Research Article

Effect of some design parameters on the performance of side access nozzle and grooved plate of centre pivot sprinkler

Abstract

This research evaluates the effect of various heights, pressures, nozzle size and groove numbers on the uniformity distribution of a developed pivot sprinkler. The experiment was set up at an open space in Niger State College of Agriculture Mokwa. The wind speed and temperature during the experiment were at an average of 2.2mph and 25°C. A nozzle of size 6mm, and deflection plate of 6 curved grooves were used in a centre pivot spray unit. In evaluating the performance of the spray unit components i.e. the nozzle and deflection plate, three different pressures of 5, 10, and 15 Psi and heights of 1, 1.2, and 1.5mm were used. The support structure for the experiment is an inverted U-shaped frame designed to support a spray sprinkler at different heights. The water source was a reservoir with a capacity of 3m^{3}and a 1.5hp electric centrifugal pump was used. The volumetric or bucket method was used to measure flow rate. The application rate was measured using catch can method. The duration of each test was approximately 30min. The data obtained from the measurements were statistically analyzed with line graphs using Excel. Relationships were also established between discharge and pressure. The highest index of jet break up was 4.89 at 15Psi and 3.74 at 10Psi. The result shows that as the pressure increases with height the CU also increases. The highest uniformity of 79.4% was obtained at 1.5m height and 15Psi.

Keywords: uniformity, nozzle, deflection plate, pressure, height

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Mohammed JM,[1] Abdullahi AS,[1] Musa SM,[1] Abubakar LG,[1] Sylvester OA[2]

[1]Department of Agricultural and Bio- resource Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria
[2]Five Bees Engineering Consultants Limited, Nigeria

Correspondence: Mohammed JM, Department of Agricultural and Bio- resource Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria, Email ikwan1565@gmail.com

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Introduction

According to Ghazwan[1] in the past 30 years the effort has been how possible it to manufacture nozzles that distribute water of large radius of coverage at a low pressure. This is resulted from the fact that high pressure needs bigger pumps and large energy and bigger financial implication. It is good to note that centre pivots work with many types of sprinkler packages Martin et al.,[2] Some of these packages have one central nozzle that is incorporated with spray plates that distribute the irrigation water. The plates are either stationary that is fixed or multiple or rotational and oscillating.

According to Lipp et al.,[3] A nozzle that distribute water is considered a precision device that enable distribution of liquid through it. They have three main uses; spray water over an area, add to liquid surface area, and making impact on a solid surface. Many distribution characteristics are used to describe different spray nozzle application.[4] Nozzles that distribute irrigation water can be grouped according to their energy input that is used for the atomization formation.[5]

Sprinkler nozzles work on the basis of several factors; these are nozzle orifice diameter to allow water to pass through, discharge flow rate, and pressure. For a given nozzle size, it is the pressure that governs the amount of water that is forced through the nozzle and it is the pressure that provides the force to create the diameter of throw of the water stream. Nozzles can be tested to determine if there is a pressure at which they provide a good distribution profile. When found, the nozzle diameter, its angle from the horizontal, its operating pressure and radius of throw are recorded. This information is used for design purposes.

Sprinklers nozzles that have pads which rotates distribute water from the nozzle by directing the water flow on the plates which then enable it to rotate in a circular style. While some of the plates rotate slowly others move or spin faster and some even wobble. Water patterns are formed; this is relying on the speed of movement of the plates an influenced by the impact of the water jet. While some jets look like slowly rotating spokes others break up the stream of water into blur of water droplets. Aside the rotation speeds the pads can have different groove design that gives different water atomization.[6]

Pressure of water from the sprinkler, the size of nozzle of jet determines the type of drop size that is formed from the sprinkler. Consequently, the application rate pattern is determined by impact of droplet size. small droplets of water are created by higher pressure and small nozzles increase application rates close to the sprinkler. Again, low pressure and bigger nozzle size gives larger droplets and increase rates of application far away from the sprinkler. In irrigation it is recommended that the uniformity of application be a uniform as possible, because lack of uniformity in water application in irrigation can lead to under wetting and over wetting of some areas consequently affecting crop production. The sprinkler package design determines the performance of the sprinkler.[7] The package is usually affected by the working conditions of operation, the environmental factors, e.g. wind. According to some researchers, the drople sizes at any distance from the spray sprinkler can be ascribed to the nozzle size.[8–10] This research evaluates the effect of various heights, pressures, nozzle size and groove numbers on the uniformity distribution of a developed pivot sprinkler.

Material and methods

Materials

The materials employed for this study include; catch cans, pressure gauge, filters and 1.5Hp centrifugal pump.

Study area

Mokwa is in Niger State, Nigeria. It has the following elevation and coordinates; 88 meters above sea level, 9°16’60”N and 5°3’0” E respectively (Figure 1).

Figure 1 Map of Niger State Showing the Study Area.

Experimental set-up

The experiment was set up at an open space in Niger State College of Agriculture Mokwa. The wind speed and temperature during the experiment were at an average of 2.2mph and 25°C. This purposefully targeted conditions were made to mimic a laboratory condition. conducting experiments in laboratory or environmentally friendly condition ensures water distribution and avoids water drift and losses.[6,11,12]

A U- shaped structure was used as a support during the experiment, this is to enable the adjustment for different test heights. A manual throttle valve was also installed to control pressure and water distribution during the experiment Figure 2.

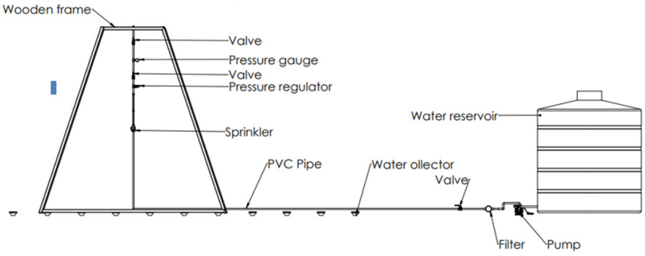

Figure 2 Structure and Components of Experimental Setup for Evaluation of Water Distribution of Individual Spray Sprinklers.

The frame was constructed with 50mm x 50mm size wooden planks such that it enables a variable height from 1.0 to 3 m above the floor and 4m wide. The frame angles were well braced to avoid spray sprinkler vibrations.

Hydraulic system

The source of water was a reservoir with a capacity of $3m^3$. A 1.5hp electric centrifugal pump was connected to a 19.05mm (0.75inch.) external diameter PVC main pipe supplying water to the 12.7mm (0.5inch) droppers carrying the spray sprinklers.

Experimental conditions

After the setup of the experiment, before data collection, the operating pressure was held steady using the installed manual throttle valve for all the tests. Three operating pressures were used in order to determine their influence on the wetting radius, discharge, and the pattern of ware application. Nelson[13] stated that Rotating spray plate sprinklers (RSPS) can be operated within the pressure range of 10 to 50Psi. this is why the pressures of 5, 10, and 15Psi were chosen for this experiment. These values cover the ranges of operational pressure values used on the field. The sprinkler working pressure was measured at the base of the sprinkler head using a pressure gauge having the sensitivity of 0 to 100Psi and accuracy of 0.4%. A control valve was installed close to the pressure gauge; this is to control the operating pressure of the nozzle. The control valve enables control of the pressure to a desired one.

The volumetric or bucket method was used to measure flow rate. This was done by positioning the nozzle of the sprinkler both inside and outside the container used in weighing immediately. In recording the time of test, a digital stopwatch was used. Equation 3.1 was used to determine the flow rate.

$$Q = 60 \div (T) \times (B) \tag{3.1}$$

Where T= time it takes to fill the bucket of container (sec)

B = Bucket or container size (L)

Q= flow rate (L/sec)

Measured parameters

The wetted radius

The wetting radius is an index to measure the performance of sprinklers. Kincaid[14] procedure was used to determine the wetted radius as it relates to the nozzle sizes, different operating pressures and deflection plate configuration. Three replications were used. Wetted radius relationships were developed as a function of nozzle diameter, pressure head, sprinkler height.

$$R = f(d, H, Sh) \tag{3.2}$$

Where R is wetted radius (m), d is the diameter of the nozzle (mm), and H is the pressure head (m) and Sh is the Sprinkler Height.

Application rate

The application rate was measured using catch can method. The period of every test was roughly 30min. four radial legs were used, spaced at 0.5m increments from the sprinkler to a distance of 11m. The radial application measurement was taken at selected pressures and heights above the topmost of the catch cans. The catch cans for testing the radial water application depths have heights of 0.08m and an inside diameter of 0.128m. The spray heads were placed on three different heights; h1-1m, h2-1.2m and h3-1.5m above the catch cans at 90^o to the horizontal and operated at pressures of P1-5 psi, P2-10 psi and P3- 15 psi at various times in the course of the experiment.

Measurement of the volume of water caught were measured manually with a container of 500mL capacity. The air and water temperatures were also noted. To standardize the flow and pressure conditions of the rotating sprinkles, the sprinklers were used or tested for few minutes before the experiment commences.

Net Application rate (mm/h) is give as;

$$MAR = \frac{\Sigma X}{n \times t} \tag{3.3}$$

Where MAR = mean application rate in mm/h (millimetre per hour). ΣX = total depth of water collected in the catch cans, mm

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(millimeter). n = total number of catch cans. t = time of operation h (hour).

Coefficient of uniformity

The coefficient of was determined applying equation (3.4)

$$CU\% = 100[1 - \frac{\Sigma X}{mn}] \quad (3.5)$$

Where: CU % = Coefficient of uniformity in (%); m = Average volume of water collected in (mm); n = number of total observations; x = deviation of individual observation from the mean (mm).

Working pressure and discharge (q) relationship

$$q = C_d \times a \times \sqrt{2gh} \quad (3.6)$$

Where, q is the Nozzle discharge, m^3/s (cubic metre per second).

a is the Cross sectional area of sprinkler nozzle, m^2 (meter square).

h is the Pressure head at the nozzle, m (meter).

Cd is the Coefficient of discharge which is a function of friction and contraction losses.

G is the Acceleration due to gravity, m/s^2 (metre per second square).

Pressure and discharge can be related and established for sprinkles using discharge equation and plotting the data of discharge (Q) and pressure (P) then relating this to the power series curve.

$$q = C_d \times a \times (2 \times g \times h)^x \quad (3.7)$$

Where, q is the Nozzle discharge, m^3/s (cubic metre per second).

a is the Cross sectional area of sprinkler nozzle, m2 (meter square).

h is the Pressure head at the nozzle, m (meter).

Cd is the Coefficient of discharge which is a function of friction and contraction losses.

G is the Acceleration due to gravity, m/s^2 (metre per second square).

x is the Slope of the power series curve

Index of jet break-up (Pd) determination

According to Pillsbury[15] to get the uniformity of coverage and minimizing the sprinkler water atomization the breakup of water jet is of paramount importance. Air resistance can cause water jets to breakup and particularly increases as the pressure increases with the presence of slots in the nozzles. The empirical equation 3.8 recommended by Pillsbury[15] is applied to estimate the index of jet break up.

$$P_d = \frac{h}{10 \times q^{0.4}} \quad (3.8)$$

Where, Pb is the jet break up index.

h is the pressure of the sprinkler nozzle head in m (meter).

q is the discharge of the sprinkler, lps (litres per second).

When Pd > 2, the drop size condition is seen to be good.

When Pd is equal to 4, the drop size condition is seen to be the best

Bu when Pb is > 4, pressure is seen to be wasted (Pillsbury, 1968).

Determination of effective radius and area (A)

In determine the effective radius of the pivot sprinkler, the boundary covered by the pivot sprinkler was used. The throw radius was measured after the sprinkler was operated at different pressures and heights and the mean taken as the effective radius. The formula by Pillsbury[15] was used to calculate the area covered by the rotating sprinkler.

$$A = \pi R^2 \quad (3.9)$$

Where

$$R = 1.35\sqrt{dh} \quad (3.10)$$

Where A is the Area covered by the sprinkler in m^2.

R is the Radius of wetted area covered by the sprinkler in m

d is the Diameter of sprinkler nozzle in mm.

h is the Pressure head at the nozzle in m.

Data analysis

The data obtained from the measurements were statistically analyzed with line graphs using Excel. Relevant mathematical equations and graphical representations were developed.

Characterization of spray unit prototypes

Water distribution pattern with varying height, grooved plates, and operating pressures

Figure 3 shows the distribution of water precipitation rate versus the distance from the sprinkler. It shows the water distribution profile of nozzle size 6mm with 6 grooved deflection plate at a pressure of 10Psi and height of 1m. The figure depicts distribution of water collected in four radial lines of catch cans. The water collected were measured in volume and converted to depth. The application depth between the sprinkler and a distance of 2.5m were lower compared to a distance of 2.5 to 7m. This may be attributed to the distribution pattern of the sprinkler package where cans closer to the sprinkler get less catches compared to those further from the sprinkler. The wider spaces seen among the sinusoidal trend lines of water distribution shows the variability of the depth of application as caught by the cans. The variations can also be attributed to the smaller nozzle size, lower height and pressure of test. The mean depth of application is 8.71mm. The lowest application is 2.2mm and the highest is 14.71mm. This result is similar to the findings of Habib S et al.[16,17]

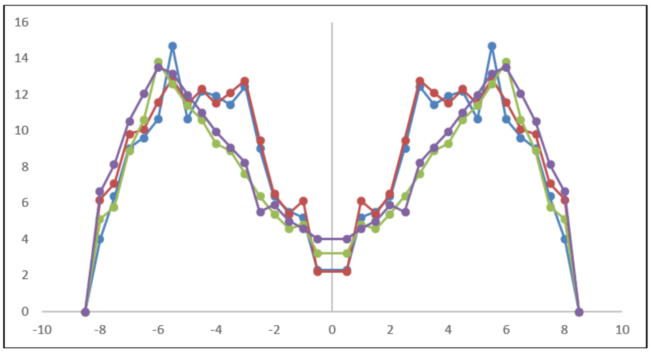

Figure 3 Nozzle Size 6mm with Spinner grooved Plate 6 at 1m and 5 PSI.

In Figure 4, the graph reflects the pattern of the of the application depth as affected by Nozzle size 6mm with Grooved Plate 6 at 1m and 10 Psi. The trend lines are more uniformly arranged showing that

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the uniformity of distribution at height of 1.2m and 5Psi was better than at 1m. The peak application depth was 14.2mm and the lowest application depth was 4.6mm. It shows that higher height gives better uniformity of application. This finding is related to the result of Habib S et al.[16] The spaces within the lines shows deviations from normal, meaning the closer the lines or lapped with one another the better the uniformity.

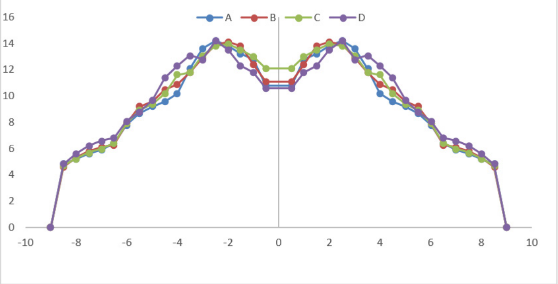

Figure 4 Nozzle Size 6mm with Spinner Grooved Plate 6 at 1.2m and 5 PSI.

In Figure 5, the graph shows a better uniformity of distribution owing to the sinusoidal trends. the graph reflects the pattern of the of the application depth as affected by Nozzle size 6mm with grooved Plate 6 at 1.5m and 5 Psi. The trend lines are more uniformly arranged showing that the uniformity of distribution at height of 1.5m and 10Psi was better than at 1.2. The peak application depth was 14.6mm and the lowest application depth was 4.6mm. It shows that higher height gives better uniformity of application this is similar to the findings of Habib S et al.[16]

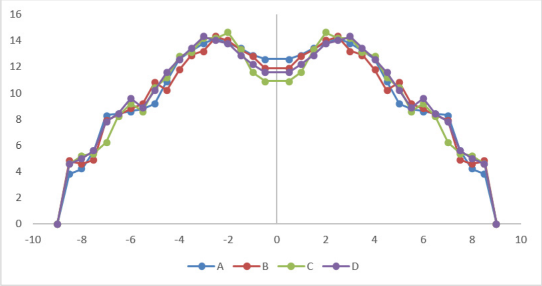

Figure 5 Nozzle Size 6mm with Spinner Grooved Plate 6 at 1.5m and 5 PSI.

In Figure 6, in the Figure 4 the distribution was more linear after the increase of the pressure from 5Psi to 10Psi. The graph reflects the pattern of the of the application depth as affected by Nozzle size 6mm with grooved Plate 6 at 1m and 15 Psi. The trend lines are closely arranged reflecting the extent of uniformly. At the distance of 2m the application rate was at the peak giving 18.5mm. The lowest application depth was 5.8mm at the distance of 9m. It shows that higher pressure gave higher radius of throw.

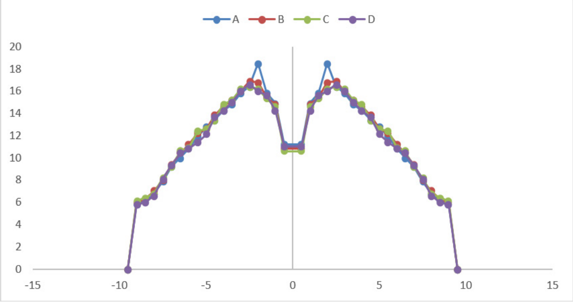

Figure 6 Nozzle Size 6mm with Spinner Grooved Plate 6 at 1m and 10 PSI.

In Figure 7, depicts the water distribution pattern of the sprinkler of having nozzle size 6mm with grooved Plate 6 at 1.2m and 10 Psi. As the pressure increased with distance. The uniformity seems to reduce reflecting the spaces between the lines. The peak application depth was 16.4mm and the lowest application depth was 5.8mm at a distance of 0.5m.

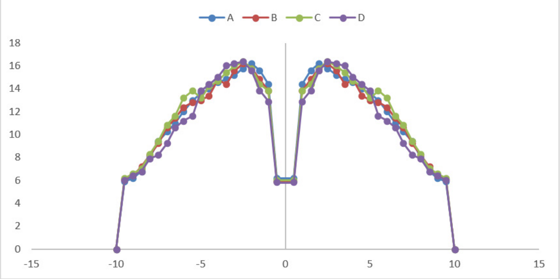

Figure 7 Nozzle Size 6mm with Spinner Grooved Plate 6 at 1.2m and 10 PSI.

In Figure 8, depicts the water distribution pattern of the sprinkler of having nozzle size 6mm with grooved Plate 6 at 1.5m and 10 Psi. As the pressure increased with distance. The uniformity seems to reduce reflecting the spaces between the lines. This result is similar to those of Kuti et al.,[18] The peak application depth was 16.4mm and the lowest application depth was 3.9mm at a distance of 0.5m.

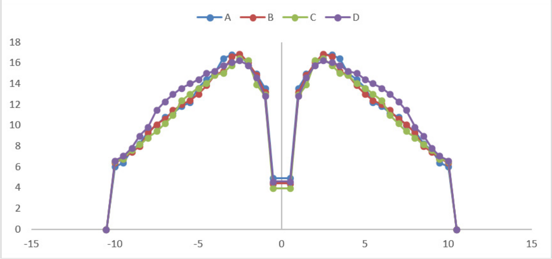

Figure 8 Nozzle size 6mm with Spinner Grooved Plate 6 at 1.5m and 10 PSI.

In Figure 9, the graph reflects the distribution pattern of the of the application depth as affected by Nozzle size 6mm with grooved plate 6 at 1m and 15 Psi. As the pressure increased at drop tube of 1m from the ground surface, the uniformity increased reflecting in the trends of the radial application. The trend lines are more uniformly arranged showing that the uniformity of distribution at height of 1m and 15Psi was better than at 1.5m at the pressure of 10Psi. The peak application depth was 17.8mm at a distance of 2.5m and the lowest application depth was 4.8mm at a distance of 0.5m.

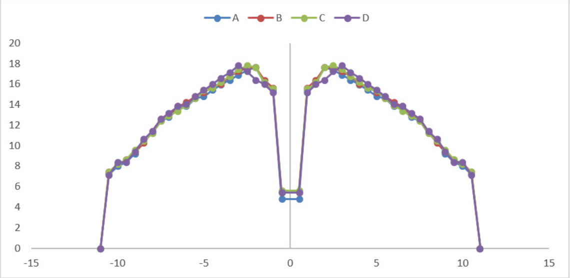

Figure 9 Nozzle Size 6mm with Spray Head Grooved Plate 6 at 1m and 15PSI.

In Figure 10, the graph describes the pattern of the of water distribution, as affected by nozzle size 6mm with grooved plate 6 at 1.2m and 15 Psi. The trend lines are more scattered as compared to when the drop tube was at the distance of 1m from the ground floor, showing that the uniformly of application has reduced. The peak application depth was 17.8mm at a distance of 2.5m and the lowest application depth was 2.4mm at a distance of 0.5m.

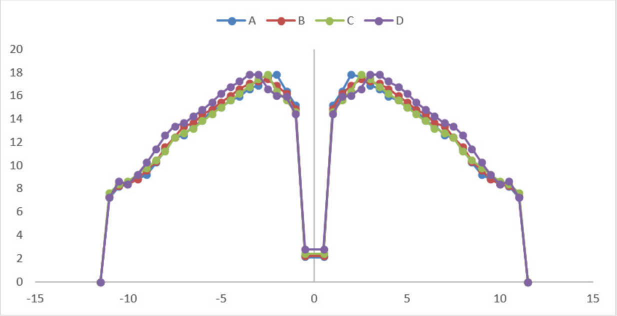

Figure 10 Nozzle Size 6mm with Spray Head Grooved Plate 6 at 1.2m and 15 PSI.

Figure 11, shows how increase in height affects application depth distribution, at 1.5m, 15Psi and plate 6, the graph reflects better uniformity as the lines overlap almost completely. The peak application depth was 17.8mm at 1.5m and the lowest application depth was 5.8mm at 0.5m. It shows that higher height and higher pressure support good uniformity of application.[15]

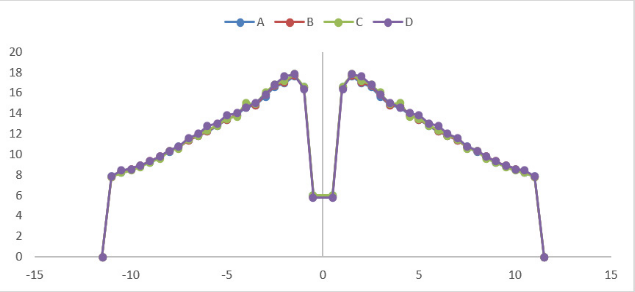

Figure 11 Nozzle Size 6mm with Spray Head Grooved Plate 6 at 1.5m and 15 PSI.

Coefficient of uniformity

Uniformity of distribution as affected by pressure, height, nozzle size and groove number

The uniformity of irrigation sprinkler depends on numerous design factors e.g; type of nozzle, diameter nozzle, working pressure and height of the riser.

The Influence of working pressure, nozzle diameter, groove number and riser heights on coefficient of uniformity (CU) are presented in Figure 12. Three different pressure levels and drop tube heights were employed i.e. 5, 10, 15Psi and 1m, 1.2m,1.5m respectively and a 6 grooved deflection plate. The graph shows that as the pressure increases with height the CU also increases. H1 P1 has the lowest uniformity of 68.3% which is considered fair by irrigation standard.[19] At H1 P2 the uniformity is 74.5% which is adequate and at H1 P2 CU was 76.5%. At H2 p1 CU was 71.7%, H2 P2 73.3%, and H2 P3 has 77.7% CU. According to Zafar et al.,[19] System uniformity coefficient can be applied to judge the overall performance of sprinkler irrigation system in numeric terms. For instance, a Coefficient of uniformity of 91 - 95% is said to be very good to excellent while at 85 - 90% is good to very good. But a CU of 87% of the system shows that some areas of the field are getting 13% less of water while some areas are getting 13% more than the mean applied. At H3 P1 the CU is 72.7%, H3 P2 73.3% and H3 P3 79.4%.

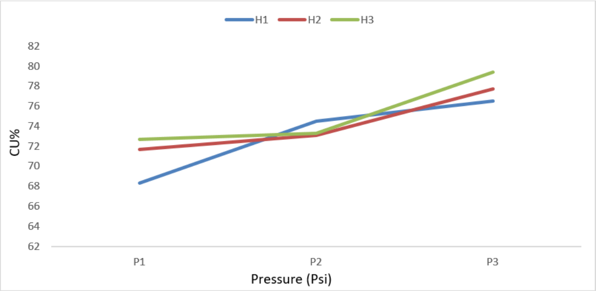

Figure 12 CU, H vs pressure for Nozzle 6 mm PLT 6.

Index of Jet break up at various operating pressures.

To get the uniformity of coverage and to reduce the droplet size of the irrigation water, the determination of the break – up jet is important. The impact of droplet size on some soils can lead to soil compaction, sealing, crusting and consequently reducing infiltration rate. A non-satisfactory drop size can give poor uniformity and crop yield. According to Stillmunkes and James;[20] King and James, (1984), The extent of soil infiltration rate reduction depends on the energy impact of the water spray for a given soil type and application rate. The findings of Dhaval et al.,[21] also shows similar result.

As shown in Table 1 and Figure 13, at the pressure remains steady at 5Psi, the value of break up index was 2.1, at this value, it shows that the droplet size is not good. When the pressure was increased to 10Psi, the break up jet value was 3.74. this is between 2 and 4. This shows that the droplet size is good. The droplet size is seen as best at the value of break up jet of 4.

Table 1 Index of Jet break up at various operating pressures

S/N	Operating pressure (Psi)	Average discharge (lps)	Index of jet break up (Pd)
1	5	0.25	2.1
2	10	0.331	3.74
3	15	0.404	4.89

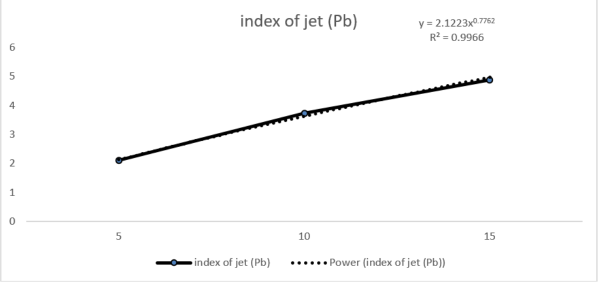

Figure 13 Index of Jet Break Up (Pd) at various operating pressures of Pivot sprinkler.

To carry out more investigation, the operating pressure was increased to 15Psi and remain steady. At this pressure the breakup value was found as 4.89. this exceeds 4. This clearly indicates pressure being wasted. When interpolation of the peak values is being done graphically, 12 Psi was the best pressure to give the required droplet size.

Discharge (q) of Pivot sprinkler at various operating pressures

Figure 14 describe the discharge Q of a Pivot sprinkler irrigation system at different pressures. I was observed that as the working

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pressure increases the discharge also increases. This is similar to Dhaval et al.,[21] in their determination of discharge versus pressure relationship. The discharge equation:

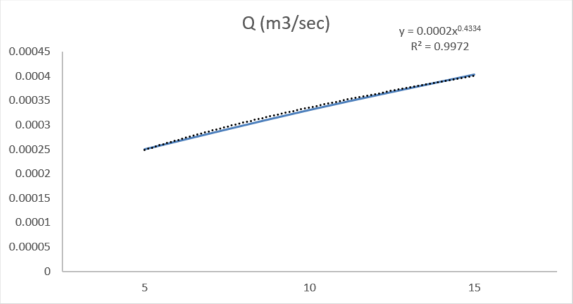

Figure 14 Discharge (q) of Pivot sprinkler at various operating pressures.

$$q = C_d \times a \times (2 \times g \times h)^x \tag{3.11}$$

was equated with the power series model to get Figure 14 and the value of x was gotten. The summation of area of nozzle orifices was gotten to be 0.000113m^2. The value x was calculated as 0.433 and shown in Table 2, 3. As seen in Figure 3, the minimum and maximum discharges of 0.000250 and 0.000404 m^3/sec were gotten at pressures of 5 and 15 Psi, respectively. The connection between pressure and discharge is shown in Table 3 with R^2 value of 0.997. The coefficient of discharge is a function of friction losses and contraction losses. To obtain the coefficient of discharge Cd values, the equation of discharge is used in evaluating Cd in the discharge from the sprinkler nozzle if already the discharge is known. The value of x is gotten from the power series curve and consequently an equation displaying relationship between discharge and pressure as seen in the Table 3. When the pressure increases from 5 to 15 Psi, there was a significant rise in the discharge.

Table 2 Discharge rates at various operating pressures for the sprinkler

S/N	Operating pressure (Psi)	Average Discharge (m³/Sec)
1	10	0.00025
2	15	0.000331
3	20	0.000404

Table 3 Operating pressure and discharge relationship of pivot sprinkler system

Type of sprinkler	Coefficient of discharge C_d	Slope of power series curve x	Relationship
Rotating pivot sprinkler	0.68	0.433	$q = 068 \times A \times (2 \times g \times h)^{0.433}$

Table 4 and Figure 15, describes the radius of throw of a pivot sprinkler at various pressures as affected by nozzle size 6mm and groove plates. The lowest radius was obtained at 5Psi and height of 1m, and the highest radius of throw was obtained at pressure of 15Psi and height of 1.5m. It shows that as the pressure increases the radius of throw also increases. This applied to Figure 16 where the area of coverage also increases as the pressure also increases. This result is similar to that of Dhaval et al.,[21,22]

Table 4 Radius (R) and area of coverage (A)

S/N	Pressure (Psi)	Radius of coverage R (m)	Area of coverage A (m²)
1	PL6h1p1	6.2	120.779
2	PL6h2p1	6.4	128.696
3	PL6h3p1	6.8	145.286
4	PL6h1p2	8.3	216.452
5	PL6h2p2	8.6	232.382
6	PL6h3p2	8.9	248.878
7	PL6h1p3	10.9	373.301
8	PL6h2p3	11.3	401.202
9	PL6h3p3	11.5	415.53

*PL6: Groove Plate 6, h: height, P: pressure.

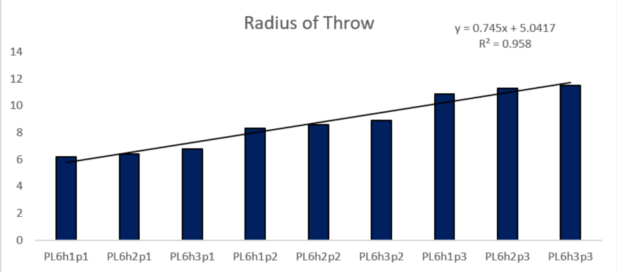

Figure 15 Radius of coverage (R) of Pivot sprinkler at various operating pressures.

*PL = plate, h= height, p = pressure.

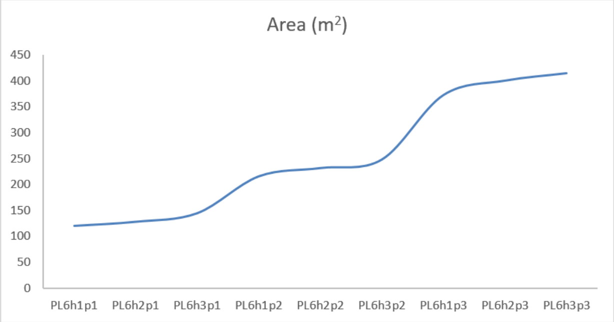

Figure 16 Area of coverage (R) of Pivot sprinkler at various operating pressures.

Conclusion

The performance of a pivot sprinkler is dependent on the configuration and composition of the spray unit components i.e. the type, size and the nature of the groove plates. The operational parameters like the amount of pressure and distance of the drop tubes from the soil has significant influence on the radius of throw and uniformity of the pivot sprinkler. The study shows that 10 Psi was adequate in providing the required pressure to give good irrigation water distribution and the Index of jet break up (P_d) was determined to be 3.74 which is well close to 4.

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Conflicts of interest

The author declares there is no conflict of interest.

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