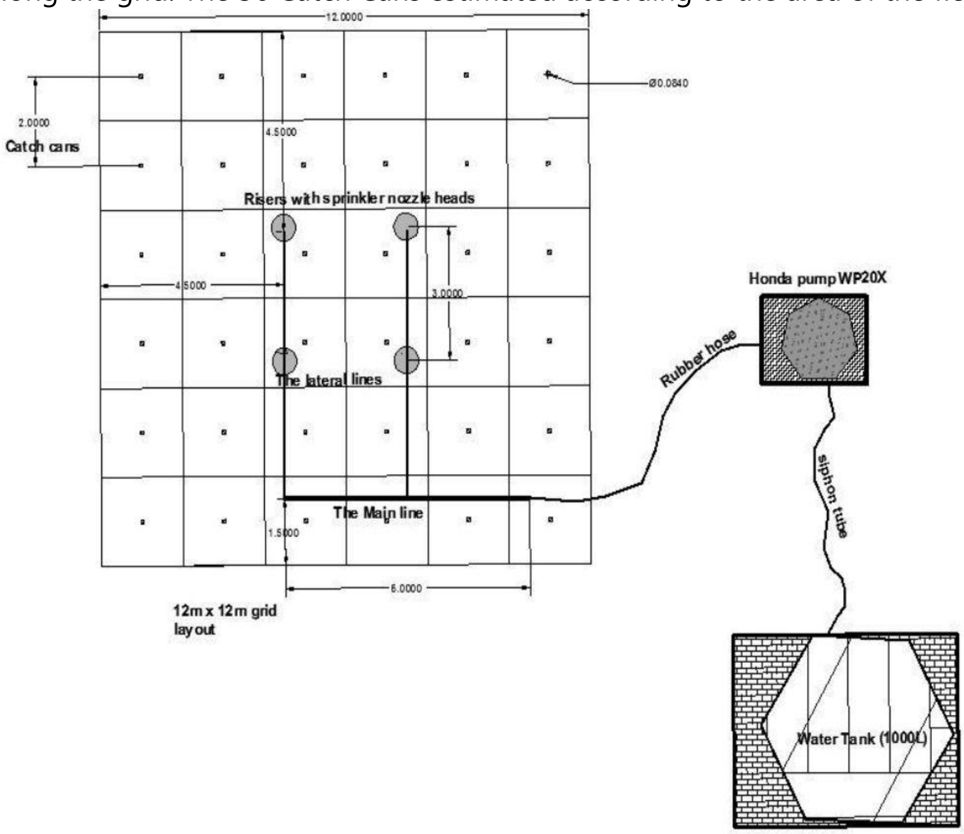

Figure 1: Experimental view of sprinkler set up, the arrangement of catch cans on the grid and design layout

2.3.2 Operation of Sprinkler System Performance

The operating pressure of the water pump adjusted via a pressure gauge and pitot tube. The Pitot tube was held at 3 mm from the nozzle head and recorded with the operating pressure. In the trial test, the operating pressure and flow rate were adequately controlled in this experiment. The speed and direction of the wind are measured every 15 minutes at height 2m with cup anemometer. At the end of the trial, the amount of water accrued in each catch cans was measured with cylinders (mL), and the procedures were repeated for each sprinkler nozzle as described by Kara et al. (2008).

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2.4 Calculation of Basic Parameters

2.4.1 Evaporation and wind drift losses

In sprinkler irrigation, water losses came from the nozzle to the irrigated areas due to the wind in the form of water drift and direct evaporation from the nozzle to the soil (Molle et al., 2012). Because of this, it is essential to determine evaporation and wind drift losses as described by Bishaw and Olumana (2015).

$$E = [1.98\,(D)^{-0.72} + 0.22\,(E_s - E_a)^{0.63} + 3.6 \times 10^{-4}(H)^{1.16} + 0.14\,(U)^{0.7}]^{4.2} \quad (1)$$

where:

E = Evaporation and wind drift, per cent

D = Nozzle diameter, m

H = Riser height, m

U = Wind velocity, m/s

$E_s - E_a$ = Vapor pressure deficit, kPa

Vapour pressure deficit is a predominant factor that affects evaporation from the sprinkler sprays. It is important to determine the vapour pressure deficit affecting the evaporation of the water from the nozzle (Bavi et al., 2009). The vapour pressure deficit was determined as follows:

$$E_s - E_a = 0.61 \exp\left[17.27 \frac{T}{T+237.3}\right](1 - RH) \quad (2)$$

where,

T = Air temperature, °C

RH = Relative humidity, fraction.

The evaporation and drift losses were determined for different riser height as recommended by Smajstrla and Zazueta (1994).

$$\ln E = 4.506 - 0.518 \ln D + 0.703 \ln H + 0.137 \ln U - 0.04 \ln RH + 0.022 \ln T \quad (3)$$

where,

E = Evaporation and drift losses, %

D = Nozzle diameter, m

H = Riser height, m

U = Wind velocity, m hr-1

RH = Relative humidity, %

T= Air temperature, °C

2.4.2 Christiansen's Coefficient of Uniformity (CU)

The coefficient of uniformity (CU) was determined as follows:

$$\mathrm{CU}(\%) = \left[100\left(1 - \frac{\text{the standard deviation of the water in the catch can}}{\text{mean of water in the catch can}}\right)\right] \quad (4)$$

2.4.3 Distribution Uniformity (DU)

The distribution uniformity (DU) was calculated as follows:

$$\mathrm{DU}(\%) = \left[100 \times \left(\frac{\text{an average low quarter of water in the catch can}}{\text{the average total of water in the catch can}}\right)\right] \quad (5)$$

2.4.4 Mean Application Rate (MAR)

The mean application rate (MAR) was determined as follows:

$$\mathrm{I} = \frac{q}{S_m \times S_l} \times 100 \quad (6)$$

I= mean application rate is (m hr-1)

q = Sprinkler discharge (m3 hr-1),

S_l = Sprinkler spacing (m),

S_m = lateral spacing (m).

2.5 Data Analysis

The quantity of water measured in each riser were subjected to One-way ANOVA with multiple comparisons in Minitab 17 Environment. The amounts of water caught in the Cans were used to compute the Coefficient of Uniformity, Distribution Uniformity and Mean Application Rate of the sprinkler irrigation system. The results are presented in Tables and charts.

3. Results and Discussion

3.1 Determination of the volume of water Caught in the Catch Cans

The evaporation and wind drift losses range between 5.22% to 10.2% which was in line with the work of Okasha and Pibars (2016). The amount of water determined in each riser was shown in Table 3. In a riser 1.5, the amount of water computed in the catch-can equal 799 ml. Also, the amount of water estimated in riser 2 was 632 ml. The amount of water calculated at riser 3m was 745 ml. The riser 4m has a total amount of 874 ml. The mean application rate for each riser 1.5, 2, 3 and 4 was 8.56 mm hr^{-1}, 7.76 mm hr^{-1}, 7.56 mm hr^{-1} and 6.76 mm hr^{-1} respectively as shown in Table 3. The study revealed that as the riser height increases the mean application rate decreases because the evaporation and drift losses also increase as indicated in Table 3. This study agrees with the work of Bishaw and Olumana (2015). The riser heights 4.0 m, 3.0 m and 1.5 m have the highest depth of water, whereas 2.0 m has the lowest volume of water caught in the catch cans as shown in Table 3. The practical implication is that more water was well distributed on the land at riser height 2 m while risers 4.0 m, 3.0 m and 1.5 m were not. Thus, riser (2 m) generates less runoff.

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Table 3: Determination of the Volume of water Caught in the Cans under constant operating pressure

Date	Time	Riser Height (m)	Total Volume of Water in the Cans (ml)	Evaporation and Drift Losses (%)	Wind Direction	Mean Application Rate (mm hr^{-1})
29/72016	5:06 PM	1.5	799	5.22	NW	8.56
30/7/2106	9:32 AM	2	632	5.7	NE	7.76
30/7/2106	10:27 AM	3	745	8.21	NE	7.56
30/7/2106	11:23 AM	4	874	10.2	SE	6.76

3.2 Effect of Riser Height on Water Caught in the Catch Cans under Constant Operating Pressure

The analysis of variance for the water determined in the catch cans was shown in Table 1. The factor riser 1.5m, 2m, 3m and 4m do bring significant information to the model since the computed p-value is less than alpha (0.05). The risers 2 and 3 were significantly different because their means do not have any letter in common (Table 1), and concluded that the riser height has the different mean value of water caught in the catch cans. Besides, the Tukey pairwise comparisons show that riser heights 1.5 m, 2 m, 3 m and 4 m have different water trapped in the catch cans because the Means that do not share a letter are significantly different.

Tukey simultaneous tests for differences of means for water caught were shown in Table 3. The difference in level between riser height 4 m and 2 m have a higher effect on the water found in the catch-can be followed by the riser 2m and 1.5m, 4m and 3m and 3m and 2m since their p-values were 0.000, 0.001, 0.016 and 0.046 respectively. Thus, the risers have a different effect on the volume of water caught.

Table 1: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-value	P-value
Riser	3	863.9	287.97	11.28	0.000
Error	140	3575.4	25.54		
Total	143	4439.3			

Table 2: Tukey Pairwise Comparison

Risers	Mean	Grouping
4	24.28	A
1.5	22.19	AB
3	20.694	B
2	17.556	C

Means that do not share a letter are significantly different

Table 3: Tukey Simultaneous Tests for Differences of Means (volume of water)

Difference in Level	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-value
2.0 - 1.5	-4.64	1.19	(-7.74, -1.54)	-3.89	0.001
3.0 - 1.5	-1.50	1.19	(-4.60, 1.60)	-1.26	0.590
4.0 - 1.5	2.08	1.19	(-1.02, 5.18)	1.75	0.303
3.0 - 2.0	3.14	1.19	(0.04, 6.24)	2.64	0.046
4.0 - 2.0	6.72	1.19	(3.62, 9.82)	5.64	0.000
4.0 – 3.0	3.58	1.19	(0.48, 6.68)	3.01	0.016

3.3 Determination of Coefficient of Uniformity (CU) and Distribution Uniformity (DU) under different Riser Heights at Constant Operating Pressure (1.6 bars)

The uniformity coefficient and the distribution coefficient of the sprinkler irrigation system were shown in Table 4. At riser height 1.5 m, the Coefficient of Uniformity (CU) and distribution uniformity (DU) were 70% and 61% respectively. The CU and DU values at 2 m riser height were 89% and 85% respectively. At riser 3.0 m, CU and DU values were 85% and 78% respectively. The CU and DU at 4 m riser height were 72% and 70 respectively. This study found out that the riser height 2.0 m had the highest CU (89%) and DU (85%) values. Also, the riser height of 1.5 m had the lowest CU (70%) and DU (61%) values. CU for riser height 4.0 m and 1.5 m were classified unsatisfactory while the CU for riser height 2 m and 3 m were rated good (Little et al., 1993). Also, the DU for 2 m and 3 m were rated excellent and fair while the DU for 1.5 m and 4 m were rated poor (Bloomer, 2006). The study revealed that riser heights 2 m and 3 m have optimum CU and DU.

Table 4: Coefficient of Uniformity and Distribution of Uniformity of different Risers

Riser Height (m)	CU (%)	DU (%)
1.5	70	61
2	89	85
3	85	78
4	72	70

4 Conclusion

The effect of different riser heights on the performance of sprinkler irrigation at constant operating pressure was assessed to provide water for the cultivation of high crops and reduce water wastage. The study revealed that as the riser height increases the mean application rate decreases. The riser heights 2 and 3 m were significantly different because their means do not have any letter in common, and concluded that some of the riser height have the different mean value of water found in the catch-can. This study reveals that as the wind direction changes the volume of water trapped in catch cans also increases which in turn cause weak CU. The study concluded that riser heights 2m and 3m have the highest CU and DU at 1.6 bars and these riser heights can provide water for taller crop and reduce water losses on the field.

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