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Effect of Micro-sprinkler Irrigation Application Efficiency for Okro (*Abelmoschus esculentus*) Farming

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Abstract
The adoption of micro-irrigation sprinkler system for okro farming has become an important approach to supplement water when water is deficiency and expensive to apply. Micro-irrigation sprinkler system was designed and evaluated for optimum water application efficiency for okoro farming in the study area which has low irrigable water sources in the dry season. The daily application efficiency of system was conducted and evaluated for optimum water usage and crop yield. The results show that the uniformity coefficient (uc) at 1.5 x 1.5 m micro-irrigation spacing is more suitable as compared to 2.25x2.25 m and 3.0x3.0 m spacing. As the operating pressures increase from 0.75 to 2.0 kg/cm² the emission uniformity and distribution uniformity decreases from 95.13 to 93.73 respectively. However, the precipitation pattern were studied in terms of the effective radius, average application depth, effective maximum depth, absolute maximum depth, mean depth distribution coefficient, coefficient of variation and emission uniformity as estimated by keller method for 1.0, 1.5. 2.0, and 2.5 kg/cm² operating pressure. Also, the crop yield to water ratio for micro-sprinkler irrigation system and border irrigation was determined to be 0.0515 and 0.0160 respectively. Determining the effect of irrigation system application efficiency on other type of crop and other type of irrigation method other than the ones used in this study were recommended among others.

Keyword: *micro-sprinkler, application efficiency, okro.*

Introduction

The development of micro-irrigation system is becoming an area of importance in the field of agriculture, to supplement insufficient rainfall in areas with limited and costly water supplies. Irrigation planning for micro-irrigation sprinkler systems is usually based on a water budget method to maintain a favorable soil moisture status in the root zone, i.e., to minimize periods of water stress and leaching below the root zone. Though, for localized micro-irrigation sprinkler systems, it is difficult to evaluate the various terms of the water application efficiency. The world practice of micro-irrigated sprinkler system has grown gradually from 1.1 million ha in 1986 to about 3.0 million ha in 2000 (Zamaniyan, 2014). However, in the world today, the micro-irrigation sprinkler system has been practiced in over 70 countries covering an area of over 6 million hectares and the area extended twice just during the last six years (Sne, 2006). In National Centre for Agricultural Mechanization (NCAM), Ilorin, farm yield has been increased by up to 60% through the use of micro-irrigation sprinkler system. Land area equipped for irrigation (hectares) in Nigeria was reported at 293000 ha in 2011, according to the World Bank collection of development indicators and based on estimates it should double in the next 6 years. Irrigation need in Nigeria increases from southern to northern Nigeria.

Hence, improvement of on-farm application efficiency of irrigation system is important not only to increase the overall irrigation efficiency on the farm but also to improve the crop water productivity. Experience has shown that if micro-irrigation sprinkler systems are not properly designed, operated, nor maintained they may not give the expected benefits and even in some situations it may adversely affect the crop growth. It is therefore essential to carry out periodic diagnostic analyses and performance evaluations of the micro-irrigated sprinkler systems for Okro farming to ensure that they are operating optimally which stands as the objective of this study.

Okro (Abelmoschus esculentus) is a very important vegetable in Nigeria used to prepare different types of soups. Virtually, every tribe in Nigeria makes use of okra to prepare at least one of their traditional meals or delicacies. Thus, it is a widely acceptable vegetable across Nigeria. The young leaves are sometimes used as a vegetable, in a similar manner to spinach, particularly in West Africa and Southeast Asia. Medicinal uses of Okro leaves and immature fruit have long been used in the East in poultices and applied to relieve pain, moisturize skin, induce sweating, prevent scurvy and treat urinary disorders
In 2011, Nigeria has a production statistics of 1,060.620 tonnes and became the second largest producer of okra all over the world after India (http://www.kew.org/plants-fungi/species-browser/Abelmoschus-esculentus.htm)

Nevertheless, the distribution uniformity of the micro-irrigation sprinkler system is acknowledged as one of the essential criteria for evaluating the micro-irrigation sprinkler system performance. The distribution uniformity and the uniformity of emitter discharges of water collected in catch cans in micro-irrigation sprinkler systems are the overall measurements which are taken into consideration through performance evaluation (Wu and Barragan, 2000).

The objective of the study was to evaluate the daily application efficiency of micro-irrigation sprinkler system system for okro farming in National Centre for Agricultural Mechanization (NCAM) Kwara State.

The disadvantages of micro-sprinklers are related to water losses due to effect of wind and evaporation. Hence, micro-sprinkler distribution uniformity has also been of concern since micro-sprinklers tend to have poor application uniformity over their wetted area.

Literature has shown that different types of micro-sprinklers have shown a uniform soil water distribution in the root zone (Klassen, 1986). Thus, the low application uniformity does not necessarily affect the spatial distribution of tree roots and the corresponding root water uptake (Boman, 1991). From the few data available to date, it is clear that more research is needed to better understand irrigation response of tree crops (Fereres and Goldhamer, 1990), especially in partially wetted soils as occur under drip and micro-sprinkler irrigation. Nimkale et al., (2011) evaluated micro-sprinkler characteristics under various conditions and found out that uniformity coefficient and distribution uniformity increases with increase in operating pressure. Zamaniyan et al. (2014) in their study on field performance evaluation of micro-irrigation systems in Iran found out that the performance of micro-irrigation systems in Iran is low and poor.

Materials and Methods

Study Area

This research was carried out at the National Centre for Agricultural Mechanization (NCAM) premises, Idofian, about 20 km to Ilorin metropolis, Kwara State, Nigeria. The study area is about 370m above sea level and lies on Longitudes 4^{o}30' East and Latitude 8^{o}26'N (Awu et al., 2016). NCAM climate is influenced by the Inter-tropical Covergence Zone (TCZ), which results in wet and dry seasons. The rainfall usually starts from April and lasts till late October, with the peak rainfall occurring both in June and September and the dry season lasts between November and March. The mean annual rainfall of the area is about 1700mm, while the mean monthly maximum and minimum temperatures in the basin are 31^{0}C and 29^{0}C, respectively, with the highest temperatures recorded in the months of February, March and April. The potential evapotranspiration of the area is between 1500 – 1700mm per annum (Awu et al., 2016).

Evaluation Parameters

Within the period of this study, the experimental plot was irrigated twice daily (morning and evening). During each period of these water applications, the distribution of the water application by micro-irrigation sprinkler was measured by catch cans placed on around each sprinkler on a grid network as shown in Figure 1.

Fig 1: Micro-irrigation sprinkler system showing water cans in grids.

The catch cans were 96 mm in diameter and 65 mm high. Using the catch can readings, the micro-sprinkler application rate was measured for one hour periods during each of the two irrigations. The catch cans were emptied near the measurement location which they represented. Coefficient of variation (CV), Christiansen Uniformity (CU) coefficient and Distribution Uniformity (DU) are the major parameters for evaluation of micro-sprinkler irrigation system as employed in this study. The Applied water as measured with catch cans was compared with the meter readings in the irrigation lateral of the experimental plot. The amount of water applied was based on California Irrigation Management Information System (CIMIS) guideline. This study was carried out on December 2015, no rain was recorded during the measurement period and the application rates were based on the estimated evapotranspiration (ET_{c},) of Okro vegetable, which was calculated using the relation as shown in equation 1:

$$ET_c = K_c . K_r . ET_o \qquad (1)$$

Where: K_c = *crop coefficient* K_r = *reduction coefficient taking into account the percentage of soil surface covered by crop canopy as compared with total surface area;* ET_o = potential evapotranspiration as estimated using atmospheric data from the nearest meteorological CIMIS station (NCAM Meteorological Centre).

Goldhamer and Snyder (1989) in his study recommended values of K_c and K_r as 0.9 and 1.0 and water application efficiency as assumed to be 90% respectively. In addition, the soil moisture content measurements were taken before and after every water application. Daily readings were taken every morning by 0600hrs and evening by 1800hrs.

Pressure Discharge Relationship: pressure discharge relationship for micro-sprinkler as proposed by Keller and Karmeli (1974) was used as shown in equation 2:

$$Q = KP^x \quad (2)$$

Where :Q = discharge relationship for micro-sprinkler, lph; P = operating pressure, Kg/cm^2;K = characteristics constant; X = discharge exponent

Precipitation pattern: the catch can was placed at grid of 0.5 x 0.5 m, 2.25x2.25, 3.0x3.0 m formed around the micro-sprinklers to determine the precipitation pattern. The precipitation pattern was studied by drawing contours of equal precipitation depth and distribution profile.

Effective radius (Re): the effective radius is the distance between centre of micro-sprinkler and the point at which the profile cut the horizontal axis on precipitation pattern (T).

Average Application Depth (mm/h): to calculate the average precipitation depth, a concentric rings approach of Marriam and Keller (1978) was used as shown in figure 3:

$$Average\ precipitation\ depth = \frac{d_1+d_2+d_3+d_4}{4} \quad (3)$$

Where: d_1, d_2, d_3 *and* d_4 *= average depth in 1st, 2nd, 3rd and 4th concentric rings, respectively around the micro-sprinklers.*

Effective Maximum Depth (mm/h): effective maximum depth is calculated as the average value in 5% of total catch cans having maximum collection and is expressed in mm/h

Absolute maximum depth (mm/h): absolute maximum depth is the maximum of all reading from the observed data.

Mean Application Depth (mm/h): mean application depth is calculated as the average depth between the areas constrained by effective radius.

Distribution Characteristics (DC): the term characterizes the water distribution of single sprinkler device. It was calculated by using the following relationship as shown in equation 4 below:

$$Distribution\ Characteristic = \frac{Area\ receiving\ the\ depth\ greter\ than\ average\ depth}{total\ wetted\ area} X100 \quad (4)$$

The Coefficient of uniformity (CU): the coefficient of uniformity values was determined by the Christiansen's formula as shown in equation 5:

$$CU = 100\left(1.0 - \frac{\sum X}{mm}\right) \quad (5)$$

Where: X = absolute deviation of the individual observations from the mean;N = number of observations;m = mean depth of water application.

Coefficient of Variation (CV): Coefficient of variation due to emitter performance in irrigation unit is evaluated according to ASAE (2003) and Capra and Scicolone (1998), following the classification criterion as shown in Table 1 below.

Table 1. System classifications according to variation coefficient of emitter performance (V_{pf}) values

V_{pf} (%)	Classification	
	ASAE (2003)	**Capra and Scicolone (1998)**
> 29	unacceptable	low
20–29	unacceptable	mean
15–20	poor	
11–15	acceptable	high
10–11	acceptable	
5–10	good	
< 5	excellent	

The coefficient of variation was calculated using equation 6 and 7 as given by Keller and Merriam.

$$CV = \frac{\sigma}{da} \quad (6)$$

Where: da = mean application depth;

$$\sigma = \sqrt{\frac{\sum X^2}{N}} \quad (7)$$

Where:
$\sum X^2$ = deviation from mean depth (mm)
N = number of observations

Emission Uniformity (EU): this term has generally been used to describe the emitter flow variation for a micro-sprinkler irrigation system. Equation 8 below was used for the determination of the emission uniformity as suggested by Keller and Karmeli (1974).

$$EU = 100\ X\ \frac{q_n}{q_a} \quad (8)$$

Where:
EU = emission uniformity (%); q_n = average of the lowest ¼ of the emission point discharges for field data (lph); q_a = average emission point charges of test sample operated at the reference pressure head (lph).

Table 2. System classifications according to emission uniformity (EU) values

EU (%)	Classification	
	Merriam and Keller (1978)	Capra and Scicolone (1998)
< 66	poor	Low
66–70	poor	
70–80	acceptable	Mean
80–84	good	
84–90	good	high
> 90	excellent	

Distribution Uniformity (DU): Distribution uniformity indicates the degree to which the water is applied uniformly over the area and this was determining using equation 10 below:

$$Du = \frac{Average\ low\ quater\ depth\ of\ water\ caught}{Average\ depth\ of\ water\ caught}\ x\ 100 \quad (10)$$

Where: DU = distribution uniformity of micro-sprinkler (%)

Results and Discussion

The pressure-discharge relationship of the micro-irrigation system as collected from the experimental plot was plotted as shown in figure 2. Maximum discharge of 80 lph were recorded under 2.0 kg/cm^2 operating pressure while a minimum of 35 lph were recorded under 0.75 kg/cm^2.

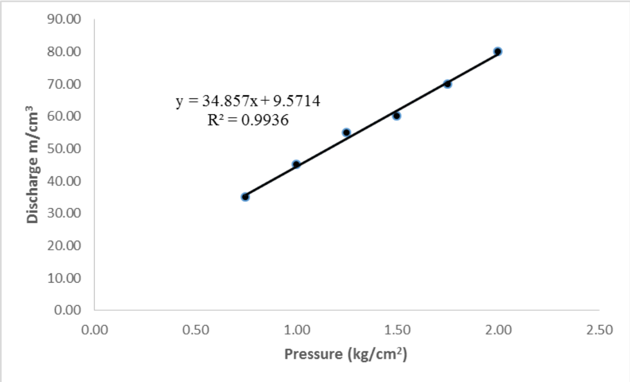

Fig 2: Pressure-Discharge relationship for micro-irrigation sprinkler system

The precipitation pattern were studied in terms of the effective radius, average application depth, effective maximum depth, absolute maximum depth, mean depth distribution coefficient, coefficient of variation and emission uniformity as estimated by Keller method for 1.0, 1.5. 2.0, and 2.5 kg/cm^2 operating pressure, the precipitation characteristics results is shown in table 3.

The results shows that the effective radius ranges from 1.0 to 1.75m under operating pressure of 1.0 to 2.50kg/cm^2 considering 50percent overlapping and low wind speed condition. The average application depth and effective maximum depth of 8.47 to 11.43mm/h and 15.49 to 14.86 respectively were recorded. The results also showed that the average application depth increase with increase of the operating pressure were as the effective maximum depth decreases with increase in operating pressure. Absolute maximum depth and mean application ranges from 21.81 to 20.70 and 11.28 to 6.58 respectively under operating pressure of 1.0 to 2.50kg/cm$^{2.}$ Comparatively the absolute maximum depth and mean application depth decrease with increase in operating pressure for the micro-irrigation sprinkler. However, the distribution characteristics and coefficient of variation (CV) for the micro-irrigation sprinkler system varies from 23.00 to 41.02 and 0.72 to 0.83. Comparatively, both the distribution characteristics and coefficient of variation increases with increase in operating pressure for the micro-irrigation sprinkler. However, the distribution characteristics have it lowest value of 17.65 at 1.5kg/cm^2 operating pressure. Hence according to Capra and Scicolone (1998) standard, the micro-irrigation sprinkler has low coefficient of variation performance since is less than 20%.

Table 3: Precipitation Characteristic for micro-irrigation sprinkler system

	Precipitation characteristics							
Operating pressure(kg/cm^2)		Effective radius (m)	Average application depth (mm/h)	Effective maximum depth (mm/h)	Absolute maximum depth (mm/h)	Mean application depth (mm/h)	Distribution characteristics (%)	Coefficient of variation
	1.00	1.00	8.47	15.49	21.81	11.28	23.00	0.72
	1.50	1.25	9.85	14.10	19.50	9.12	17.65	0.79
	2.00	1.50	10.12	14.00	17.20	8.09	18.10	0.85
	2.50	1.75	11.43	14.86	20.70	6.58	41.02	0.80

The relationship between the operating pressure and the uniformity coefficient (UC) for different micro-sprinkler spacing shows 80.01percent in 1.5 x 1.5m spacing. This indicate that 1.5 x 1.5m micro-irrigation spacing is more suitable as compared to other with higher spacing as shown in figure 4 below.

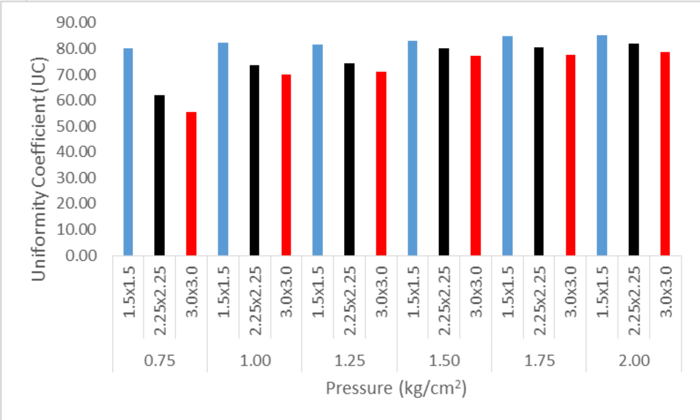

Fig 4: Uniformity coefficient for micro-irrigation sprinkler system.

The emission uniformity for different micro-irrigation system and operating pressure shows that the emission uniformity decreases with the increase in the grid network of the micro-irrigation sprinkler system from 95.13 to 93.73. However it increases as the operating pressure increase from 0.75 to 2.0kg/cm^2. Likewise, according to Keller and Karmeli (1974) emission uniformity standard (Table 2) 1.5x1.5m grid network micro-irrigation sprinkler have the best emission uniformity of 95.13 at 0.75kg/cm^2 operating pressure

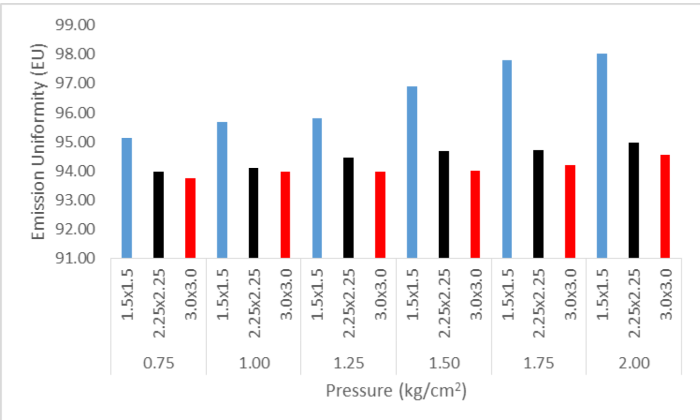

Fig 5: Emission uniformity for micro-irrigation sprinkler system

Likewise, the distribution uniformity (DU) for the micro-sprinkler irrigation system as determined by Mirriam and Keller (1978) equation for operating pressure and spacing shows that the distribution uniformity decreases with the increase in the grid network of the micro-sprinkler system from 71.87 to 54.37. Though, it increases as the operating pressure increase from 0.75 to 2.0. this confirm that for given operating pressure there is a substantial reduction in distribution uniformity for micro-sprinkler irrigation system when operated at higher pressure with the grid network for the sprinkler is closely spaced (table 2)

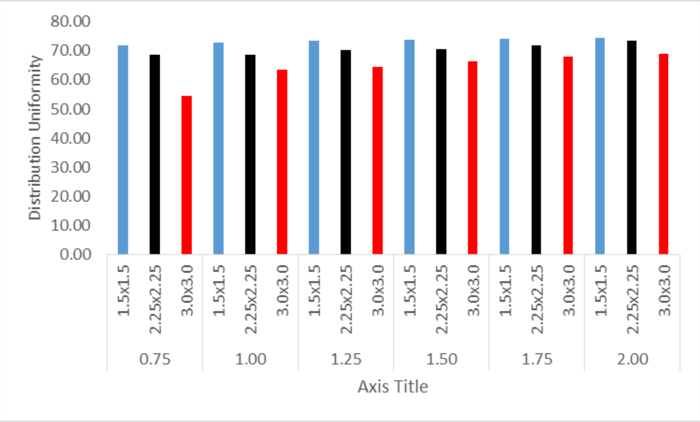

Fig 6: Distribution Uniformity for micro-irrigation sprinkler system

Conclusion and Recommendation

To ensure daily effective water applicability, it is essential to know the uniformity of operating micro-irrigation sprinkler in order to enhance system's performance. This study was carried out at national centre for agricultural Mechanization-Ilorin. Data were collected and calculated for coefficient of variation, emission uniformity and distribution uniformity as estimated by Mirriam and Keller (1978). The results shows the micro-irrigation system should be operated at 1.5 to 2.0kg/cm^2 under low wind speed condition. This result confirms the study of Nimkale et.al (2011). Data regarding operating effective radius, average application depth, absolute maximum depth, mean depth, distribution characteristics were also used for the estimation of precipitation pattern. Determining the effect of irrigation system application efficiency on other type of crop and other type of irrigation method other than the ones used in this study were recommended among others.

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