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Performance Evaluation of a Drip Irrigation System inside the Automated Greenhouse in Huye Ecological Condition

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Abstract: This research, titled Performance Evaluation of a Drip Irrigation System inside the Automated Greenhouse in Huye ecological Condition, was carried out in the Research Center of Integrated Polytechnic Regional College (IPRC)-Huye Campus, which is located in the Ngoma Sector of Huye District of Rwanda, in 2023. The study has mentioned the specific objectives of determining the average emitter discharge of the irrigation system, evaluating Christiansen Coefficient Uniformity (CU), and evaluating the distribution uniformity (DU) of the system. The research design was a randomized complete block design with four replications. The experiment was conducted on 24 laterals and 288 drippers installed in the greenhouse. Each lateral had an equal distance of 36.5m and carried 94 total drippers. Data analysis of variance (ANOVA) and LSD for means were used as statistical tools in MINITAB software version 17. The confidence interval was 95%. The obtained results indicated an average discharge (q) of 3.98 L/h in the drip irrigation system, coefficient uniformity (CU) of 99.96%, and distribution uniformity (DU) of 57.72%. The research concludes that the performance of irrigation systems is excellent for water application. However, the way water is distributed in all systems is poor. In addition, the drip irrigation system may reach an adequate level of performance when it works in a shifty manner.

Keywords: Coefficient uniformity, Distribution uniformity, Drip irrigation, Automated greenhouse, Performance.

Research Paper

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1. INTRODUCTION

Irrigation aims to ensure most of the crop receives adequate water (Bay, 2018). However, the amount and timing of rainfall are not adequate to meet the moisture requirements of crops in many parts of the world (Hamidatu *et al.*, 2021). In this way, the concept of precision agriculture technologies is used to support customized agricultural practices with higher efficiency and a lower impact on the environment (Kittas *et al.*, 2016). Greenhouse production systems are one agricultural practice that decreases crop water requirements by as much as 20% to 40% compared to open-field cultivation (Fernandes et al., 2003).

The drip irrigation system is the most efficient and popular application method used (Ravina *et al.*, 1997; Hassanli *et al.*, 2010). However, Veeranna *et al.*, (2017) indicated that emitter clogging is a severe obstacle to the wide applications of drip irrigation technology. Performance evaluation has been an important part of irrigation design and management since the first man began using water to increase crop production (Bos *et al.*, 1993). Distribution uniformity (DU) or emitter uniformity (EU) is a measure of how evenly the irrigation system spreads water along its wetted length (Bay, 2018). The two most commonly used methods are distribution uniformity (DU) and the Christiansen uniformity coefficient (Einsenhauer *et al.*, 2021). A distribution uniformity goal for drip irrigation systems is designed to have a DU of 95% or better. Drip irrigation systems operating with DUs of between 85% and 95% are acceptable; 75% to 85% should be improved; and below 75% needs to be improved (Zellman, 2016).

Dariman *et al.*, (2021) conducted research in Ghana to evaluate the water application uniformity for a drip irrigation system, considering the water quality and the duration of usage. They reported a 90% uniformity of water application. They concluded that the emitter was still good after a year of installation. Ghazouani *et al*., (2019) determined that the distribution uniformity for two operating pressures on emitters ranged between 127.6 kPa and 131.7 kPa. The results indicated that the flow rates varied from 4.00 L/h to 4.07 L/h, with an average value of 4.02 L/h, and the value of the emission uniformity coefficient was equal to 96.3%. Mhmdy and Dulaimy (2017) found the uniformity coefficient varies from 94.65% to 98.85% for 4 L/h emitter discharge and from 94.6% to 97.17% for 8 L/h emitter discharge. Jamrey and Nigam (2018) reported the average discharge values are 1.67 L/h and 1.79 L/h with average application efficiencies of 83.23 and 85.09 percent, an average CU value of 96.24 percent and 93.63 percent, an average DU value of 88.07 and 89.69 percent, and the average EU value of 90.45 and 89.99 percent.

This study focused on the evaluation of drip irrigation performance and uniformity of emitters inside the greenhouse constructed at the Integrated Polytechnic Regional College (IPRC-HUYE) to evaluate the flow rate discharge of drip emitters along the lateral system, water distribution uniformity, and water application uniformity. Uneven water distribution in drip irrigation systems due to emitter clogging and variation of pressure has become a major problem, limiting the widespread use of drip irrigation systems. Therefore, the water distribution along the lateral lines needs to perform well to meet the water requirement for the plant. To date, there has not yet been adequate information carried out to evaluate irrigation system performance inside a greenhouse in this study area.

2. MATERIALS AND METHODS

The research was carried out in the automated Greenhouse Research Center of Integrated Polytechnic Regional College (IPRC)—Huye Campus, located in the Ngoma sector in the Huye district of Rwanda. Huye District is located at a latitude of 2º 31´1´´ and a longitude of 29º 41´45´´. It is classified as a tropical climate with an average rainfall of 1160 mm. The temperature ranges from 16 to 24 oC, and the wind is generally around 1-3 m/s (Twagiramungu, 2006). Gentle and steep mountains characterize the topography of Huye. It is an area of mountains with altitudes ranging from 1609 to 1890 m above sea level (Habarurema, 1997). The best soils are found in the swamps, where sand and humus are formed from the erosion of the hills. The largest part of the land is under cultivation for food plants such as rice, bananas, beans, maize, cassava, and coffee (Anonymous, 2018). The experiment was designed inside the greenhouse with dimensions of 40m x 63m (Figure 1). The whole greenhouse was divided into six multi-spans: four for production and growing areas, one for vegetable nursery production, and one for technical rooms.

Figure 1: Control room, Vegetable nursery room and growing area in greenhouse

The drip irrigation system was equipped with a centrifugal pump to supply the water from the mixing tank to the point of discharge during the tested period. The system consists of four tanks (one mixing water tank and three storage water tanks) to supply the water mixed with fertilizer to the field. The capacity of each tank is 120 liters. The pressure used during the experiment was adjusted to 100 kPa (1 bar). The main line is a high-density polyethylene pipe with a 50-mm diameter, which is connected directly to 24 laterals of 16 mm. Each lateral has an individual control valve. The lengths of the main line and lateral are 39 m and 36.5 m, respectively. Each lateral has 94 drippers; lateral spacing is located at a distance of 1.6 m apart; and dripper spacing is 0.4 m. Pressure gauges were installed at the control unit to measure operating pressure during the cultivation period. The whole system was tested for two weeks during the cultivation period. During the data collection period, all drippers functioned correctly and there was no leakage along the pipelines. The materials used during the collection of field experimental treatments the Plastic cups of 400 ml were used as the catch can for collecting water from emitters along the lateral. The measuring tapes are used to measure the length or distance between the drippers, manifolds, and lateral spacing. A stopwatch is used to determine the rate of flow of irrigation water that passes through the dripper nozzle. The time to fill the bucket was recorded for each dripper treatment. The electronic balance is a device that measures the weight mass of soil and the weight of soil after drying at 105^0 C. The moisture content and bulk density were determined during the experiment using Eisenhauer et al., (2021). The media soil sample characteristics from different soil layers of 0–20 cm, 20–40 cm, and 40–60 cm are indicated in Table 1. The media soil moisture contents were 25.52%, 23.78%, and 24.85%, with an average of 24.85%, respectively, by the gravimetric method. However, the volumetric moisture contents were 36.06%, 35.31%, and 35.98%, with an average of 35.98%, respectively. The average soil bulk density from the field experiment was 1.45 g/cm3.

Table 1: Media soil properties of experimental treatment

media layers	Bulk density	Gravimetric moisture content	Volumetric moisture content
cm	g/cm^3	%	%
0-20	1.45	25.26	36.57
20-40	1.41	25.52	36.06
40-60	1.49	23.78	35.31
0-60	1.45	24.85	35.98

Experimental Design

Determination of flow rate

In the tested drip irrigation system flow rates, the field experimental data collection was recorded from 24 laterals attached to four manifolds (one manifold cultivated of cucumber, the second cultivated of tomatoes, and the third and fourth were uncultivated areas). Each lateral was selected for 12 drippers for flow rate testing. The total points of drippers' samples were 288 for treatments (Figure 2). Four different positions were selected according to Gultekin *et al.*, (2022), at 1/3 and 2/3 distances from the beginning of the manifold and the last laterals at the end of the manifold. These were the first laterals on the manifold. The flow rates of the drippers at the test points on the laterals were measured volumetrically. Each dripper flow was measured three times; the average flow rate of a dripper was determined at each position. Therefore, the average flow rate of the system was determined by averaging the flow rates of all the systems.

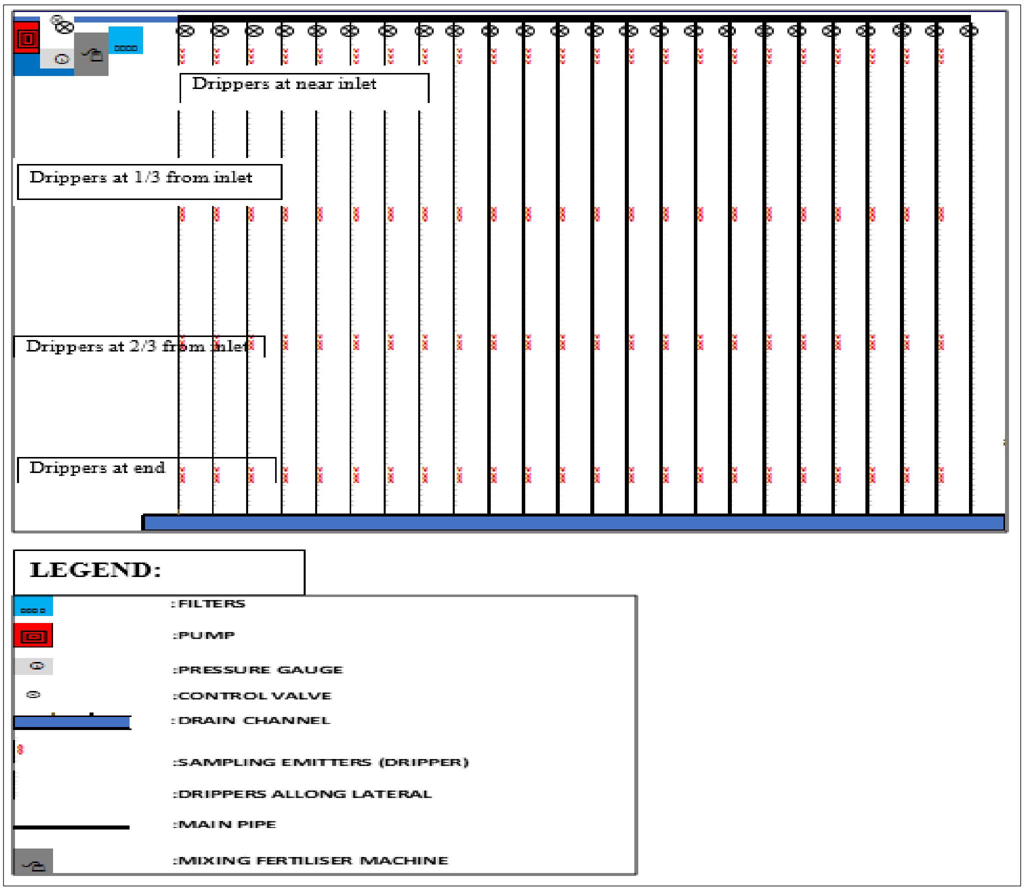

Figure 2: Drip irrigation of an experimental design layout

Determination of Christiansen's Coefficient of Uniformity (CU)

Christiansen's uniformity coefficient, CU, is used to determine the irrigation efficiency by the catch can method (ASAE, 1998). Equation 1 was established by Christiansen's (1942). It is used to determine the uniformity coefficient (CU) of a drip irrigation system in a greenhouse.

$$CU = 100\left(1 - \frac{\sum_{i=1}^{n}|(q_i - \bar{q})|}{\bar{q}xn}\right) \ldots\ldots\ldots\ldots\ldots (1)$$

Where: n = number of observations or number of drippers used in evaluation, qi = dripper flow rate in L/h, $\bar{q}$ = Average dripper flow in L/ hr.

The indicators used to evaluate the Christiansen's uniformity coefficient were indicated in table 2 (ASAE, 1998).

Table 2: Coefficient of Uniformity values and its corresponding classification

Uniformity Coefficient, Cu (%)	Classification
Above 90%	Excellent
90-80%	Very Good
80-70%	Fair
70-60%	Poor
Below 60%	Unacceptable

Source: American Society of Agricultural Engineering (ASAE, 1998)

Determination of Distribution of uniformity (DU)

Distribution uniformity (DU) is the most commonly used measure of evenness of flow among emitters. This DU value is called the Low Quarter Distribution Uniformity (DULQ). It was calculated as the ratio of the average value (sub quarter average flow rate) of the lowest 1/4 of the emitter flow rates considered in the evaluated sub-unit to the average flow rate for the sub-unit (James 1988). Since DU is a ratio, the value of the denominator is always larger than the numerator, as shown in Equation 2 (Eisenhauer *et al*., 2021).

$$DU = 100\frac{\overline{q_{lq}}}{\bar{q}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, in the equation, $\overline{q_{lq}}$ refer to the lower quarter average of emitter flow rate in L/h. $\bar{q}$ Indicates the average emitter flow in L/h.

Merriam and Keller (1978) indicated the indicators used to evaluate distribution uniformity (DU) values, as indicated in Table 3. DU is always between 0 and 1. The larger the value of DU, the better the uniformity.

Table 3: Distribution Uniformity (DU) values and its corresponding classification

DU values	Classification
100%	Impossible
90% above	Excellent
90%-70%	Good
Below 70%	Poor

Source: Merriam and Keller (1978)

Data analysis

The recorded flow rate of each sampled point in the system was arranged in ascending order (ranked) using an Excel spreadsheet. Data obtained from the field was analyzed statistically using MINITAB software version 17 to analyze the source of variation of means (ANOVA) of discharge from the irrigation system at a confidence interval of 95% or a confidence level of 0.05.

3. RESULTS AND DISCUSSIONS

Average Emitter Flow Rate of Irrigation System

Figure 3 indicates the emitter flow rate of 24 laterals varied from near the water source to far from the water source. The study revealed that the average discharge of the irrigation system was tested at 3.39 L/h. The average minimum discharge was 2.96 L/h in lateral 24. The maximum average discharge was 5.27 L/h found in the first lateral of the system, which is located near the water source, and the working pressure operation was 100 kPa (1 bar) during the experiment in all plots. The results indicated that lateral 1 and lateral 3 were statistically significantly different from other laterals, and they had high values of mean discharge of 5.27 L/h and 4.87 L/h, respectively. The study revealed that the lateral 18, lateral 19, lateral 20, lateral 21, lateral 22, lateral 23, and lateral 24 were significantly different with a low discharge of 3.67 L/h, 3.17 L/h, 3.11 L/h, 3.11 L/h, 3.15 L/h, 3.14 L/h, and 2.96 L/h, respectively. Ghazouani *et al*., (2019) reported an average discharge of 4.02 L/h at a working pressure of 127 kpa. This result is close to the same as obtained in this study.

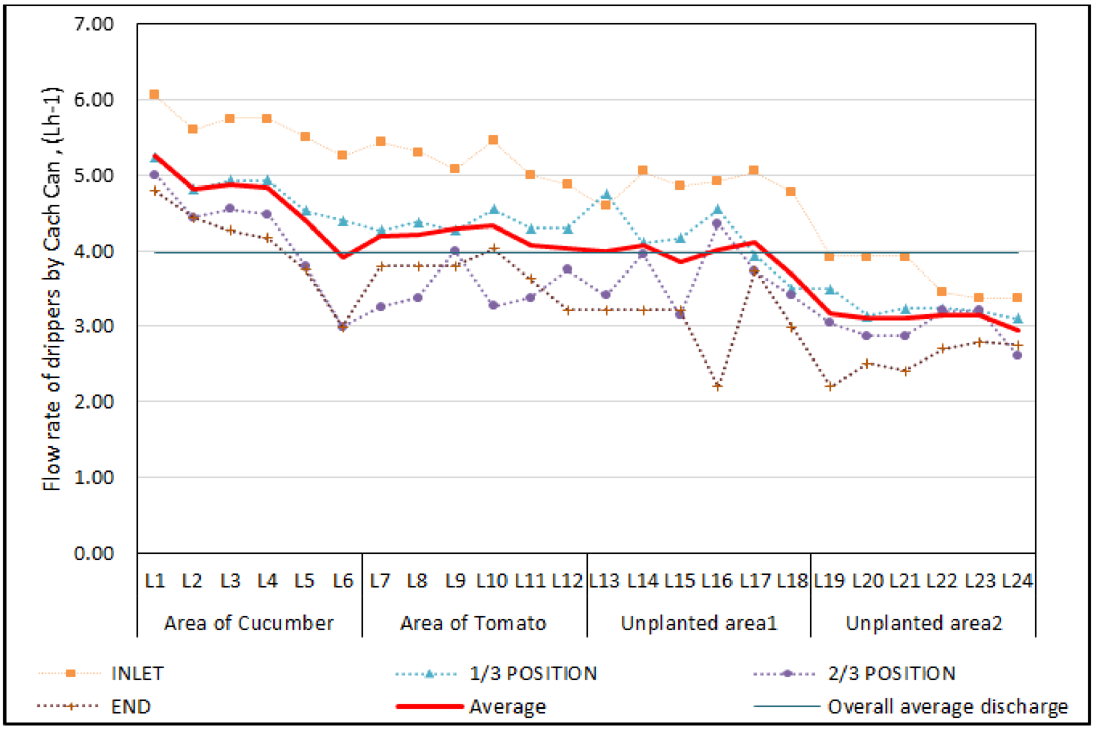

Figure 3: Discharge of drippers of irrigation system measured by catch can method (L/h)

Figure 4 indicates the variation of flow rate by considering the position of the emitter on laterals. Four positions of the emitter on the lateral have been evaluated. The first position was located at the inlet of a lateral or at the head of the system. The second position was 1/3 the distance from the first position, or 12m away. The third position was located at 2/3, or 24 m, from the first position, and the last position was 36 m, far from the first or tail of the system. According to LSD at 95%, those emitter positions do not share the letters. Therefore, the results obtained indicated that all positions had a statistically significant difference in discharge. The range decreased from head toward end or tail of the system. The maximum discharge was 4.84 L/h with letter A at the head, the second average discharge was 4.14 L/h with letter B at 1/3 distance, the third was 3.59 L/h with letter C at 2/3 position, and the minimum was 3.36 L/h located far away from the inlet of the system.

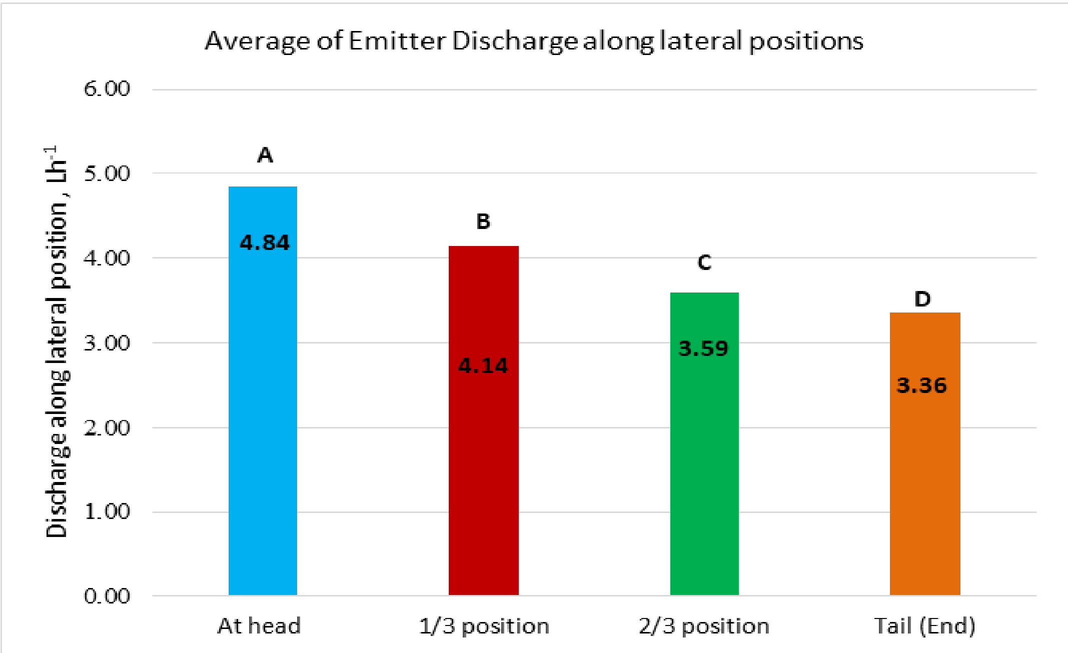

Figure 4: Average of Emitter Discharge along lateral positions

Simply put, the results indicated that when moving away from the source of water, the flow rate has been minimized. When water flows from the head to the end of the system, the flow rate decreases. To meet the amount of water required for the crop, it is better to do the shift operation during irrigation. For example, the crops located near the source can get three times more water than the crops located farther from the source, from the left to the right side of the irrigation system in the greenhouse of IPRC-Huye. On the other hand, the decreasing flow rate from the head toward the tail of the system is due to a variation in pressure. The clogging problem is also more common as the flow rate decreases.

Coefficient Uniformity (CU)

Table 4 indicates the results of coefficient uniformity measured from 24 laterals of the drip irrigation system inside the greenhouse. Among these treated laterals, they had excellent performance tests according to ASAE Standard (1998). The overall CU of the irrigation system was 99.92%. Guidelines to judge whether uniformity is acceptable at a CU of 80% are commonly the lowest acceptable uniformity (Eisenhauer *et al.,* 2021).

Table 4: Results of CU of irrigation system inside the greenhouse

Laterals along manifold of irrigation system	Coefficient Uniformity of each manifolds (Laterals)	System judgment
Lateral 1	99.96%	Excellent
Lateral 2	99.95%	Excellent
Lateral 3	99.98%	Excellent
Lateral 4	99.93%	Excellent
Lateral 5	99.94%	Excellent
Lateral 6	99.95%	Excellent
Lateral 7	99.98%	Excellent
Lateral 8	99.38%	Excellent
Lateral 9	99.96%	Excellent
Lateral 10	99.89%	Excellent
Lateral 11	99.88%	Excellent
Lateral 12	99.88%	Excellent
Lateral 13	99.97%	Excellent
Lateral 14	99.94%	Excellent
Lateral 15	99.94%	Excellent
Lateral 16	99.96%	Excellent
Lateral 17	99.99%	Excellent
Lateral 18	99.97%	Excellent
Lateral 19	99.87%	Excellent
Lateral 20	99.96%	Excellent
Lateral 21	99.99%	Excellent
Lateral 22	99.86%	Excellent
Lateral 23	99.96%	Excellent
Lateral 24	99.91%	Excellent
OVERALL	99.92%	Excellent
SE at $\propto = 0.05$	±0.025%	

Dariman *et al*., (2021) conducted research in Ghana for a drip irrigation system; they reported the results of the uniformity of water application of 90%, which is in the same range as obtained in this study. Ghazouani *et al*., (2019) reported the UC 96.3 at an average discharge of 4.02 L/h, and operating pressures on emitters ranged between 127.6 kPa and 131.7 kPa. This result is the same as that obtained in this study. The result obtained in this study is close to the result obtained by Mhmdy and Dulaimy (2017), where they reported that the uniformity coefficient varies from 94.65% to 98.85% for 4 L/h emitter discharge and from 94.6% to 97.17% for 8 L/h emitter discharge. Jamrey and Nigam (2018) reported a lower average CU value of 96.24 percent and 93.63 percent for an average discharge value of 1.67 L/h and 1.79 L/h. Raphael *et al*., (2018) reported a lower value but were located in the same class of excellent with a CU of 93%.

Distribution Uniformity (DU)

The results indicated that the distribution uniformity (DU) of the overall irrigation system in the study area is 57.72%. The DU value was found to be relatively lower than the CU. This value of DU is classified as poor by ASAE (1998). DU for microirrigation systems should be at least 0.8 (Eisenhauer *et al*., 2021), which is greater than what the study found. Solving the problem of low DU is of the utmost importance because uniformity levels in this range can produce a reduction in crop productivity (Wang *et al*., 2017; Pérez *et al*., 2015; and Contreras *et al*., 2020). According to Contreras *et al*., (2020), DU of

50% not only affected the production of crops but also reduced vegetative growth and modified the harvest index, significantly reducing it from 0.40 to 0.30 g/g, as well as the water use efficiency and the efficiency of the use of nutrients, which were reduced by about 30%. The guidelines of Merriam (1978) and Keller (1978) stated that a DU value below 75% means the system needs to be improved. The probable cause of the diminished DU is either pressure losses or variations, but more likely, it would be the partial plugging of emitters by silt and clay, algae, or chemical precipitates (Zellman, 2016).

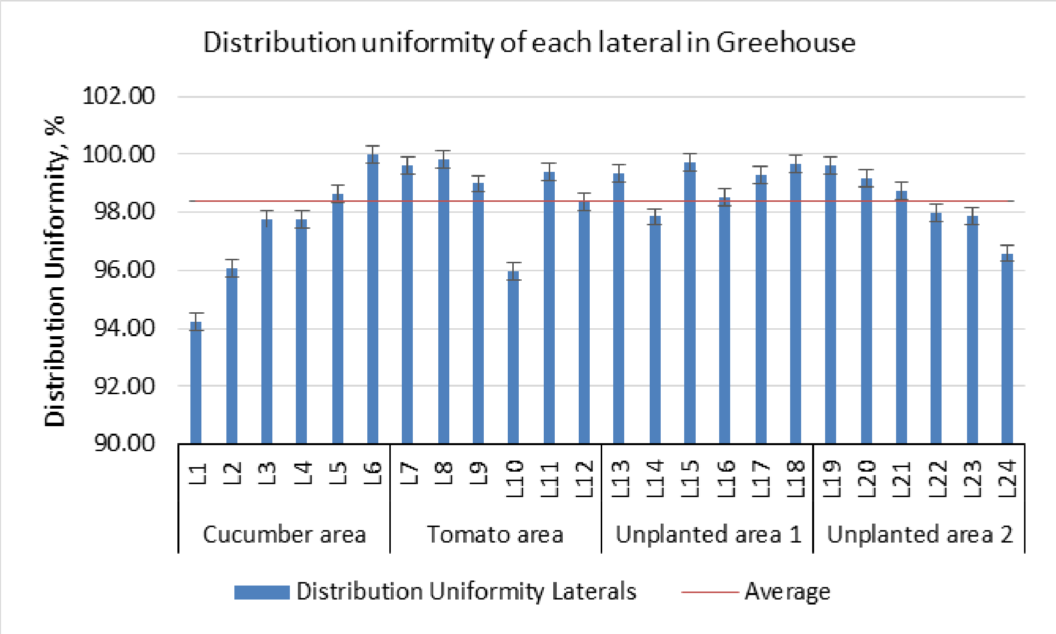

Figure 5: Distribution uniformity of each lateral in Greenhouse

Figure 5 indicates that the distribution uniformity of each lateral varied in range from the minimum of 94.2% to 99.99%. This figure also indicated the situation of water distribution uniformity according to the cultivated area in the green house. It showed the distribution uniformity in the area of the cucumber increased from lateral 1 to lateral 6. In the tomato area, DU has the same distribution except for lateral 10. It was the same as unplanted area 1, except that lateral No. 14 has less DU. In unplanted area number 2, DU falls from lateral 19 to 24. These values indicated that those with less DU needed some particular maintenance. By referencing the previous research, Pranav *et al*., (2017) reported the average emission uniformity coefficient (DU) of 79.9, 90.9, 94.0, 87.3, 90.3, 91.1, 94.5, and 94.7 percent, respectively, at the discharge rate of nine different pressures of 0.3, 0.4, 0.5, 0.6, 0.7, 0.9, 1.0, 1.1, and 1.2 kg/cm2 for 2 L/h. However, Raphael *et al*., (2018) reported a high DU of 86 ± 3%. Average. Jamrey and Nigam (2018) reported DU values of 88.07 and 89.69 percent.

4. CONCLUSION AND RECOMMENDATIONS

The research project for the performance evaluation of the drip irrigation system inside the greenhouse was carried out in the research center of the greenhouse at IPRC-Huye. Three specific objectives were determining the average emitter discharge of the irrigation system, evaluating Christiansen Coefficient Uniformity (CU), and evaluating the distribution uniformity (DU) of the system. For the first objective, the study revealed that the average discharge of the irrigation system was 3.39 L/h with a working operation pressure of 1 bar. For the second objective, the overall CU of the irrigation system was 99.92% classified as excellent, and for the third objective, the distribution uniformity (DU) was 57.72%, which is less than the threshold of 75%. The DU of the system is poor. Low DU affected the production of crops and reduced vegetative growth. To meet the amount of water required for the crop, it is better to do the shift operation during irrigation. Achieving high quality and uniform ripeness of vegetables or crops requires that the irrigation system deliver water uniformly to each crop within an individual irrigation block. The process of testing and evaluating irrigation systems should be material for extension to all growers in the region.

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