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Development and Evaluation of a Pilot Scale Gravity-Centre Pivot Sprinkler Irrigation System under Okra (*Abelmoschusesculentus*) Cultivation

[1]Ahire, Orduen, [2]M.O.Udochukwu, [3]*S.O.Enokela, [4]R.T.Iwar

[1]Department of Agricultural and Bio- Environmental Engineering Technology, Akpran Orshi Polythecchnic, Yandev Gboko, Nigeria

[2,3,4]Department of Agricultural and Environmental Engineering, Joseph Sarwuan Tarka University, Makurdi Benue State, Nigeria

*Corresponding Author's E-mail: enokladish@gmail.com

***Abstract* - A pilot scale gravity-centre pivot sprinkler irrigation system (GCPSIS) was designed, constructed and evaluated at two operating speeds on an Okra field at the experimental field of the Department of Agricultural and Environmental Engineering of Joseph Sarwuan Tarka University Makurdi, Analysis of variance (ANOVA)at P(0.05)from the data sets showed mean Soil Wetting Depth (SWD) ranging between 7.75±0.35 to 13.75±035cm/hr and 5.90±0.14 to 3.15±0.49cm/hr at speeds 5 and 7 rpm respectively and were not significantly different both in speeds, orientation and distances from the pivot station. The mean Soil Moisture Content (SMC) was 15.95 ±6.30 and 11.78 ±1.81% at 21-40cm depth at 5rpm and 7rpm respectively. The average Soil Bulk Density (SBD) at 0-20, and 21-40cm soil depth was1.23+0.5g/cm^3 and 1.23±0.13g/cm^3 respectively at 5rpm indicating a higher variability. At 7rpm mean values were 1,31±0.06 and 1.28+0.06g/cm^3 at 0-20, and 21-40cm soil depth respectively indicating similar variability at both depths. Both speed and depth were not significant with respect to the SBD but speed was significant for SMC. Application Efficiency (Ea), Coefficient of Uniformity (CU), Distribution Uniformity (DU) along the pivot lateral complied with acceptable standards and were 77.67, 45.35 and 85.80 % respectively at 5rpm and 86.83, 44.89 and 94.03% at 7rpm respectively. The and Nozzles Discharge (ND) was highest (9.12 L/min) at the nozzle closest to the pivot station, high (9.00 L/min) at the middle nozzle and low (8.94 L/min) at the nozzle at the end of the lateral line in the first week and decreased slightly up to week five due to clogging.**

Keywords: Design and Construction, Evaluation, Pilot-Scale, GCPIS, Okra field.

I. INTRODUCTION

Climate change resulting in droughts has caused water resources to become scarce. Thus, water resources have to be utilized properly to protect and conserve the available water reserves. In irrigated agriculture this will have to be obtained through the effective management of water application and avoiding over irrigation.

Therefore, irrigation systems have to apply water in the most efficient way possible to prevent unnecessary losses and water wastages. In the field of agricultural crop production by irrigation, the fields irrigated by properly designed irrigation system and operated under optimal condition give high crop yields [1] (Reuben *et al.*, 2010). The design of the system should consider factors that influence the performance, such as the condition of sprinkler packages, strength and direction of the wind and the pressure variation within the system [2]. These factors need to be correctly managed to ensure that the distribution uniformity and efficiencies are in acceptable level. Among the tested irrigation systems, gravity center pivot sprinkler irrigation (GCPSIS) has been found to be the most suitable form of irrigation especially in a constantly changing climate because of its high reliability, low operation and maintenance cost, use of a central delivery point and its economic nature [3].

II. LITERATURE SURVEY

In Nigeria, surface irrigation is a dominant method of irrigated agriculture and can be classified into public irrigation projects which are government owned and managed schemes; farmer- owned irrigation projects which receive support from government in the form of subsidies; and the traditional flood plain irrigation system where no assistance is rendered to irrigators [4]. A wide variety of crops have been successfully brought under irrigation agriculture particularly under the small holder systems including vegetables, rice, wheat and maize [4]. At present, only about 10 % of arable land in Nigeria is under irrigation, in spite of the numerous crops including rice, sugar cane, vegetable, wheat, maize, sorghum, cotton which have been successfully grown under this farming system [5].

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Irrigation is all about water in motion: moving water with the correct flow and pressure that are necessary to allow water to be correctly and uniformly distribute over a planted area. In surface irrigation water is applied on the ground at ground level and the water flows by gravity over the surface of the field [6].Under current irrigation conditions irrigated areas include those equipped with full or partial water control, spate irrigation, equipped wetlands and inland valley bottoms irrespective of their types and management types [5].

2.1 Sprinkler Irrigation System

In sprinkler irrigation system, water is sprayed in to the air and allowed to fall on ground surface in a similar manner to that of actual rainfall. The sprinkler system simulates rainfall whereas other systems apply water directly on or below the surface of the soil [7]. The spray is developed by the flow of water under pressure through sprinkler nozzles. Sprinkler irrigation systems are broadly categorized into set and continuous-move systems [8]. In set systems, the sprinklers are stationary while irrigating, whereas the sprinklers move in a straight or circular path, while irrigating in the case of continuous- move systems. The set-move or solid set system is divided into portable and periodic move systems. The portable systems are either hand-moved, tractor-moved (side-row, end-tow, side-move, gun and boom). In these systems, the sprinkler laterals are moved manually or mechanically between irrigation sets [9]. The periodic move also called the self-propelled or wheel lines is suitable for low to medium height crops [10]. For the irrigation of low growing crops, the sprinklers may be attached directly to the pipe lines or attached to a riser for vegetables and taller crops such as citrus and grains. The fixed or permanent set systems consist of sprinklers attached to buried laterals that are installed to cover the entire field. Usually a line/lateral or block of laterals is irrigated at once and the next irrigation set is adjacent lateral or block of laterals [9]. In both solid and permanent set systems movement within set irrigation events is enhanced by valves which are strategically installed in the pipe network. Continuous-move system types include: travelers, centre-pivot, and linear move systems.

2.2 Center pivot sprinkler irrigation systems (CPSIS)

A CPSIS consists of a lateral circulating around a fixed pivot point [11]. The lateral is supported above the field by a series of A-frame towers, such that each tower has two driven wheels at the base. Irrigation water is discharged under pressure from the sprinklers or sprayers mounted on the laterals as it sweeps across the field or suspended by a flexible hose over the crops. The lateral line is rotated slowly around a pivot at the center of the field by electric motors at each tower. Center pivots are machines that continuously revolve around a pivot point, and the revolution time is controlled by the speed of the outermost support tower. A unique design characteristic of these systems is that the water application rate must increase along the lateral to apply a uniform depth of water, since the area irrigated per unit length of lateral increases along the lateral. This rate can be increased by using:

i) A constant sprinkler spacing with a progressively increasing nozzle orifice diameter, or
ii) A constant nozzle diameter with progressively decreasing sprinkler spacing.

A large sprinkler, mounted at the end of the last lateral, called an end gun, is frequently used to increase the irrigated acreage. The evaluations entailed measuring pressures, system and individual nozzle flow rates, travel speed, and depth and uniformity of applied water. However, transects of catch cans extending radically from the pivot points provided data on depth and uniformity. Both standard statistical methods (mean, standard deviation, and coefficient of uniformity and time space series statistics may be used to analyze the can data. The former give a measure of uniformity that can be related to a standard; time space series statistics describe patterns of non-uniformity in the applied water.

CPSIS are often the preferred type of sprinkler irrigation system by producers due to their relatively high water application uniformity and degree of automation which can substantially reduce operational labor costs compared to other types of sprinkler irrigation systems.

CPSIS is classified as a medium to low pressure sprinkler system capable of irrigating large circular areas. It consists of a single galvanized steel lateral which rotates about a fixed point in the centre of the irrigated field. It is equipped with impact or spray sprinklers mounted on top or below the lateral through tubes usually dropped near the crop canopy [12].

The performance of centre pivot sprinkler irrigation system can be quantified by the distribution uniformity and uniformity coefficient [13. application efficiency, and potential application efficiency. It is reported that soil parameters also influence crop yields under centre pivot irrigation systems. These soil parameters include bulk density in relation to roots penetration [14[, low fertility, salinity and sodicity [15], low pH, occurrence of soil toxicity, cation and anion exchange capacity [16] and low water infiltrability [17]. Similarly, the qualities of irrigation water may also influence crop yields under a centre pivot sprinkler irrigation system just like any other irrigation method [18] . But for the current study, only the efficiencies and uniformities as mentioned earlier will be considered during the evaluation of centre pivot irrigation system as the soil and water quality factors are beyond the scope of the current study.

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Several studies have shown that center pivots are the preferred type of sprinkler irrigation systems due to several advantages associated with its application. [19] listed superior performance characteristics of the center pivot systems, emphasizing their relative higher water application uniformity and degree of automation which reduces labor cost substantially when compared with other types of sprinkler irrigation systems. Center pivot irrigation system has also been characterized by higher water application efficiency and ability to apply water and nutrients over a wide range of soils.

2.3 Performance of CPSIS

The performance of CPSIS is often evaluated in terms of the timelines of irrigation and uniformity coefficients from water collected from array of measuring devices popularly referred to as “catch cans” [20]. Water application uniformity is gaining popularity as energy and water cost increases and the need for water conservation increases. An important step for evaluating water distribution parameter is the accurate measurement of the water applied from sprinklers using catch cans or collectors [21] [11];.

According to [21], traditionally, CPSIS are evaluated by placing a transect of catch cans uniformly spaced and radially outward from the pivot point along the lateral. As the machine travels along and across the transect, the water is caught in the cans and then the system performance is evaluated from the measured water caught in the cans. Non- uniformity in the center pivot is perceived to occur more along the lateral than in the direction of travel [22] [23] .

The uniformity of water applications could be influenced by several factors among which are; improper sprinkler nozzling and spacing, wear off of sprinklers and pipes, variation in pressure distribution along the lateral and wind speed and direction during irrigation. The evaluation also entails measuring pressures and nozzles flow rates and travel speed of the endower. The most commonly used measure of water application uniformity in the irrigation systems is the Christiansen's coefficient of uniformity expressed as a percentage. It is based on the absolute deviation of individual amount from the main amount. An equally important parameter which is widely used is the distribution uniformity (DU). It is defined as the ratio of mean depth caught on the quarter of the field, receiving the least amount divided by the mean depth caught on the entire field and multiplied by 100 to express this as a percentage. The magnitude of coefficient of uniformity (CU) is usually higher than that of DU, however this is not always so as this depends on different data sets [24] . DU is usually defined as the ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution [21] [25]; Ascough and Kiker, 2002).

2.4 CPSIS efficiency

Generally, there are three variants or categories of definitions of irrigation efficiency: irrigation efficiency, application efficiency, and distribution efficiency [26]. Irrigation efficiency essentially refers to the fraction of water applied to the field which is really utilized beneficially by the crops. [21]. The measurement of beneficial use is however only attainable on long basis rather than on a single event term. Beneficial uses of irrigation include replacement of evapo-transpiration (ET), crop cooling, frost protection, crop germination and metabolism, leaching requirement and pest control. Meeting crop ET requires the highest volumetric use over an irrigated season [26] [27] defined application efficiency as the volume of water applied to the surface divided by the volume of water exiting in the sprinkler emitter. It is an indicator of water that is lost during the process of supplying water to the field due to evaporation and wind drift losses. Water application efficiency of portable sprinkler irrigation systems in Nigeria has been reported at the rate of 87% by [28], which may be relatively adequate for most crops. According to [29], application efficiency refers to the fraction of applied water used by crops.

III. PROBLEM DEFINITION

Water scarcity is becoming a global phenomenon due to drastic increase in population and climate change impacts on water resources. There is therefore need to efficiently utilize available water resources for effective productivity including water use for irrigation. Centre pivot sprinkler irrigation systems (CPSIS) have been recently described as the most effective and economic irrigation system in the United States and Europe [30]. However, its design seems to be a little trickier as it entails high technical requirements in terms of materials and labour. This has made the adoption of the technology almost impossible in developing countries including Nigeria. It is therefore pertinent to design, construct, install and evaluate pilot scale CPSIS units using locally available materials and technical manpower with a view to perfecting the systems for full utilization and commercialization. This if successful will go a long way in cutting down on the high initial cost requirements for importation and installation of the systems in the country. The aim of the current research is to design, construct and carry-out performance evaluation of a pilot scale (one tower) CPSIS under okra cultivation on a sandy loam soil in Makurdi Metropolis-Nigeria.

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IV. METHODOLOGY/APPROACH

4.1 The Study Area

The project was carried out in the Department of Agricultural and Environmental Engineering Research Farm, Joseph Sarwuan Tarka University Makurdi (JOSTUM), Benue State. Makurdi, the Benue state capital, has an estimated population of 500,798 and lies between latitudes 7° 45'S and 7° 52'N of the equator and between the longitudes 8° 35'W and 8° 41'E of the Greenwich meridian [31]. The state is predominately an agricultural area operating on subsistence small scaled raining seasoned agriculture. Cash crops produced are for direct consumption and just a little for sell. The Climate is humid with little seasonal temperature variations of 21-37°C throughout the year. Two major seasons do exist; the rainy season between April and October and the dry season between November and March. The relative humidity is between 65 – 69% and the rainfall varies between 1000 mm to 2500 mm [32].

According to [33], the soil type and mineral composition of the project site are greatly influenced by relief, decomposition of parent materials, climate and activities of resident soil organisms. There is existence of a sand- loamy soil, showing high rate of water infiltration in the study area.

4.2 System design

The GCPSIS was designed by considering Okra water requirements and characteristics, Soil characteristics, A pilot-scale one tower of 7.5 m long for an irrigated area of 176.79 m^2, Water supply by gravity thus requiring no pumping, Utilizes medium–low energy, pressure and cost, Ideal discharge (or application rates) and elude runoff during operation, Constant sprinkler spacing with same nozzle diameter and to be operated without an end gun and make complete revolution in a period less than the required irrigation interval for okra. They system was designed for a hydraulic system that will be operated by a selected motor; the Pressure distribution in lateral and Main were based on selected sprinklers; Lateral were uniformly spaced for the estimated discharge

4.3 Summary of Design Parameters

The important parameters for the evaluated during the design process are as presented in Table 1.

Table 1: System Design Specifications

S/N	Parameter	Model equation	Unit Value
1	Number of Towers		1
2	Length of Tower (m)		7.5 3
3	Number of Laterals per Tower		3
4	Lateral Spacing (m)		
5	Lateral diameter (mm)		27
6	Length of Lateral (mm)		600
7	Size of Main Line (mm)		50
8	Height of Pivot (m)		2
9	Pressure Head (m)		3
10	ETo (mm/day)	ETo = P(0.46Tmean + 8) [34]	6
11	ETc (Okra) (mm/day)		3
12	Soil infiltration rate (cm^3/minutes)	IR = k (1 + SM/f) [35]	142.85
13	Net Irrigation Requirement (mm)	NIR = RAW = $\frac{(MAD)\times(Drz)\times(FC-PWP)\times(P)}{100}$	15.6
14	Gross Irrigation Requirement (mm)	GIR = RAW/FE	18.3
15	Effective Wetted Area m^2		176.79
16	Area to be Irrigated m^2		176.79
17	Irrigation Interval (Days)		5.18
	Required Irrigation Water per irrigation period(L)	Ic = Aeff × GIR	3,270
18	Total discharge or Required Irrigation Water (L)	Ic = Aeff × GIR x 5	16350.19
19	Irrigation Capacity L/Sec	Q = $Vd \times T\ (na)/\ t$	0.772
20	Capacity of Electric motor (Hp)		0.5
21	Power Requirement (Hp)		
22	Revolution period (hr)		1
23	Speeds Rpm		5 and 7

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Where;

ETo is the average daily reference evapotranspiration for Makurdi (mm/day).
Tmean is the daily percentage of annual day time hours for Makurdi which is on Latitude 70N.
IR is the infiltration rate (m^3 /sec).
SM is soil characteristics associated with moisture content and soil moisture tension.
K is hydraulic conductivity of the wetted zone (m/s).
F is the cumulative infiltration in (m).
MAD is maximum allowable depletion (cm).
AW is the available water (cm)
Therefore,
Drz is effective rooting depth of crop (okra) = 0.78 m [34] (Wuese, 2018).
FC is field capacity (%) = 11.7% [34].
PWP is permanent wilting point (%) = 3.7% [36].
FE is field efficiency (%) = 85% for center pivot system [37].
ET is the consumptive use of Okra = 3 mm.
Ic is the irrigation capacity or water requirement in Litres.
Aeff is the effective wetted area of a centre pivot which is taken as 100 % for the current design considering the circular path.
Q is the discharge or capacity of the centre pivot system (L/day).
T is the irrigation interval = 5 days.
Vd is water requirement per day = 3270/5 = 654 L.
na is water application efficiency = 0.85.
T is duration of each irrigation day = 1 hours.

The GCPSIS was assemblage consisted of a) 5 m high overhead stand constructed using 9” cement blocks and iron Y12 rods for reinforcement. A plastic storage tank of 3000 L capacity placed on the stand for water supply. The stand was located 20 m from the Pivot station. (b) Main Line was 2” pressure pipes (plastic) laid below tillage level from the stand to the pivot station. (c) Water Shut off Valve located by the side of the overhead stand. (d) The Pivot Station was a three-legged frame made from 2” galvanized pipe, 2m high and connected to a rotating elbow shaped fitting and mounted on concrete slab and located on the centre to form a solid anchor for the system (Figure 1). (e) Lateral made of 2” galvanize pipe, 7.5 m long and supported by 1½ angle bars and a tension string to resist effect of wind and provide for tension. (f) Three (3) rotary head sprinklers attached to plastic pipe and mounted on the lateral line at a spacing of 1.8 m apart. Each had 4 nozzles. The distance between the sprinklers and the ground was 1.4 m. (g) A control panel located under the overhead stand and equipped with a timer that controls the percentage of time per minute that the motor was operating. (h) The drive system mounted on an inverted T shaped frame made of galvanized 2”pipe and consisted of two rubber tyres (Wheel barrow type) driven by an electric motor (capacity), a gear transmission device and a drive axle (shaft) mounted between the tyres. The gear transmission device and axle provided the power transfer from the electric motor to the tyres. The speed of the system was controlled by controlling the motor.

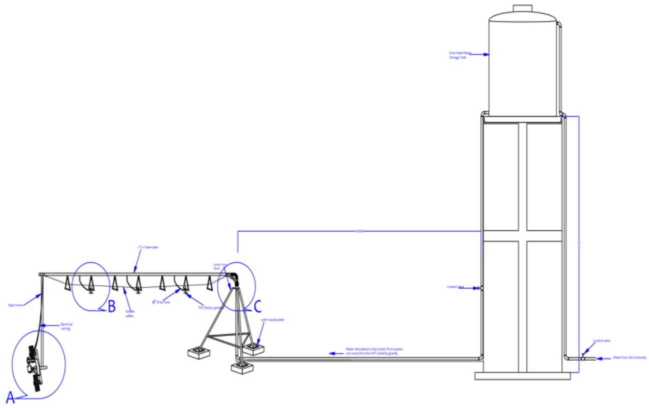

Figure 1: Schematic diagram of the centre pivot system

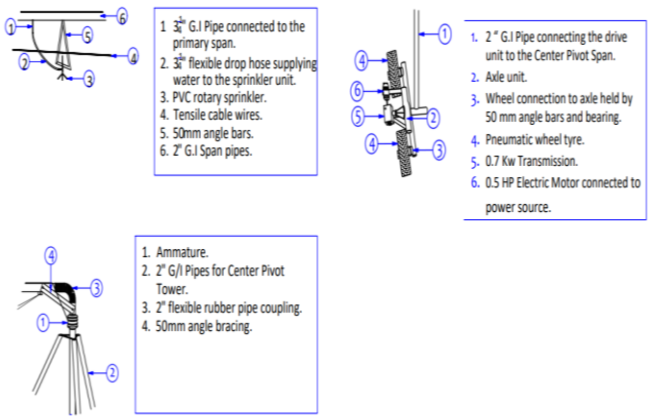

Figure 2: Exploded diagram of the Centre Pivot System

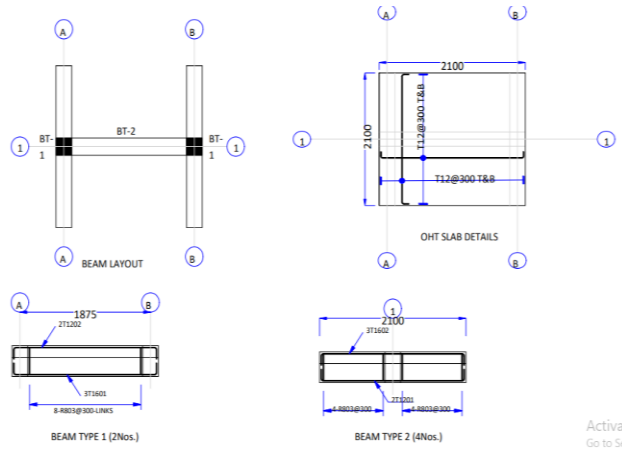

Figure 3: Details structural design of Beam and Slab

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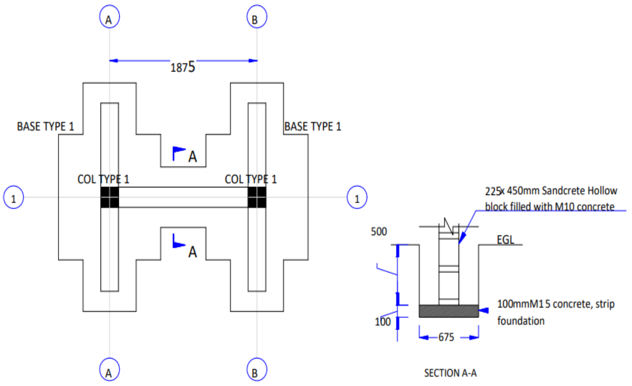

Figure 4: Detail structural design of foundation

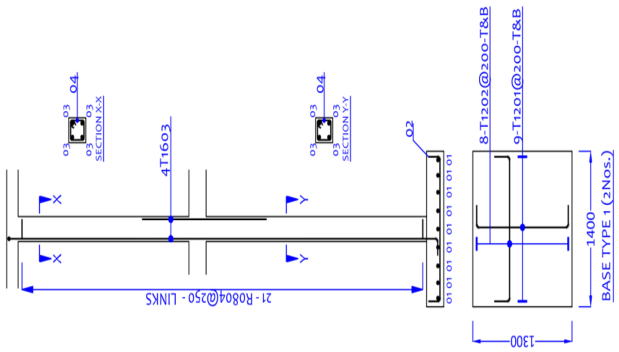

Figure 5: Detail structural design

4.4 System Performance Evaluation

The system was evaluated in terms of the timelines of irrigation and uniformly coefficients using spray cans as described by [20] Magagula (2013). Six (6) cans were placed on the ground at equal distance in four different directions along the pivot point outwards (Plate 1). The centre pivot was allowed to Passover the cans at two different speeds (5 rpm and 7 rpm) and measurements were recorded. A 250 ml graduated cylinder was used for measuring the volumes of water collected in the catch cans. The amount of water collected in the cans in (mL) was converted into depths of water in (cm). The performance indices calculated from the experiment were;

Application efficiency (%) Ea = $[Dc/Ds]$ x 100
Uniformity coefficient (CU) % Cu = 100(1 - $\sum x/mn$)
Pattern efficiency/distribution uniformity % Dp = $[Lm/Da]$ x 100 %

Nozzle discharge Q = A stop watch, measuring cylinder, rubber hoses and calibrated containers were used. Volumetric measurements of water discharge were made by connecting the hoses over the nozzles to direct water flows into the container and the stop watch was used to record the time taken (seconds).

Where;

Ea = Application Efficiency
Dc = Average depth of water caught in catch can (cm)
Ds = Designed depth of system
Cu = Coefficient of Uniformity (%)
x = Deviation of Individual observation(s) from mean
n = Number of observations
m = Mean value of observations
Dp = Pattern Efficiency (Distribution Uniformity)
Lm = Law quarter caught in catch cans (cm)
Da = Average depth of water caught in all cans (cm)
The collected water from each sprinkler was then carefully transferred into the measuring cylinder and the corresponding volume (mL) recorded. The sprinkler discharge was estimated as the ratio of the measured volume to the time taken.

Wetting depth (Cm); this is the depth to which water contents have increased due to the introduction of water from external sources, or due to capillarity rise after elimination of evapotranspiration. It was measured by slicing the soil surface with a shovel to a depth of 40 cm one hour after irrigation at equal distance from the pivot station and the wetted part of the sliced soil measured with a meter rule. The measurements were carried out in four different directions at the rated speeds of 5 rpm and 7 rpm. Natural moisture content test; Moist samples were collected from the representative sampling area one hour after irrigation and placed in plastic bags in order to avoid any initial loss of moisture. Empty aluminum cans which with proper identifications (labels) were weighed and recorded. Representative samples of wet soil were placed in the cans and weighed, after which they were placed in the oven at 1100C for 24 hours. The moisture content of each of the samples was computed as

Percentage moisture content = $[w2-w3 /w3-w1] \times 100$

Where;

w1 = Weight of can
w2 = Weight of wet soil + can
w3= Weight of dry soil + can

Bulk density test; A 100 ml graduated cylinder of known weight was filled with oven dry soil sample. Secondly, the first addition of soil was compacted by tapping the bottom of the cylinder with some support [38]. The soil was added until a volume of 50 ml was obtained. The cylinder and its content (soil sample) were weighed and recorded [39]. This was repeated and average result recorded to determine the bulk density as

Bulk density (BD) = M (1+w)

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Where:

BD = bulk density
M = mass of oven dry soil
w = moisture content
Vs = volume of soil (Brobst, 2015)

V. RESULTS & DISCUSSION

5.1 Soil moisture content and bulk density

The mean values for the effect of operating speed and depth on soil moisture content and bulk density recorded after 1 hr of irrigation and in comparison with the results from the non-irrigated soil at site is presented in Table 2. From the results, the non-irrigated soil has moisture content of 0.36 and t 4.12 at 0-20 and 21-40 cm profile depth respectively. For the irrigated soil at 5rpm of the irrigation system the mc were 15.66 and 15.94 at0-20 and 21-40 cm profile depth respectively while that of 7rpm were 6.82 and 11.86 at0-20 and 21-40 cm profile depth respectively. The bulk density was 1.4 and 1.35 at 0-20 and 21-40 cm respectively for non irrigated soil. It was however constant (1.23) at irrigation speed on 5rpm but increases to 1.28 and 1.31 for 7rpm at 0-20 and 21-40 cm respectively.

Table 2: Mean values of Moisture Content, and Bulk Density by Speed, and Depth

Moisture Content (%)			
	Profile Depth (cm)		
Speed PTSs (rpm)	0-20	21-40	Total
20 PTSs (5rpm)	15.66 ±2.29	15.95 ±6.30	15.80 ±4.52
40 PTSs (7rpm)	6.82 ±2.91	11.78 ±1.81	9.30 ±3.47
Total	11.24 ± 5.25	13.87 ±4.93	12.55 ±5.15
Non irrigated soil	0.36	4.12	3.48
Bulk Density (g/cm^3)			
	Profile Depth (cm)		
Speed PTSs (rpm)	0-20	21-40	Total
20 PTSs (5rpm)	1.23±0.05	1.23±0.13	1.23 ±0.09
40 PTSs (7rpm)	1.28±0.06	1.31±0.06	1.30 ±0.06
Total	1.27±0.07	1.26±0.10	1.26 ±0.08
Non irrigated soil	1.40	1.35	2.75

5.2 Wetting depth

The result of mean wetting depth of the experimental site recorded 1hr after irrigation at speeds 5 rpm, and 7 rpm is presented in Table 3. From the results, the order in wetting depth were 10.65 > 8.25 > 6.15 <13.15 > 7.65 > 6.15, 13.15 > 10.9 > 6.5 > 12.15 < 8.25 >8.05; 12.60> 10.15 > 5.90 < 11.25 >9.10 <9.15 and 9.25 <12.15 > 9.95 <10.10 >8.25 < 5.90 at 1; 2; 3; 4; 5; and 6 distance from pivot station in North; South; EAST AND West poles respectively.

Table 3: Mean Values of Wetting Depth, by Distance from Pivot, Orientation, and speed

Speed: 20*PTSs* (5 rpm)				
	Orientation			
Distance from Pivot Station (m)	North pole (cm/hr)	South pole (cm/hr)	East pole (cm/hr)	West pole (cm/hr)
1	12.90 ± 0.14	13.75 ± 0.35	13.65 ± 0.21	11.75 ±1.08
2	10.75±1.06	10.25±0.35	10.75±1.06	9.50±0.71
3	8.85 ±0.49	10.10 ±0.14	9.65 ±0.21	8.90±0.14
4	7.90 ±1.27	8.25 ±0.36	7.75 ±0.35	11.00±0.71
5	11.50 ±0.71	11.85 ±0.49	10.00 ±0.71	10.90±1.27
6	10.50 ±0.85	9.10 ±0.14	10.25 ±0.35	8.35±0.21
Speed: 40*PTSs* (7 rpm)				
Distance from Pivot Station (m)	North	South	East	West
1	10.65 ± 0.64	13.15 ± 0.49	12.60 ± 0.85	9.25± 0.35
2	8.25±0.35	10.90±0.35	10.15±0.07	12.15±0.49

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3	6.15 ±0.92	6.50 ±0.71	5.90 ±0.42	9.95 ±0.21
4	13.15 ±0.92	12.15 ±0.47	11.25 ±0.35	10.10±0.14
5	7.65 ±0.21	8.25 ±0.35	9.10 ±0.14	8.25 ±0.35
6	6.15 ±0.49	8.05 ±0.07	9.15 ±0.49	5.90±0.14

PTSs Percent time settings

5.3 GCPSIS Performance

Table 4 shows the effect of operating speed on Application Efficiency (Ae) %, Uniformity Coefficient (CU) % and Distribution Uniformity (DU) of the system in comparison with the acceptable standard. From the Table; the mean AE calculated were 77.67 and 86.83 at 20PTSs (5 rpm) and 40PTSs (7 rpm) respectively with 2.91% and 8.53 % variation respectively. The mean AE calculated were 45.35and 44.89at 5rpm and 7rpm respectively with 43.31% and 43.88% variation respectively The mean AE calculated were 85.80and 94.03at 5rpm and 7rpm respectively with -7.25% and -17.54 % variation respectively.

5.4 Nozzle Discharge

Table 5 shows the result of sprinkler discharge per minute at operating speed 20 PTSs (5rpm) and40 PTSs (7rpm). From the Table, two irrigation periods were observed for each week up to 5 weeks, the discharge from each of the three sprinkler between 9.12 and 6.18 L/Min and the duration for rotation at 5rpm and 7rpm were 56 an 52 minutes respectively while the volume of water applied was highest (1,515.36L) for sprinkler 2 in week 1 at 20 PTSs (5rpm) and lowest (1,045.20L) for sprinkler 1 of week 5 at 40 PTSs (7rpm).

Table 4: Variation of Application Efficiency (Ea), Uniformity Coefficient (CU) and Calculated (DU) % with different operating speed and scale of evaluation

Replication	Calculated AE %		Calculated CU %		Calculated (DU) %	
	20 PTS (5rpm)	40 PTSs (7rpm)	20 PTS (5rpm)	20 PTS (5rpm)	20 PTS (5rpm)	20 PTS (5rpm)
1	78	87.33	89.7	89.7	89.7	95.40
2	77.33	86.33	81.0	81.0	81.0	92.66
Mean	77.67	86.83	85.80	85.80	85.80	94.03
% variation	2.91	-8.53%	-7.25	-7.25	-7.25	-17.54
Standard	80	80	80.00	80.00	80.00	80.00
Remarks	Good	Very good	Very good	Very good	Very good	Excellent

Table 5: Discharge of Sprinklers by Speed, and Volume of Irrigation water applied

Week	Irrigation Period	Discharge (L/Minute) Sprinkler No.			Total Discharge	Duration of Rotation (Minutes)		Volume of Water Applied (L)	
		1	2	3	L/Minute	5rpm	7rpm	5rpm	7rpm
1	1	9.12	9.00	8.88	27.0	56	52	1,512	1,404
	2	9.12	9.00	8.94	27.06	56	52	1,515.36	1,407.12
2	1	8.70	8.52	7.80	25.06	56	52	1,401.12	1,301.04
	2	8.64	8.34	7.50	24.48	56	52	1,370.88	1,272.96
3	1	8.46	7.86	7.20	23.52	NIL	52	-	1,223.04
	2	8.46	7.80	7.08	23.34		52		1,213.68
4	1	8.28	7.56	6.90	22.74	NIL	52	-	1,182.48
	2	8.16	7.32	6.66	22.14		52		1,151.28
5	1	7.44	7.14	6.36	20.94	NIL	52	-	1,088.88
	2	7.08	6.84	6.18	20.10		52		1,045.20
	Total								12,289.68
	Mean								1,228.97

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5.5 Discussion

Moisture content: Moisture content was also measured at the speed variation of 5rpm, and 7 rpm and at different depth of 0- 20 and 21 – 40cm. The results show that the moisture content were highest at higher depth with both operating speeds of 20 PTSs (5 rpm), and 40 PTS (7 rpm). These were 15.95 ± 6.30 and 11.78 ± 1.81 respectively (Table 2). However, the speed of 5 rpm showed higher water content variability. Moisture content values are more uniform at 40 PTS (7 rpm) speed, than at 20 PTS (5 rpm). The higher moisture content with 40 PTS (7 rpm) speed was probably because the sprinkler returned to areas earlier irrigated in quick succession due to its higher speed and supply water to add to residual soil moisture. This also shows that soil moisture distribution pattern is a mirror for surface water distribution pattern. The variations in soil moisture content obtained can also be clarified by the variation of application depth caught by the catch cans. ANOVA for the current work showed that speed but not depth was significant for soil moisture content at 5 % level of significance.

Soil bulk density: The soil bulk densities at 0-20, and 21-40 cm soil depths were 1.23 ± 0.05g/cm^3 and 1.23 ± 0.13g/cm^3 at the speed of 200 PTS (5 rpm) respectively indicating a much wider variability at the higher soil depth. At the speed of 40 PTS (7 rpm)however, there was a slightly different values of bulk densities, with a bulk density of 1.28 ± 0.06 g/cm^3 and 1.31 ± 0.06 g/cm^3 respectively for the 0-20 and 21-40 cm soil depth, but with similar soil densities variability at both depths Table 4. The result suggests that at 40 PTS (7 rpm), bulk density was slightly higher at higher depth. This shows that, bulk density increase with depth as a result of increase in percentage of clay-loam with depth. The soil bulk densities were good for all speeds. Soils with a bulk density more than 1.6 g/cm^{3}tend to restrict root growth [40] [41].ANOVA for the current work showed that both speed, and depth were not significant with respect to soil bulk densities at 5% level of significance.

Wetting depth: Mean wetting depth for this work are reported in Table 5. The wetting depths appeared to decrease, generally with increase in distance from the pivot point. In the case of 5rpm with north orientation, the highest wetting value obtained was 12.90 ± 0.14 cm while the lowest value for the orientation was 7.90 ± 1.27 cm for the 1m and 4m distance from pivot point respectively. Wetting depths were maximum (13.75 ± 0.35 cm) at 1m distance from pivot point with the south orientation and minimum (8.25 ± 0.49 cm) at 4 m at 5 rpm speed of operation. For East and West orientations, wetting highest depths were respectively 13.65 ± 0.21 cm and 11.75 ± 1.08cm for the 20 PTS (5 rpm) depth of irrigation were therefore generally highest at short distance from the pivot point.

Speed variation affected wetting depth and therefore the results of speed of 7 rpm are also presented in Table 5. The results show that the mean wetting depth was 6.15 ± 0.49cm with the north orientation at 6m from the pivot. This was the lowest wetting depth in the north orientation. The highest (13.15 ± 0.92 cm) was at 4m distance from the pivot for the same orientation. For the south orientation, the highest wetting depth was 13± 0.49cm, and this was observed at 1m distance from pivot point, and the lowest (6.50 ± 0.71 cm) wetting depth was observed at 3m distance from pivot point.

The east orientation also showed mean wetting depth of 12.60 ± 0.85 cm as highest depth with a mean wetting depth by 5.90 ± 0.42 cm as the lowest at the distance of 3 m from the pivot point. The west orientation produced wetting depth of which was the lower than all orientation at distance of 1m from the pivot. This suggested that wetting depths are highest with North, South, and East orientations, in the experimental site.

The lowest wetting depth value at the west orientation is most likely due to speed variation in the orientation which was observed during field work to be highest due to the topography of the area. The sudden change in wetting depth for each coordinate can be attributed to sprinkler characteristics such as number of nozzles, size and shape of the nozzles, operating pressure and sprinkler spacing [42] (Solomon, 2010). This produced an overlapping spray by the sprinklers that resulted in more droplets at some points along the lateral. Water application rate must increase along the lateral to apply a uniform depth of water as reported by [43] Armstrong *et al.* (2001).

Sprinkler system is not suitable for application in very fine textured soils where the infiltration rate is less than 4 mm/hr. Since wetting depth is synonymous with infiltration rate both are recorded as water moves into the soil per time taken, it can be concluded that the infiltration rates obtained for this work therefore were generally high. The good performance indices (Ea and Du) obtained for the experiment and the soil type of the site may be the reason for this high infiltration rates. This type of soil with high infiltration rate is suitable for sprinklers irrigation method. The results obtained are in agreement with findings of [40] [41] [44]. However, infiltration rates as found in this work were generally higher than those of earlier researchers'. Highest infiltration rates reported by [40] were 6.43 cm with a mean Value of 4.30 cm.

ANOVA for the current work showed that there was no significant difference in the soil wetting depth at various speeds, orientation and distances from the pivot stations at 5%

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level of significance, therefore post hoc test such as mean separation were not required for further analysis.

Performance Evaluation: The system was operated at the rated speeds of 5 rpm, and 7rpm corresponding to the 20PTSs and 40PTSs one irrigation cycle. These two operating speeds were chosen because, although speeds ranges of 1rpm to 7rpm were available for selection, the time taken for other speeds to complete one irrigation cycle was not significantly different. The average Ea as affected by speed of operation was found to be 77.67% and 86.83% for 5rpm and 7rpm respectively (Table 6). The EA value obtained for speed 7rpm was considered within acceptable range (79.7-92.9%) proposed by [45]. This result indicated that the Ea value increases as the speed increased [46]. High Ea connotes adequate water applications. Since the depth of water applied in a given application is determined by the speed at which the system moves around the field and the system flow rate [47], it can be concluded that the speed and flow rate of the system was very good. Another reason for the good result recorded may be the use of spray nozzles that deliver water in a fixed 360-degree spray pattern. These sprinklers have some relatively small wetted radius that results in high application rates. They produce larger water droplets that when combined with drop hoses reduce losses to wind drift and evaporation [47] [48] [49] .The lower value of Ea obtained during the second run of the system at both speeds can be attributed to clogging of Nozzles caused by sedimentation, trashes and or Nozzles being worn out [50] . The result obtained in this study are similar to those obtained by [51] at Wadi El-granish; [44] at Omdoum and [40] at West Omdurman.

The mean CU for the system was found to be 45.35%, and 44.89% for 5rpm, and 7 rpm, respectively (Table 6). The CU values as found in this study were low when compared with CU standard values. They were, thus, not within acceptable range. The CU values must be up to 80% to be acceptable [52] The low values of CU for the system are not within the acceptable range. The CU values must be up to 80% as acceptable range [53]; [54]. Usually, in sprinkler irrigations, low CU values could be attributed to the inaccurate arrangement in nozzle size along the system lateral. Also, the low value of CU under centre pivot system can be attributed to clogging of nozzles and/or nozzles being worn out as mentioned by [55]; [50]. [56] Stated that low values of CU are usually indicators of a faulty combination of factors such as nozzle sizes, working pressure and spacing of sprinklers. [8] linked the performance of sprinkler irrigation systems to the sprinkler physical characteristics (i.e. jet angle, number and shape of nozzles and mode of operation), nozzle size and pressure. Other reasons for low CU in the current work could be the equal spacing of sprinkler along the lateral. This could lead to pressure drop along the lateral and reduction in sprinkler discharge which lead to low CU values. However, CU is not known to affect crop performance as can be seen in Table 10. High Irrigation Uniformity connotes water being applied adequately with little excess and low uniformity indicates that some portions of the field would be deprived of water while other locations will be over irrigated. Unfortunately, no irrigation system or even Mother Nature, applies water in a perfectly uniform way, so wet and dry spots always occur.

The DU values for the system as affected by speed of operation are shown in Table 6. The mean values of 85.80 % and 94.03 % were obtained at speeds 5 rpm and 7 rpm respectively. These results indicate that Du increases as the Centre pivot speed increased as the mean DU is excellent for the two speeds [56]. The excellent result may be because the system is new. Similar to the situation for Ea, the speed and flow rate of the system were very good hence the excellent result recorded. The use of spray nozzles that deliver water in a fixed 360- degree spray pattern with a relatively small wetted radius that result in high application rates may also be the reason for these excellent results. The lower values observed during the second run at both speeds may be attributed to partial clogging of the sprinkler packages caused by sedimentation, rashes and/or nozzle being worn out. The results of this study were within acceptable limits as recommended by Harrison *et al.* (2010). The results are also similar to those reported by several authors that distribution uniformity of Centre pivot irrigation system should be at least 75% [57].

The result of nozzle discharge presented in Table 6 show that the discharge of the system was highest at the nozzle close to the pivot station, high in the middle nozzle and low at the nozzle at the end of the lateral line. The differences observed in nozzle discharge may be as a result of using the same nozzle size along the lateral line. The difference in elevation around the experimental site may also have contributed to the reduction in operating pressure and hence the discharge of the nozzles especially the middle one. [8] linked the performance of sprinkler systems to nozzle sprinkler physical characteristics (i.e. jet angle number, and shape of nozzles, and mode of operation). The general reduction in nozzle discharge recorded as the experiment progressed may be as a result of leakages observed especially around the elbow close to the pivot station, clogging of nozzles and/or nozzles being worn out as mentioned by [55] .The discharge of the sprinklers at speed of 7 rpm was used to determine the volume of water applied by the system since it was the speed that was used from the beginning to end of the experiment. The findings revealed that there was no over irrigation since the average volume of water applied per irrigation event was within the range of the designed value.

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VI. CONCLUSION

The study revealed the following conclusions:

i) The performance of centre pivot irrigation system is relatively suitable to be introduced in the country.
ii) Centre pivot irrigation system investigations showed a very good application efficiency and high distribution uniformity.
iii) Higher water application uniformities were obtained as the speed of the system increased.
iv) Centre pivot irrigation system was successful in obtaining high yield compared with traditional surface system.
v) The system has the ability to operate under different rotational speeds. This makes it flexible to be changed according to the crop water requirements and the intake rate of the soil.
vi) The soil analysis of the area under study showed that it is suitable for this type of Irrigation.
vii) Wheel slippage problem which was encountered in current study can be solved by using gravel of small sizes in the wheel track and bigger tyres.

VII. FUTURE SCOPE

Based on findings from this study, there are promising prospects for CPSIS application in Nigeria as such, the system should be adopted by small holder farmers and the future scope of the study be expanded to cover:

i) Crop water requirements studies prior to crop establishment should be made to apply the optimum amount of the required quantity at the required time.
ii) The CU of the system should be improved in future studies. This can be achieved by utilizing variable sprinkler spacing or variable sprinkler sizes along the main line.
iii) Cost benefit analysis of the system should be done in future studies to guarantee its economic viability.
iv) Renewable energy such as solar PVC should be tested for their efficacy in powering the drive system and pumping of water to the overhead tank via an onsite sank borehole.
v) The system capacity should be increased to 2 – 4 towers in future works to serve for improved productivity.
vi) Due to the lower values of DU and Ea at low speeds, it is advisable not to operate the system at speeds lower than 7 rpm in tropical climates.

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AUTHORS BIOGRAPHY

Ahire, Orduen, Department of Agricultural and Bio- Environmental Engineering Technology, Akpran Orshi Polythecchnic, Yandev Gboko, Nigeria.

M.O.Udochukwu, Department of Agricultural and Environmental Engineering, Joseph Sarwuan Tarka University, Makurdi Benue State, Nigeria.

Engr. Enokela Onum Shadrach has 23 years' experience in in air, soil and water spectra; from hydrology to Municipal Solid Waste (MSW)-contaminated sites based on visible monitoring of soil, water and air pollution and remediation. He is an Ass. Professor of Environmental Engineering in Department of Agricultural and Environmental Engineering JUSTUM. He is a Fellow of International Society for Development and Sustainability (ISDS) Japan.

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R.T.Iwar, Department of Agricultural and Environmental Engineering, Joseph Sarwuan Tarka University, Makurdi Benue State, Nigeria.

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