International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 8 No. 3 Sep. 2014, pp. 891-897

http://www.ijias.issr-journals.org/

Performance assessment, monitoring and evaluation of a portable sprinkler irrigation system at CSIR-Crops Research Institute

P. Oteng-Darko[1], E. Annan-Afful[1], E. Ofori[2], and S. K. Amponsah[1]

[1]CSIR-Crops research Institute, P. O. Box 3785, Kumasi, Ghana

[2]Department of Agricultural Engineering, KNUST, Kumasi, Ghana

ABSTRACT: Increased pressures on the finite water resources of the world are requiring the irrigation sector to become more accountable for its water use. There are a multitude of factors which can affect the uniformity of an irrigation system. An evaluation or performance assessment of irrigation systems can point out flaws or otherwise of an irrigation system for improvement. An evaluation of a recently installed sprinkler irrigation system was done to gather the necessary data needed to determine the systems performance and also to determine whether excessive application loses were occurring in the system. The assessment took into account the operating pressures, lateral and sprinkler discharges, sprinkler distribution patterns and uniformity coefficient. Operating pressures and discharge deviated marginally from manufacturers specifications. A uniformity coefficient of 84.13% suggested a good system with very minimal water loses.

KEYWORDS: Discharge, operating pressures, uniformity coefficient, irrigation, sprinkler

1 INTRODUCTION

A portable sprinkler irrigation system was installed to cover a 20 ha operational area of the research fields of the CSIR-Crops Research Institute with financial assistance from the West African Agricultural Productivity Programme (WAAPP). In portable set sprinkler irrigation systems, the sprinklers and associated pipelines are temporarily set up and operated for each irrigated zone. They are then moved to a new zone for irrigation. These systems are used to irrigate several zones; thus, they are designed so that all zones can be irrigated before the first zone needs to be re-irrigated.

The individual sprinkler spacing and discharge rates determine the average irrigation application rate. Many additional factors, including operating pressure, changes in elevation, friction pressure losses, wind, and individual sprinkler characteristics affect the uniformity of water application within an irrigated zone. The performance of a sprinkler irrigation system is described by uniformity and application efficiency. Water application efficiency is an irrigation concept that is very important in both system design and irrigation management due to its relationship with the energy and the labour requirements for implementing a sustainable irrigation scheme. One of the standard practices to characterize water use in an irrigated area is to conduct evaluations.

Several factors regarding soil, plant and atmosphere interact to determine the productivity of agricultural crops. If the water necessary for plant growth is not applied uniformly, growth and yields will be affected. Non-uniform application also leads to surface redistribution and eventual leaching of nutrients on over-irrigated areas whilst under-irrigated portions end up as dead spots, unable to support plant growth and also create non-uniform crop stands. Irrigation uniformity is linked to crop yield through the effects of under or over irrigation. Inadequate water results in high soil moisture tension, plant stress and reduced crop yields, whilst excess water may also reduce crop yield through mechanisms such as leaching of plant nutrients, increased disease incidence or hindered growth of commercially valuable parts of crops [1]. The uniformity and performance of an irrigation system are inherently associated with the manner in which agricultural resources are utilised. So that non-uniformity and under performance result in excess pumping costs and fertiliser loss either through fertigation or leaching by the excess water. Capital losses are also incurred due to the extra capacity put into the irrigation and drainage systems to convey the excess water from the field [1].

Reference [2] reported several studies that show a linear relationship between yield reduction in crops and seasonal evapotranspiration deficit. Generally, the production functions regarding water permit an analysis of the total dry matter production or commercial matter production of the crops for transpiration, evapotranspiration or quantity of water applied by irrigation. Knowing these relationships is necessary to assess irrigation strategies [3]. Thus, the uniformity of a sprinkler irrigation system is significant to realising the basic aim of efficient application of water to eliminate wastage and the overall improvement in potential irrigation systems efficiency. Reference [4] identified some benefit of conducting performance evaluation of a sprinkler irrigation system. Some of these are: improved soil moisture uniformity; lower water and energy requirement; easier irrigation system scheduling and management; reduced runoff and deep percolation and healthier plant growth for optimum yield.

The main objective of this paper was to examine the performance of a recently installed sprinkler irrigation system at the CSIR-Crops Research Institute. This research has the potential benefit of improving irrigation efficiency and reducing stress on water resources and losses of water and nutrients to groundwater and surface water resources. Furthermore, findings from the study would serve as a guide in irrigation scheduling and the implementation of future sprinkler systems for irrigating larger areas with a given volume of water. This study would also contribute to knowledge in the field of irrigation practice in Ghana at large.

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF STUDY AREA AND IRRIGATION SYSTEM

The Crop Research Institute (CRI) is one of the 13 institutes of the Council for Scientific and Industrial Research of Ghana. It is mandated to develop and disseminate environmentally sound technologies, comprising improved high yielding, good quality, pest and disease resistance varieties and improved crop management and post harvest practices. It is located at Fumesua, 30km away from Kumasi, in the Ejisu-Juabeng District of the Ashanti Region of Ghana. It is on longitude 1° 32’ W and latitude 6° 43’ N. The location of the project area is as shown on the Google image in Figure1 below. The topography at the site and its surrounding areas is undulating with gentle slopes. The slope is flows between 3 – 8 percent. The average elevation is 295m taken from GPS readings and corroborated from 1:25,000 topographic map of Ghana.

Supplementary irrigation is currently being applied to sections of the fields covering an area of 23 ha. The overall objective of the irrigation project was to enhance crop improvement and technology development capacity of the CSIR-Crops Research Institute to improve food security and livelihoods of smallholder and commercial farmers in Ghana.

A portable sprinkler irrigation system was installed to cover a 20 ha operational area with the remaining 3 ha fitted with a drip irrigation system. In portable set sprinkler irrigation systems, the sprinklers and associated pipelines are temporarily set up and operated for each irrigated zone. The main components of the sprinkler irrigation system are as follows:

2.1.1 THE CONTROL STATION

This consists of a supply line (rigid galvanized steel suction pipes and manifolds), two 45 HP electric pumps, control panels, pressure sustain valve, water flow meters, and a filter. It is also equipped with an air release valve and a check valve

2.1.2 THE MAINS AND SUB MAINS (PIPELINES)

The main and sub main pipelines are made up of 160mm, 110mm, and 75mm PE pipes. The main pipelines have the largest diameter (160mm and 110mm) of the network and it conveys water from the pumping station through the system. The pipes are black high density polyethylene (HDPE), buried permanently at a depth of 1m. The sub mains are smaller diameter pipelines (75 mm HDPE) which extend from the main lines and from which the system flow is diverted for distribution to the various plots.

2.1.3 THE HYDRANTS

There are 5 major hydrants fitted on the main (160mm) pipeline. These are equipped with a 50-75mm (2-3”) shut-off valve. They deliver part of the flow to the sub mains and serve as controls for switching between sets. The sub main pipelines

(75mm PE pipes) are also installed with a total of 94 valves connected to elbows for delivering water to the laterals. The valves are spaced 12 m apart on the sub mains.

2.1.4 THE LATERALS (IRRIGATING PIPELINES) AND SPRINKLERS

These are the smallest diameter pipelines of the system. They are made of 40 mm low density polyethylene (LDPE) pipes. They are fitted perpendicular to the sub mains at fixed positions (12 m intervals), laid along the plant rows and equipped with water emitters spaced 12 m apart.

2.2 FIELD EVALUATION

Field evaluations were conducted by adopting the methodology of [5] and [6], following ASAE standard S330.1 [7] and ASAE standard S398.1 [8].

2.2.1 MEASURING OPERATING PRESSURE

Pressures within zones were measured at the sprinkler nozzles using Pitot tube pressure gauges. The pitot tubes were positioned in the discharge stream about 3mm from the nozzle. It was adjusted by moving it slowly within the stream until the highest constant pressure reading was obtained. Pressures were recorded at critical points within the system, including at the pump discharge, at the entrance to zones, at the distant end of laterals, and at extreme high and low elevations. This was done to correct any extreme deviations from the pressures specified by the system designer.

2.2.2 MEASURING LATERAL AND SPRINKLER DISCHARGES AND SPRINKLER APPLICATION RATES

Lateral discharge**:** A 40mm pipe was connected to the lateral and directed into a bucket of known volume. The valve was switched on and the water collected into the bucket. The time taken to fill the bucket was noted. This was repeated three times. The volumes were divided by their respective times (as show in equation 1) and the average was taken as the lateral discharges.

$q_l = \frac{Vl}{t}$ (Equation 1)

Where:

ql = lateral discharge, mm/h
v_l = volume of water collected, ml
t = catch can fill time, s

Lateral Number	Volume (V), L	Time (T), s	Discharge(Q), L/s
1	10.8	1.32	8.18
2	11.2	1.48	7.56
3	12.7	1.51	8.41
Mean	11.57	1.44	8.05

Thus, the mean lateral discharge was determined to be 8.05 L/s

Sprinkler discharge**:** The length of a garden hose was connected to the nozzle of a sprinkler and whilst the sprinkler was operating, the water was directed in a bucket of known volume. The time taken to fill the bucket was noted. The discharge was determined by dividing the volume collected over time taken to collect the known volume. This was later converted to mm^3/h

$q_s = \frac{Vs}{t}$ (Equation 2)

Where ;

qs = the sprinkler discharge, ml/s
Vs = volume of water collected, ml
t = catch can fill time, s

Sprinkler application rate: Sprinkler application rates must be known so that irrigation durations needed to apply specific depths of water can accurately be determined. This was done: (1) to verify irrigation system designs and (2) to determine whether runoff can occur during the period of irrigation. The application volume was measured directly with catch cans. The volume of water collected was converted to depth by dividing the volume to the base area of the catch can. The average application rate was then calculated as the average depth of water measured divided by the time (measured using a stopwatch) during which the data was collected The average flow rate and area covered by each sprinkler was measured. Since the sprinklers are regularly spaced, the application rate was calculated from:

$$\text{Rate} = \frac{sprinkler\ discharge(\frac{mm}{h})}{lateral\ spacing(m)*sprinkler\ spacing(m)} \qquad \text{(Equation 3)}$$

2.2.3 DETERMINING SWATH RADIUS, ROTATIONAL SPEED, AND SPRINKLER DISTRIBUTION PATTERN AND PATTERN EFFICIENCY

The farthest distance covered by water droplets (throw) from the sprinkler was measured for the swath radius. This was done during the dry season whilst the irrigation system was operated at full pressure. .

The speed of rotation of a sprinkler varies with nozzle size, stator size, operating pressure and condition of the impact drive mechanism. Several sprinklers were selected and allowed to make one revolution. The time taken to make the revolution was taken.

Uniformity was determined by placing 24 catch cans spaced 3 m, across the travel lane of four selected sprinklers. Because application rates may vary throughout a large irrigated field, measurements were made at several locations. Test locations were selected over the entire range of pressures that were encountered in the irrigation system. That is, locations were selected closer and farther from the irrigation pump at both high and low elevations.

The Christiansen's coefficient was used to test the distribution uniformity using the formula below;

$$\text{CU} = 100\%(1 - \sum\frac{x}{mn}) \qquad \text{(Equation 4)}$$

Where:

$\sum x$ is the sum of the absolute deviations from the mean (mm or ml) of all the observations
m is the mean application depth measured (mm or ml)
n is the number of observations (catch cans)

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution [9]. This uniformity measure is also called low-quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems [10]. The DU coefficient takes into account the variation of can readings from the mean but concentrates on the lowest 25% of readings. A commonly used fraction is the lower quarter, which has been used by the USDA since the 1940s [9].

3 RESULTS AND DISCUSSIONS

The results and discussions are as follows.

3.1 PUMP OPERATING PRESSURE

The operating pressure of the pump was measured as **330 KPa.**

3.2 SPRINKLER OPERATING PRESSURE, SWATH RADIUS, ROTATIONAL SPEED, SPRINKLER DISTRIBUTION PATTERN AND PATTERN EFFICIENCY

The sprinkler operating pressure used in the study was satisfactory inferring from the manufacturer specification of 30Kpa. The sprinkler operating pressures ranged from 12 – 30Kpa. The average sprinkler precipitation profiles obtained were also consistent with established profiles of a single nozzle sprinkler operating at a satisfactory pressure.

To achieve good water distribution, rotation speed is to be consistent between sprinklers. Reference [11] stated that impact sprinklers should complete one revolution in 2 minutes (±15 seconds) and that under no circumstance should a sprinkler complete a revolution in less than 105 seconds. However, [12] asserts that the ideal rotation speed of a 19mm impact sprinkler is 1 rpm and that tighter spring tension increases the number of beats per minute and speed of rotation. The mean rotational speed determined was 1.96 rpm.

The Swath radius of the sprinklers were found to range from 8.10m to 8.81m with an average of 8.47m, and their corresponding wetted area ranging from 206.12m^2 to 243.84m^2. A mean discharge of 479L/h was recorded which deviated marginally from the standard values 495L/h quoted by the manufacturer.

Table 1. A table showing data collected from seven sprinklers on a lateral

Sprinkler	Distance from valve, m	Speed rev/min	Pressure (KPa)	Swath radius, m	Throw area, m^2	Discharge, l^3/h
1	12	2.259036	305	8.81	243.84	498
2	24	2.162942	295	8.72	238.88	490
3	36	2.009377	285	8.65	235.06	485
4	48	1.892148	273	8.41	222.20	481
5	60	1.838799	270	8.38	220.62	472
6	72	1.805054	265	8.24	213.30	467
7	84	1.726122	261	8.10	206.12	462
Mean		1.96	279.14	8.47	225.71	479

3.3 Uniformity of Application

CU values of 80-90% is attainable for set-move systems which are properly designed and maintained, operating under moderate wind speeds less than 16km/h [13]. It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions [10]. Sprinkler uniformity is generally affected by the combination of wind speed/direction, operating pressure and sprinkler spacing, in the case of set-move sprinkler system. Reference [13] indicated that the uniformity of application is acceptable for CU values greater than 0.84 or 84%. Reference [15] also wrote that in general CU of at least 85% is recommended for delicate and shallow-rooted crops such as potatoes and most other vegetables, whilst values between 75% and 83% is acceptable for deep-rooted crops like alfalfa, corn, cotton and sugar beets. In cases where chemicals are applied through the irrigation water, the CU should be at least 80%.

Table 2. A table of values used to calculate the lowest quartile

Catch can number	Volume, ml	Absolute deviation
1	37.1	12.7
2	39.1	10.7
3	40.2	9.6
4	40.4	9.4
5	41.0	8.8
6	44.0	5.8
7	45.0	4.8
8	45.8	4.0
9	47.0	2.8
10	48.4	1.4
11	49.1	0.7
12	49.4	0.4
13	50.2	0.4
14	51.0	1.2
15	52.3	2.5
16	54.7	4.9
17	56.4	6.6
18	57.6	7.8
19	60.4	10.6
20	62.6	12.8
21	65.1	15.3
22	69.5	19.7
23	71.8	22.0
24	73.5	23.7
Total	1251.6	198.6
Mean	52.15	
Median (50^{th} Percentile)	49.8	
Mean absolute deviation	2.35	
Sum of absolute deviation		198.65

From table 2, equation 4 becomes

CU = 100 %($1 - \frac{198.65}{52.15x24}$) = 84.13%

The system gave a CU of 84.13% which according to [13] is acceptable for such systems.

4 CONCLUSIONS

The average sprinkler distribution patterns obtained were consistent with established profiles of a single nozzle sprinkler operating at a satisfactory pressure. The operating pressure and application rates were satisfactory inferring that the sprinklers could be used without runoff or major losses. However, detailed irrigation scheduling is needed to attain the maximum benefit from the system.

REFERENCES

[1] Solomon K. H. Sprinkler Irrigation Uniformity. 1990. Available: http://cati.csufresno.edu/CIT/rese/90/900803/index.html (3rd May, 2014)

[2] Stewart, J. I.; Hagan, R. M.; Pruitt, W. O.; Heanks, R. J.; Riley, J. P.; Danielson, R. E.; Franklin, W. T.; Jackson, E. B. Optimizing crop production through control of water and salinity levels in the soil. Publ, PRWW 15 1 -1, Logan: Utah State University.191p. 1977

[3] Mantovani, E. C.; Villalobos, F. J.; Orgaz, F.; Federes, E. Modelling the effects of sprinkler irrigation uniformity on crop yield. Agricultural Water Management, v.27. p.243-257.1995

[4] Wilson, T.P. and Zoldoske, D.F. (1997). Evaluating Sprinkler Irrigation Uniformity, Center for Irrigation Technology, USA. Available: http://cati.csufresno.edu/cit/rese/97/970703/ (11th May, 2007)

[5] Merriam, J. L., Shearer, M. N. and Burt, C. M.. Evaluating Irrigation Systems and Practices. In: Design and operation of farm irrigation systems, Ed. Jensen, M. E., St Joseph, Mich.: ASAE, pp 721-760. 1980

[6] Merriam, J. L., and Keller, J.,. Farm irrigation system evaluation: A guide for management, Logan, Utah: Utah State University. 1978

[7] ASAE Standards, S330.1. Procedure for sprinkler distribution testing for research purposes. St. Joseph. MI.: ASAE. 1985a

[8] ASAE Standards, S398.1. Procedure for sprinkler testing and performance reporting. St. Joseph, MI.: ASAE. 1985b

[9] Ascough, G.W. and Kiker, G.A. The Effect of Irrigation Uniformity on Irrigation Water Requirements. 2002. Available: http://www.wrc.org.za/archives (28th July, 2007)

[10] King B. A., Stark J. C. and Kinkaid D. C. Irrigation Uniformity, University of Idaho, USA. 2000 http://info.ag.uidaho.edu/pdf/BUL/BUL0824.pdf (3rd May, 2014)

[11] Huck, M. (2004). Irrigation Uniformity, Turfgrass Information Center, USA. Accessed on 27 July 2007 Available: http://turf.msu.edu/docs/74th_Conference/Huck_Water_Irrigation (3rd May, 2014)

[12] ISL. Impact Sprinkler Spring Tension and Sprinkler Arm Weights, Irrigation Systems Ltd, UK. 2007. Available: http://www.plowcon.com/sprinkler_weights.htm (3rd May 2014)

[13] Dalton, P. and Raine, S. Measures of Irrigation Performance and Water Use Efficiency, Department of Environmental and Resource Management, Australia. 1999. Available: http://www.nrw.qld.gov.au/rwue/pdf/publications (3rd May, 2014)

[14] Keller, J. and Bliesner, R.D. Sprinkle and Trickle Irrigation, Van Nostrand Reinhold, New York, 3-5, 86-96. 1990.