Journal of Agricultural and Crop Research
Vol. 9(7), pp. 176-181, July 2021
doi: 10.33495/jacr_v9i7.20.179
ISSN: 2384-731X
Research Paper

Performance evaluation of small scale irrigation technologies for improved management at Mukono ZARDI

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Accepted 28th September, 2020.

Abstract. Poor performance of irrigation systems can lead to substantial losses both of water and crop yields. It may also reduce the water economic index and overall sustainability. Already installed systems should be audited for performance to identify and rectify management and design gaps. Four irrigation technologies; Gun sprinkler, LF2400 sprinklers, 8mm surface drip (SDI) and 0.109" Drip buttons at 60 cm spacing, were evaluated for performance against water application efficiency, irrigation uniformity and capital cost of equipment per unit area in the open fields at Mukono ZARDI Research Station. Crop response to application uniformity and rate were evaluated using tomatoes under drip and green bean under sprinkler irrigation. Soil moisture content was used to surmise application uniformity. Cost of equipment was obtained through a request for quotations (RFQ) from suppliers. The gun sprinkler had a higher coefficient of uniformity at 77% compared to LF2400 sprinklers (64%), but their overall performance was limited by the low water application efficiency estimated at 35.98%. A reduction in productivity of green beans equivalent to 5.159 kg/m^2 was recorded attributable to low moisture levels on 1.4% of the planted field area under the LF2400 sprinklers. Technology cost was related to the irrigated land size by different functional equations.

Keywords: Cost, irrigation technology, uniformity, water application, yield.

INTRODUCTION

Efficient use of irrigation water can improve agricultural productivity and reduce competition for water resources. Inadequate irrigation application results in crop water stress and yield reduction, (Irmak *et al*., 2011; Kizza *et al*., 2016). Practices such as improper timing and operation conditions can damage plants and lead to wastage of water (Payero *et al*., 2009). Choosing the most economical system can however prove a daunting task especially to non-experienced practitioners. Some of the factors that have been documented as drivers for choice of irrigation technology include; water costs (for the case of Uganda, water for agricultural use is generally without charge and farmers are only concerned about availability within reach), labor costs, topography, soil characteristics, and climate (Negri, 1990).

The best choice should be technology that is efficient, of low cost and easy to use. Irrigation efficiency is generally defined from three points of view: (1) the irrigation system performance, (2) the uniformity of water application, and (3) the response of the crop to irrigation, and it may vary spatially and temporally (Irmak *et al*., 2011). Availability of water and cost of the equipment are largely prioritized by farmers. The one factor in irrigation that is most often overlooked is the efficiency of the irrigation system (Martin, 2011).

This research anticipated that increasing water shortage and costs of operating irrigation systems will motivate practitioners to opt for techniques that are more efficient and aimed at documenting the comparative advantages of the locally available irrigation techniques in terms of cost and uniformity of water application to the plants.

MATERIALS AND METHODS

Site location and characteristics

The study was carried out at Mukono Zonal Agricultural Research and Development Institute, MuZARDI, Uganda (0.37450613; 32.73084372) at 1157 m above sea level. The soil at the experimental plots was classified as clay soil with field capacity of 42% at 0.05 bars. The field studies were conducted for three dry seasons, January – March 2017, 2018 and June – September 2017. The average daily ET_0 was 5 mm. The site mostly, > 85%, received south westerly and southerly winds of average speed 6.75 mph and 19 mph in the morning and evening respectively.

Technology performance evaluation

Technologies evaluated were among those commonly used or promoted locally. These included:

i. Single nozzle Gun Sprinkler mounted on a tripod stand at water outlet height of 2 m (15 m radius) with an inlet 50 mm hose pipe and running on a 7 HP petrol pump. These were sold as sprinkler kits and were promoted for production of various perennial and annual crops. The Ministry of Agriculture Animal Industry and Fisheries (MAAIF) in collaboration with researchers at NARO-MuZARDI, distributed 26 kits to selected farmer groups in 9 out of the 21 districts of the Lake Victoria Crescent Agro-ecological Zone, between July and November 2017. The irrigated area under this system was 0.25 acre.
ii. LF2400 Medium range sprinkler (10m radius) system with nozzles spaced at 58% diameter, and raised at 1m height. The system was installed on a 0.159-acre plot of land.
iii. A 0.25 acre 8 mm surface drip irrigation (SDI) system with emitter spacing of 30 cm and manufacturing flow rate of 2l/hr was operated at a pressure of 1 m. These were available as kits in the range of 0.125 to 1 acre.
iv. 0.109" Drip buttons at 60 cm spacing. These were tested because tomatoes were planted at a spacing of 60 × 60 cm and farmers were of the view that some water would be saved from the 30 cm spaced emitters and was considered a better alternative to 30 cm SDI.

The technologies were evaluated for performance in terms of:

Irrigation uniformity

It was determined using the coefficient of uniformity; CU, for overhead irrigation calculated using equation 1, which is detailed in Irmak *et al.* (2011).

$$CU = 100 * \left(1 - \sum \frac{|Z-M|}{\sum Z}\right) \quad (1)$$

Where Z is the amount of water collected per container. $M = \frac{\sum Z}{n}$; n is the number of catch containers used. 20 Plastic containers of 0.131 m^2 and 0.15 m depth were used to collect the water applied over a period of 1 hour. The catch containers were placed on the nodes of a 1 m grid, along and perpendicular to the sprinkler line.

The sprinkler systems were operated on an electric centrifugal pump at 241.32 Kpa operating pressure.

The drip systems were evaluated using emission uniformity, EU.

Emission uniformity, EU, was estimated according to equation 2 also detailed in Irmak *et al.* (2011).

$$EU = \left[1 - \frac{1.27Cv}{\sqrt{n}}\right] * \left[\frac{q_{min}}{q_{ave}}\right] \quad (2)$$

Coefficient of manufacturing variation, Cv was estimated using the standard formula Cv = $\frac{S}{\bar{X}}$, Where; S is the standard deviation of discharge from 20 emitters. Cv was determined as 0.083.

Soil moisture content was recorded using a (3 × 1) meter schematic grid, parallel and perpendicular to the sprinkler line, and three meters apart for drip systems, using Delta-T type HH2 soil moisture probe, 20 min after irrigation application.

Water application efficiency

This was estimated using Equation 3.

$$Ei = \left({}^{Dp}/_{Df}\right) * 100 \quad (3)$$

Where:
Ei = irrigation efficiency (%)
Dp = Depth of water required by plants (mm)
Df = Depth of water delivered to the field (mm)

The depth of water applied to the field was estimated using the Irrigator's Equation, 4 which is discussed in detail by Martin (2011).

$$Q \times t = d \times A \quad (4)$$

Q the flow rate used was the average value obtained from field collected data in cubic meters per hour (m^3/h); t time of irrigation (hours); d is the depth of water applied (mm) and A is the area irrigated.

Cost of equipment

Requests for quotations (RFQ) were sent to 3 supplier companies of irrigation equipment in Uganda and average prices per technology were calculated. Drip irrigation kits evaluated (8 mm) were supplied solely by Balton Uganda. Although the standard measure is price per hectare, we developed prices for various land sizes given that many individual smallholder farmers especially in the peri urban areas utilize plot areas ranging between 0.25 and 1 acres. Large acreages were mostly used by farmer groups. The data obtained was used for plotting price against area curves in Microsoft excel 2007.

Response of the crops to irrigation

The drip systems were installed on 0.25-acre double row beds (12 × 1.2) m^2 planted with tomatoes at a plant density of 3 plants/m^2. Green bean was used as a test crop under overhead irrigation at a planting density of 5 plants/m^2.

RESULTS AND DISCUSSION

Irrigation uniformity

The overall uniformity coefficient for the LF2400 sprinklers was 63.4% for the evening irrigation and 65.3% for morning application. Gun sprinkler had a uniformity efficiency of 77%. The distribution pattern was impacted by wind speed and direction for both sprinkler systems. The wind was mostly southerly and formed fresh breeze (19 mph) in the evening and southwesterly light breeze (6.75 mph) in the morning as categorized in the Beaufort scale. This finding was in agreement with Kamey and Podmore (2012) who observed that maximum water application rate is a function of average wind speed in the principal wind direction. The drift effect was less in Gun sprinkler than LF2400 sprinklers due to the difference in droplet sizes. The later generally had a high percentage of fine droplets at 241.79 Kpa operating pressure.

The 8 mm drip system was 87% efficient. This result corroborated that of Koegelenberg *et al.* (2002). In their evaluation of dripper performances, they observed a tendency of the Emission Uniformity (EU) measured in the field of all the dripper types to deteriorate over time from 87.1% in the first evaluation to 82.4% a year later. The system evaluated was within the first year of use.

It was evident from the soil moisture distribution (Figure 1) that the lowest 2 beds were kept at higher soil moisture levels which was attributed to partial closure of the control valves hence a 'leakage'. From the same figure, the soil moisture distribution 20 minutes after irrigation indicated low soil moisture levels for some beds, which was due to poor emitter performance/blockage. The soil moisture levels however, tended to redistribute as time from end of water application increased to 24 hours, as also observed by Shaju (2017). The non-uniformity in drip irrigation was easy to correct, upon identification, through system flushing and regulating control valves.

The overlapping pattern in overhead sprinkler systems caused areas of high water application compared to drip systems where overlap was minimal.

Water application efficiency

Gun sprinklers had the lowest irrigation efficiency at 35.98%. The system had the highest water application rate and with no significant yield advantage over the LF2400 sprinkler system, which had an efficiency of 79.4%. The gun supplied more than enough water to the plants, which on several events resulted in surface run off. The gun water spray had an average water application of 10.6 l/hr at 8m from the center, 8 l/h at 5 m and 5.2 l/h, 3 m from the center in the principal wind direction. There was a lot of runoff in the zone which received 10.6 l/h which was not redistributed in the field at the peripherals. The redistribution advantage discussed by Kamey and Podmore (2012) can be realized in the inner field depending on the slope of the irrigated field. The common types of planting methods used were plants on raised beds and now farmers are adapting use of planting basins for sustainable land management. Under raised beds, the runoff under the gun sprinkler would quickly flow between beds and to the drainage channel with little time to infiltrate. It would be advisable to irrigate the field from peripheral to inner parts to retain the runoff.

Application rate in Drip buttons was low due to a lower operating pressure available at the station. They required much more time to supply the required amount of water to the plants than recommended by the manufacturer. The 8 mm drip system at 99.8% had the best application efficiency. Their efficiency can however be reduced by failure to observe the optimum irrigation time to supply the required amount of water of irrigation (duration) based on the flow rates.

Soil moisture distribution

The soil moisture distribution maps indicated that the area below the sprinkler line was receiving less water per application both during morning and evening irrigation. The percentage of the zone affected was influenced by wind speed and direction. When compared to the soil moisture status following a single rainfall event received

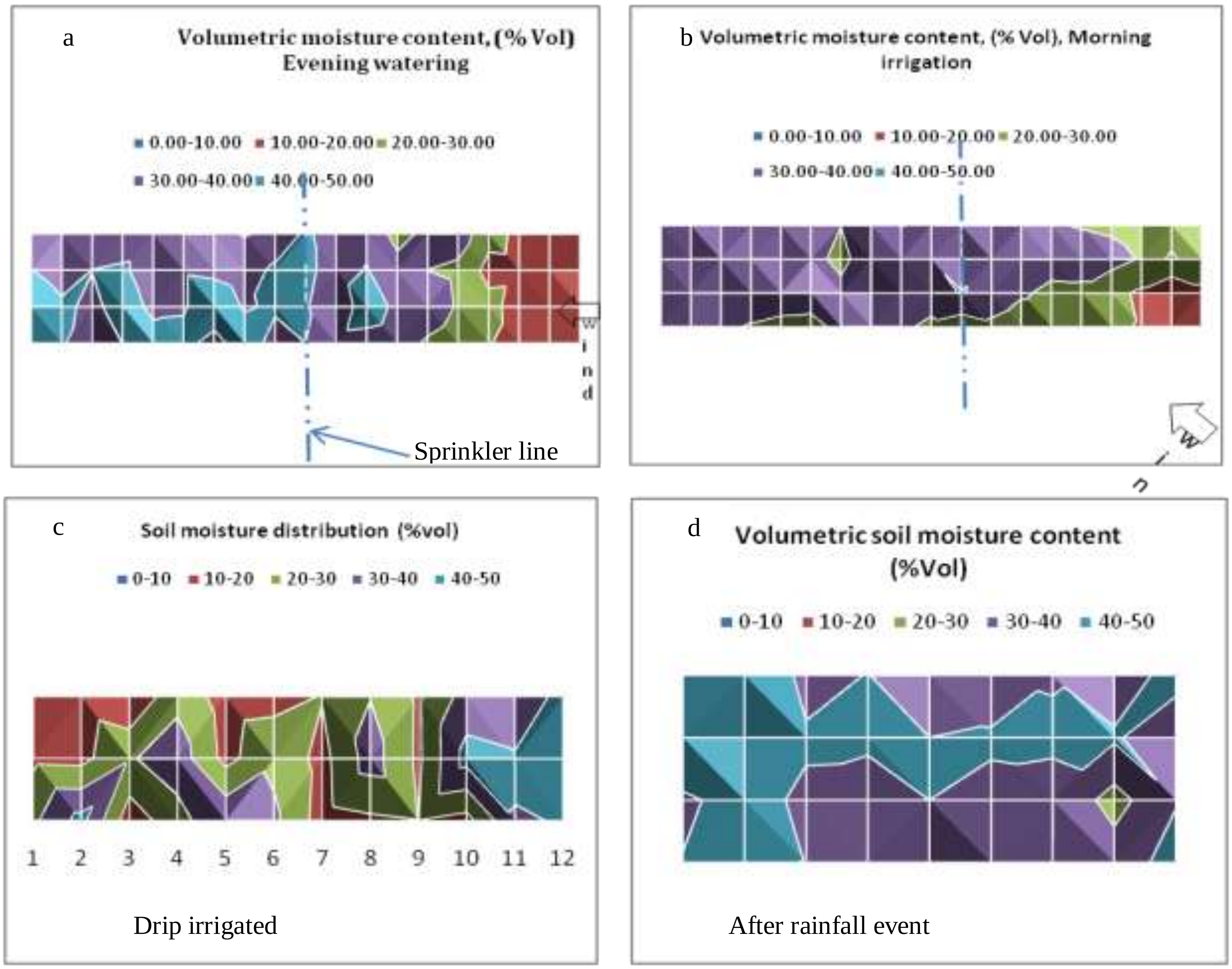

Figure 1. Soil moisture distribution patterns under LF2400 sprinklers (a, b), Surface drip irrigation with a 3.3 % slope in 1-12 direction (c), and sprinkler irrigated field after a rainfall event (d).

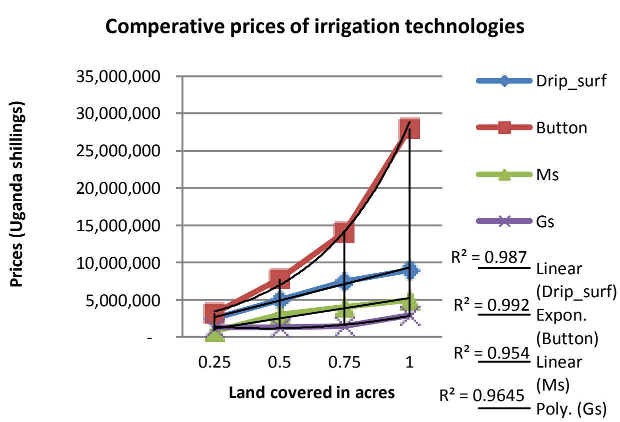

Figure 2. Technology performance in terms of cost per unit area coverage; 1 $ = 3750 Ugx.

on March 5th 2018, the moisture distribution pattern was altered but there was still a small patch with low soil moisture compared to the rest of the garden (Figure 2). This trend indicates the influence of antecedent soil moisture on the current moisture level depending on amount of the water added.

Table 1. Average green bean yield as influenced by soil moisture distribution.

MC (% Vol)	Average number of pods /plant (n = 3)	Fresh weight (g)
30-40	131.5	1299.8
20-30	76	836
10-20	25.3	268

Figure 3. Farmer group garden, mapped with stars, was covered for irrigation of multiple crops under SLM _MAAIF project, February 2018.

Crop response to irrigation uniformity

At harvest of green beans, five plants per square meter yielded 6.499kg in the well-watered zones of the field. The plants growing where the soil moisture content was consistently below 20% volumetric soil moisture level, had delayed maturity by 3 weeks. The area with delayed maturity was $9m^{2,}$ which led to a yield loss of 58.49 kg amounting to 58,500 Uganda shilling at 1000 Uganda shillings per kilo. Although the harvest later took place, productivity had reduced by 5.159 kg/m^2.

The green bean yield across the different soil moisture zones is presented in Table 1.

Soil moisture yield relationship in maize was studied by Milics *et al.* (2017), who found significant interaction. There was no observable yield difference across the field under drip irrigation due to the high level of uniformity recorded.

Cost of equipment

In the calculation of cost per unit area, it was assumed that water had been conveyed up to the garden.

One case where actual small-scale irrigation installation was made is reported below. The area coverage was five hectares. Water source was a (5 × 4 × 2) m^3 pond excavated along the stream below the garden (Figure 3).

Irrigation technology used was a gun sprinkler selected as the most economical for the acreage covered.

The budget cost by a contracted company was as presented in Table 2 including tax charges.

CONCLUSIONS AND RECOMMENDATIONS

In terms of cost per unit area, gun sprinklers were the most appropriate but where water is limiting, medium range sprinklers properly calibrated for windy conditions would be preferred. Drip systems would be economical for small areas up to 1 acre otherwise; the cost would be prohibitive for many low-income farmers. The button system, although water saving was the most costly and should be discouraged for small plant spacing as the one studied. Observing optimum operating pressures improved the performance of each given technology. It is therefore important to keep the irrigation systems well maintained. Soil moisture distribution was a good system performance monitor and may be used to eliminate patches of low and high water application across fields. Deliberate effort can then be made to apply more water to the areas that received less water in the previous application whenever identified. Wind speed and direction should be taken into consideration during installation of overhead irrigation systems to improve their efficiency. We suggest increasing the speed from the recorded 5 revolutions per hour to higher value as a design improvement for gun sprinkler and recommend use of

Table 1. Priced bill of materials for sprinkler irrigation installation on a 5 ha field.

Item	Description	Unit	Qty	Rate '000	Gross '000
1.	Transport (~40km)	LS	01	750	750
2.	Motorized Petrol Engine Pump (minimum head = 75 m, discharge = 20m^3/h, including accessories	Pcs	01	1,560	1,560
3.	Installation and training of users	LS	01	5,250	5,250
4.	Mainline, 2" HDPE pipe (PN 6)	M	300	12	4,800
5.	Fire Hose 2" (25m per roll)	Roll	8	250	2,000
6.	Accessories (end cap, T-joints, valves, MTAs….)	LS	01	8,380	8,380
7.	Hydrants per enterprise	Pcs	03	260	780
8.	Excavation of collection pond at stream (size: 5 m × 4 m × 2 m) including compaction and stabilization of embankments	No.	01	1,800	1,800
9.	Gun sprinkler (size = 2 inch)	No.	2	1,500	3,000
	Grand-total			**28,320,000**	

certified irrigation technicians to install the irrigation systems as well as occasional audits for performance of the irrigation systems.

ACKNOWLEDGEMENTS

The study was carried out with ATAAS funds. The authors acknowledge the generous contribution of intern students from Uganda Christian University in field data collection.

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