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RESEARCH

Performance Evaluation of Micro-Irrigation Systems in Coconut Plantations

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ABSTRACT

Most of the coconut farmers in Sri Lanka are reluctant to adopt micro-irrigation systems, complaining about low performance. A field study was conducted to verify the claim. The performance was evaluated in two subunits at the inlet and distal end of two micro-irrigation systems with drippers and mini sprayers. The subunit at the inlet of the system with drippers showed a fair Emission Uniformity (78%) and all other tested subunits in both systems showed poor Emission Uniformity, falling below the 70% threshold set by the American Society of Agricultural Engineers. In the drip irrigation system, the increase of Emission Uniformity in the subunit at the distal end was approximately 33%. The increase of Emission Uniformity in all subunits of both systems was 4-6% after replacing the emitters with new emitters. The system with drippers showed severe clogging risk and the system with mini sprayers showed minor clogging risk. Despite the water being in the low clogging risk category, the mini sprayer exhibited the highest percent weight reduction (2%) after washing to remove clogging substances. The coefficient of manufacturer's variation of the new drippers was in the marginal category of the classification. The Emitter Flow Variation of all the subunits were unacceptable level (>25%) with the existing drippers and mini sprayers. Only the subunit at the inlet of the drip irrigation system showed acceptable Emitter Flow Variation with new emitters. This study revealed that the low performance in both systems was due to emitter clogging and poor hydraulic design.

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INTRODUCTION

Coconut cultivation extends to more than 90 countries in Asia, the Pacific Islands and South America. Currently, most coconut growers have drawn their attention to intensification due to the growing demand for coconut products from the American, European, Middle East and East Asian markets (Hoe, 2018). Sri Lanka ranks as the fourth largest global coconut producer, with coconut cultivation accounting for approximately 19% of the country's total crop cultivation area (Anonymous, 2018). Due to climate change, coconut production in Sri Lanka now requires irrigation, especially during the dry season. However, the water availability during the dry period and the labour shortage limit the irrigation of coconut plantations in Sri Lanka.

Micro-irrigation is the most efficient irrigation technology successfully practiced in the world and it provides the ability to apply small quantities of water frequently on or below the soil surface under low pressure through a plastic tubing system (Maughan et al., 2017). According to Kumar and Palanisami (2010) drip irrigation systems have a big impact on saving resources, reducing cultivation costs, increasing crop yield, and improving on-farm profitability when there is a shortage of water and labour. However, many coconut farmers in Sri Lanka are reluctant to use Micro-Irrigation Systems (MIS), due to concerns about low performance and shorter lifespan of MIS. Also, the coconut growers observed non-uniform water application as a challenge in MIS. Uniform application of water for each palm is important to avoid over-irrigation and under-irrigation (Ascough and Kiker, 2002). The uniformity of micro-irrigation is affected by water pressure distribution in the pipe network and the hydraulic properties of emitters (Smajstria et al., 1990). Also, Jhorar *et al*. (2018) propose that the lack of uniformity in MIS stems from manufacturing variation of emitters, the emitter blockages, as well as influences from land topography and fluctuations in pressure head. Hence, it is crucial to identify the technical reasons causing the low performance and short lifespan of MIS. This recognition will pave the way for the re-development of MIS to address the challenges posed by the current adverse climatic conditions in coconut plantations.

Micro-irrigation system has the potential to apply the same amount of water to every palm if the system has been designed and maintained well. Additionally, nutrient application via micro irrigation is anticipated to maximize the system's benefits. Therefore, inconsistent water distribution may lead to varying chemical levels across individual palms, consequently causing additional agronomic complications. Hence, the objective of this study is to identify the factors responsible for the suboptimal performance of MIS in coconut plantations in Sri Lanka. The findings will offer coconut growers guidelines to address and mitigate potential failures in MIS implementation.

METHODOLOGY

Site selection

Out of 53 MIS present in coconut plantations within the Marawila and Kurunegala Regional Office Areas (ROAs) of the Coconut Cultivation Board (CCB), Sri Lanka, two systems featuring drip emitters and mini sprayers were selected for the study. The study site selected for drip emitters was in Wanathawilluwa (Latitude: 8°13'15.65"N, Longitude: 79°52'41.20"E) and the study site selected for mini sprayers was in Wilpotha (Latitude: 7°44'26.67"N, Longitude: 79°50'20.92"E). Both irrigation systems were in the Dry Zone of Sri Lanka and the Dry Zone receives a mean annual rainfall of less than 1750 mm with a distinct dry season from May to September (Mapa et al., 2010). Table 1 provides the basic information regarding the two MIS.

Data collection and analysis

Essential components and maintenance routine of MIS

The availability and performance of essential components (Anonymous, 1997) in MIS were examined. Additionally, details regarding the routine maintenance procedures (Pandey et al., 2020; Shehzad and Ali, 2014) were gathered directly from the owners of MIS.

Evaluation of uniformity parameters in MIS

The subunit layout of each micro irrigation system has lateral lines with equal lengths on either side of the sub-main line. Two subunits were chosen from each micro irrigation system at the inlet (subunit 1) and distal end (subunit 2) of the mainline for assessment of the uniformity parameters. Four lateral line pairs, each from either side at the inlet, one-third, two-thirds and far end of the sub-mainline and two palms in each lateral line were selected for flow measurements at one-third and two-thirds distance from the lateral inlet.

Catch cans were placed under each emitter in all the selected palms and volume of water collected into the catch can over a period of 5 minutes was measured using a measuring cylinder for uniformity evaluation of the system with drip emitters. Two catch cans having a diameter of 18 cm were placed 30 cm away; on either side of each mini sprayer in all the selected palms and the volume of water collected over a period of 5 minutes was measured for uniformity evaluation of the system with mini sprayers.

The flow rate based on the volume of water collected into two catch cans was used as a measure of flow rate in the irrigation system with mini sprayers. In both systems, the palm-wise average flow rate (16 emission values) was used for calculations (Sinha et al., 2021). Flow rate measurements were taken with the existing drip and mini sprayers and after replacing the new drip and mini sprayers of the same model.

Emission Uniformity (EU), Absolute Emission Uniformity (AEU) and Emitter Flow Variation (EFV) were calculated as the uniformity parameters in each micro-irrigation system.

Emission Uniformity (EU)

The EU is the key measure to identify how uniformly water is distributed to plants through the emitters. It shows the relationship between minimum emitter discharge and the average emitter discharge of the subunit. Equation (1) suggested by Keller and Karmeli (1974) was used for the calculation of the EU.

$$EU = \frac{Qmin}{Qa} x\ 100 \qquad \text{Equation (1)}$$

Where, $Qmin$ is the average flow rate of the lowest $1/4^{th}$ emitter flow readings and Qa is the average of all tested emitter flow rate readings (Barragan et al., 2006). The classification for EU (ASAE, 1999) mentioned in Table 2 was used for data interpretation.

Table 1: The basic information of micro irrigation systems

Component	System 1	System 2
Emitter type	Drip (Online)	Mini sprayer (Online)
Emitter model	Netafim – PCJ (Dripper)	Super Products – TP 361 (Mini sprayer)
Nominal flow rate	4 LPH at 1-4 bar pressure	80-100 LPH at 1-3 bar pressure
Age of the system	8 years	7 years
System extent	3.24 ha (20 Acres)	3.24 ha (20 Acres)
Number of subunits	13	17
Subunit layout	Central Fish Bone (CFB)	CFB
Emitters per palm	6-7	2
Power source	Diesel pump	Electric pump (3 HP)
Designed pressure	4 bars	3 bars
Water source	Tube well	Tube well
Topography	Flat land	Flat land
Irrigation duration subunit	4 hours	0.5 hours

Table 2: Emission Uniformity classification

Emission Uniformity (%)	Classification
≥ 90	Excellent
80 - 90	Good
70 - 80	Fair
≤ 70	Poor

Table 3: Classification for Emitter Flow Variation

Emitter Flow Variation	Classification
≤ 10	Desirable
10-20	Acceptable
> 25	Unacceptable

Table 4: Potential clogging risk of emitters based on water quality

Clogging factors	Hazard Rating		
	Minor	Moderate	Severe
pH	<7	7-8	8<
Electrical Conductivity, mS/cm	<1	1-4.5	4.5<
Total Iron, mg/l	<0.5	0.5-1.2	1.2<
Manganese, mg/l	<0.7	0.7-1	1<
Calcium, mg/l	<250	250-450	450<
Magnesium, mg/l	<25	25-90	90<
Suspended Solids, mg/l	<200	200-400	400<

Absolute Emission Uniformity (AEU)

AUE is a measure of uniformity in MIS that considers the effects of both under-watering and over-watering on the plant root zone. The Equation (2) introduced by Keller and Karmeli (1974) was used to determine the AEU.

$$AEU = 100\ x \left[\frac{Qmin}{Qa} + \frac{Qa}{Qmax}\right] x \left(\frac{1}{2}\right) \quad \text{........ Equation (2)}$$

where $Qmax$ was taken by averaging the flow rates of 1/8th plants, which receive the highest flow rates in the subunit (Zamaniyan et al., 2014).

Emitter Flow Variation (EFV)

The EFV of subunits was calculated using Equation (3) provided by Keller and Karmeli (1974) and the classification provided by the American Society of Agriculture Engineers (Table 3) was used to determine the acceptability of flow variation (ASAE, 1999).

$$EFV = \left[\frac{Qa - Qmin}{Qa}\right] x\ 100 \quad \text{.................. Equation (3)}$$

where Qa is the average and $Qmin$ is the minimum flow rate of the subunit.

Water quality testing and assessment for potential clogging risk of MIS

Water samples were collected in both MIS and tested for pH, Electrical Conductivity (EC), Calcium (Ca), Magnesium (Mg), Sodium (Na), Iron (Fe) and Manganese (Mn) contents. The pH/ Conductivity Meter (Thermos Scientific, Orion Star A215) was used to test the pH and EC of water samples and the other elements were tested using Atomic Absorption Spectrophotometer (Shimadzu, AA-7000). The potential clogging risk of emitters was assessed using the classifications provided by Capra and Scicolone (1998) and Bucks et al., (1979) (Table 4).

Emitter clogging assessment of MIS

Fifty used drippers and mini sprayers were randomly collected from each MIS and the weights were measured after drying in an oven for 2 hours at 60 °C. The same drippers and mini sprayers were washed thoroughly with distilled water followed by 85 %

phosphoric acid and weights were taken after drying in the same condition. The same types of drippers and mini sprayers (fifty of each type) were purchased from the market and the weights were measured. Equation (4) was used to assess the weight reduction of both types after the removal of clogging substances by washing.

$$Wr\ (\%) = \left(\frac{Wc - Ww}{Wn}\right) x\ 100 \ \ldots\ldots\ldots\ldots \text{ Equation (4)}$$

where, Wr, Wn, Ww and Wc are the weight reduction dripper/ mini sprayer after removal of clogging substances after washing, the average weight of a new dripper/ mini sprayer, the average weight of a used dripper/ mini sprayer after washing with distilled water followed by 85% phosphoric acid and average weight of a used dripper/ mini sprayer, respectively.

Assessment for Manufacturer's Variation of drip emitters

A laboratory set-up was created to test the Manufacturer's Variation of drip emitters. The same model of new drip emitters (4 LPH, Netafim, PCJ) was purchased from the market and flow rates were measured at constant pressure (1 bar). A 0.5 HP water pump was connected to a PVC line (D= 32 mm) and three lateral lines were connected to the PVC line with 1m distance between the laterals. Twenty drippers were connected to each lateral line with 30 cm spacing and the volume of water discharge in 5 minutes was measured in each dripper using a catch can and a stopwatch. The Standard Deviation of all flow rate values (S) was divided by the average flow rate value of all the emitters (QA) to obtain the Manufacturer's Variation of drip emitters as given in Equation (5) (Keller and Karmeli, 1974). Finally, the classification recommended by the American Society of Agricultural Engineers (ASAE, 1999) for the Manufacturer's Coefficient of Variation as mentioned in Table 5 was used to interpret the results.

$$Manufacturer's\ Coefficient\ of\ Variation = \left(\frac{S}{QA}\right) \ \ldots\ldots\ldots\ldots\ldots \text{ Equation (5)}$$

Statistical analysis

When both subunits of the same irrigation system function optimally, the mean flow rates are expected to exhibit similarity. To assess this, a two-sample t-test was conducted to compare palm-wise flow rate means between the two subunits, aiming to identify any statistically significant difference. The sixteen palm-wise mean flow rate values collected from each subunit were used for the test. Additionally, the same statistical method was applied to compare palm-wise flow rate means within the same subunit, both before and after the replacement of emitters, to examine the impact of emitter characteristics on performance. The analysis was conducted using R studio (version 4.2.1) software package

RESULTS AND DISCUSSION

Availability of essential components and routine maintenance

A micro-irrigation system mainly comprises a pressure source, a Head Control Unit (HCU), the water distribution network and emitters. Most of the essential components such as filters, chemical injectors, pressure gauges, flow meters etc. are installed in HCU. Each component in MIS has a specific function for better performance of the system. Usually, filters are selected and installed based on the water quality to reduce the emitter clogging. The pressure gauges are used to monitor the pressure of the system to identify any failure in the pipe network or the filters. Table 6 displays the status of the examined systems in terms of system components.

The practice of routine maintenance is essential to prevent the failures of MIS (Pandey et al., 2020; Shehzad and Ali, 2014). Very few maintenance practices were conducted in both MIS (Table 7). Only the inspection of lines for damages, examination of the field for any precipitation/ clogged emitters, replacement of fully clogged emitters, and lubrication of pump/engine were conducted in both MIS regularly. Filters of a MIS separate the suspended particles from water which clogs the emitters. These suspended particles accumulate in the filter and reduce the filtration efficiency if it is not cleaned timely. A high head loss and low filtration efficiency resulting from an uncleaned filter may cause a reduction in the performance of the MIS. (Chi et al., 2021). According to Fernando *et al.* (2020) the most common problem reported by the farmers for MIS usage in coconut plantations was frequent line breakdown and the regular examination of lines for damages. Therefore, the longevity of these two MIS depends on the regular inspection for damages to pipelines.

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Table 5: Recommended classification for the coefficient of manufacturer's variation by ASAE

Coefficient of Manufacturer's Variation	Classification
0.05	Excellent
0.05-0.07	Average
0.07-0.11	Marginal
0.11-0.15	Poor
>0.15	Unacceptable

Table 6: Availability of essential components in MIS

Component	MIS (Drippers)	MIS (Mini sprayers)
Flow meter	No	No
Pressure gauge/s (inlet)	Yes	Yes
Fertigation	Yes	No
Filters	Yes	No
Pressure gauges (upstream & downstream of filters)	No	No
Pressure release valves/ Safety valves	No	No
Flush valves	Yes	Yes

Table 7: Routine maintenance practices of MIS

Maintenance practice	MIS (Drippers)	MIS (Mini sprayers)
Daily		
Monitor the pressure of the system whether it reaches to prescribed pressure	No	No
Inspect the drip line for damages	Yes	Yes
Check whether the last drip at the corner receives the water	No	No
Inspect for dry patches after irrigation cycle	No	No
Examine the field for any precipitation and the clogged emitters	Yes	Yes
Replacement of fully clogged emitters	Yes	Yes
Flushing the lateral and sub-main pipe lines	No	No
Check inlet and outlet filter pressure	No	No
Backwash secondary filters	N/A	N/A
Flush screen and disc filters	No	No
Every fortnight		
Open the filters and cleaning	Yes	N/A
Acid treatment	No	No
Half-yearly		
Lubricate the pump and motor	Yes	Yes
Check out for system wear and tear	No	No

Uniformity status of MIS with the existing emitters

The EU and AEU of each subunit of both systems with the existing drippers and mini sprayers are shown in Figures 1 and 2, respectively. Subunit 1 showed a fair EU value (78%) and subunit 2 showed a poor EU value (56%) in the system with drippers while both subunits of the system with mini sprayers showed poor EU values (<70%). However, both systems showed lower EU values in the subunit at the distal end compared to the subunit at the inlet. The same trend was observed for AEU in both systems. Even though the distal end subunits of both MISs showed lower EU, only the drip irrigation system showed a statistically significant difference ($P<0.05$) in mean flow rates between the inlet and distal end subunits. Generally, clogging of the emitters, manufacturing variation of the emitters, topography, inadequate working pressure and drastic pressure differences in MISs reduce the uniformity of water distribution (ACAR et al., 2011; Camp et al., 1997; Zamaniyan et al., 2014; Jhorar et al., 2018). There could be one or several reasons mentioned above for the lower EU shown in these systems. However, the topographic variation was minimal in these two systems.

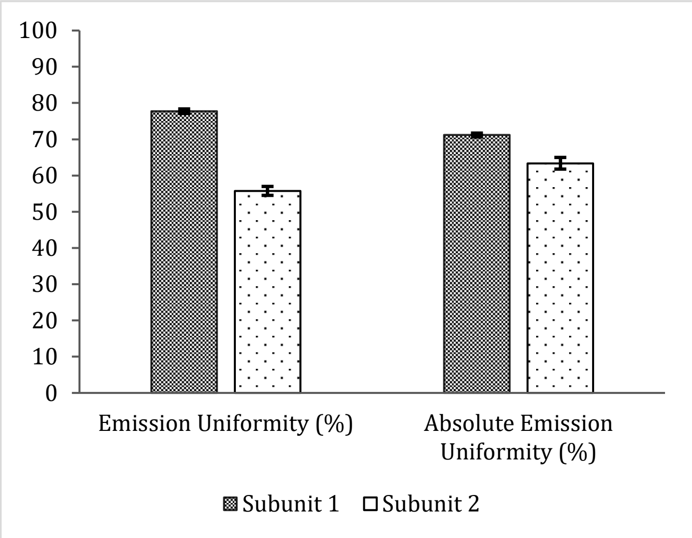

Figure 1: Emission Uniformity and Absolute Emission Uniformity in subunits of system with drippers. Error bars indicate the standard deviation.

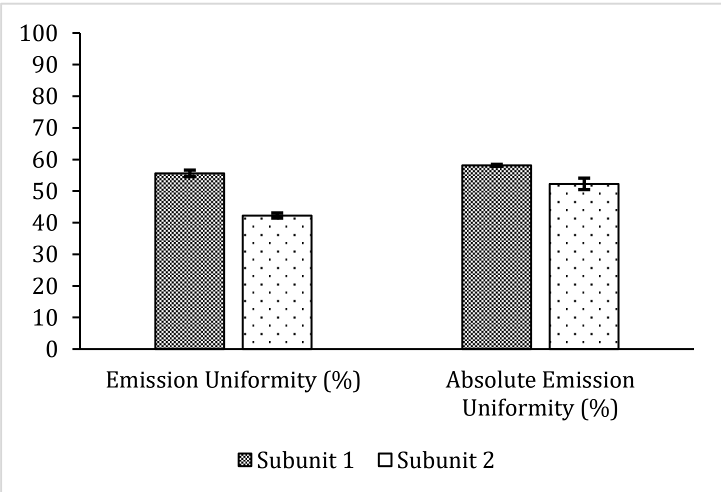

Figure 2: Emission Uniformity and Absolute Emission Uniformity in subunits of system with mini sprayers. Error bars indicate the standard deviation.

Uniformity status of MIS after replacement of the emitters

The EU and AEU values of all the tested subunits of two MIS increased when the existing drippers and mini sprayers were replaced with the new drippers and mini sprayers (Figure 3 and Figure 4) of the same model. However, only the distal end subunit of the drip irrigation system showed a significant increase in the average flow rate after the replacement of the emitters (P<0.05).

In the drip irrigation system, the increase of EU in subunit 1 was about 5% and the increase of EU in subunit 2 was approximately 33%. The increase of EU in both subunits of the system with mini sprayers was nearly 4-6%. The improvement of EU in both irrigation systems depicted the effect of emitter performance for uniformity in MIS. According to Capra and Scicolone (1998), emitters at the lateral ends were more prominent to be clogged with suspended particles due to low water speed. The same reason may be applicable to justify the prominent increase of EU in the subunit at the distal of the system with drippers. Although both systems increased EU with the replacement of the drippers and mini sprayers, only the system with drippers could reach an acceptable EU. The poor uniformity level in the system with mini sprayers could be due to poor hydraulic design which leads to inadequate working pressure or high-pressure difference in the system.

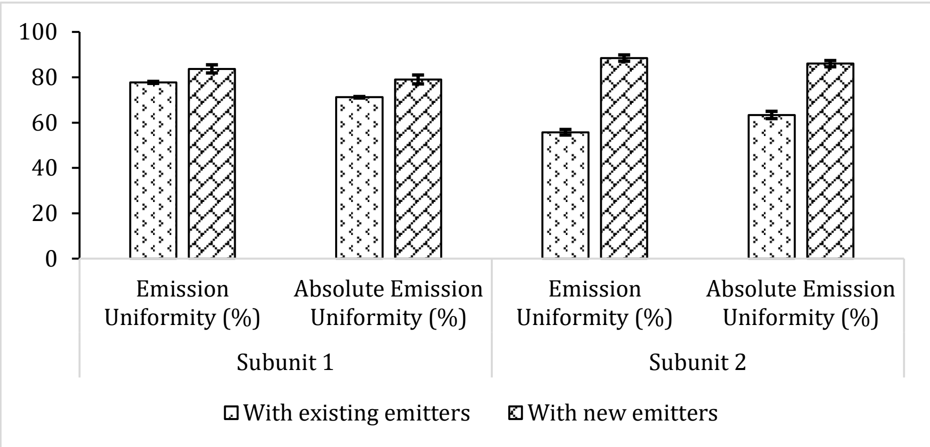

Figure 3: The change of Emission Uniformity and Absolute Emission Uniformity values after replacing the existing emitters with new emitters in subunits of system with the drippers. Error bars indicate the standard deviation.

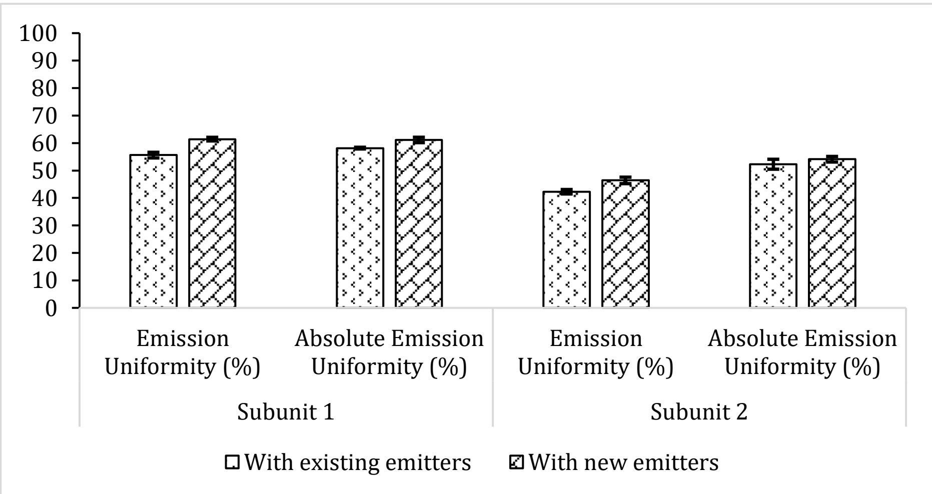

Figure 4: The change of Emission Uniformity and Absolute Emission Uniformity values after replacing the existing emitters with new emitters in subunits of system with the mini sprayers. Error bars indicate the standard deviation.

Potential clogging risk assessment of emitters in MIS

Partial or complete emitter clogging happens due to the deposition of chemical, biological or physical constituents in the water passageway (Copra and Scicolone, 1998). Determination of water quality in the water source before designing MIS is a key requirement to establish the preventive measures for the emitter clogging. Table 8 shows the potential risk of emitter clogging in both MIS based on water quality. The system with drippers showed severe clogging risk for EC level and the system with mini sprayers showed minor clogging risk for all the evaluated parameters.

Assessment properties of used drippers and mini sprayers

Chemical precipitates of micro irrigation systems can be dissolved using acid treatment (Haman, 2022). Chemicals, 35% Hydrochloric acid, 33% Nitric acid, 65% Sulphuric acid and 85% Orthophosphoric acid are used for treatment in MIS (Manda et al., 2019). Ahmad et al., (2009) observed the best performance in the emitters with acid-treated water. Figure 5 shows the weight variation before and after treatment. It is interesting to note that, the percent weight reduction of the mini sprayer due to the removal of clogging substances after washing was high (2.1%) even though the water quality was classified as a low clogging risk category. It may be due to the deposition of suspended solids in water as the system did not consist of a filter, or entrance of soil particles and the algal growth inside the mini sprayer. The percent weight reduction of the dripper due to clogging substances was 0.5%. The average weight of the used drip emitter was less than that of the new dripper, possibly indicating wear and tear of the emitter over time. However, in support of Smajstrla *et al*. (1990), it was observed that emitter clogging and/or wear in both systems have impacted the uniformity of the systems.

Assessment of hydraulic properties of new drippers

The coefficient of manufacturer's variation depicts the amount of variation expected from any particular model of drip emitters. The coefficient of manufacturer's variation was 0.1 in drip emitters and the value was in the marginal category of the classification (Table 5). According to Perea et al., (2013), manufacturer's emitter variation had a big impact on the uniformity because the number of emitters in the drip line was increased. The average flow rate of the emitters at 1 bar pressure was 3.74 LPH even though the irrigation scheduling was planned assuming the nominal flow rate as 4 LPH. The drip model examined was of the Pressure Compensation (PC) type, known for consistently discharging the same amount of water, even in uneven terrain. If the drip emitter operates at 1 bar pressure for the scheduled duration (4 hours), the anticipated water deficit for each palm (with 6 emitters per palm) from the expected volume is approximately 6.5%. If the drip emitter operates at a pressure of 1 bar for the scheduled duration (4 hours), the anticipated water deficit for each palm (with 6 emitters per palm) from the expected volume is approximately 6.5%.

Table 8: Potential clogging risk of emitters in micro irrigation systems based on water quality

Parameter	MIS (Drippers)		MIS (Mini sprayers)	
	Value	Potential Risk	Value	Potential Risk
pH	6.84	Minor	6.54	Minor
EC (mS/cm)	4.34	Severe	0.82	Minor
Ca (mg/L)	254.43	Moderate	25.19	Minor
Mg (mg/L)	78.53	Moderate	16.44	Minor
Fe (mg/L)	ND	Minor	ND	Minor
Mn (mg/L)	ND	Minor	0.629	Minor

*ND - Not Detected

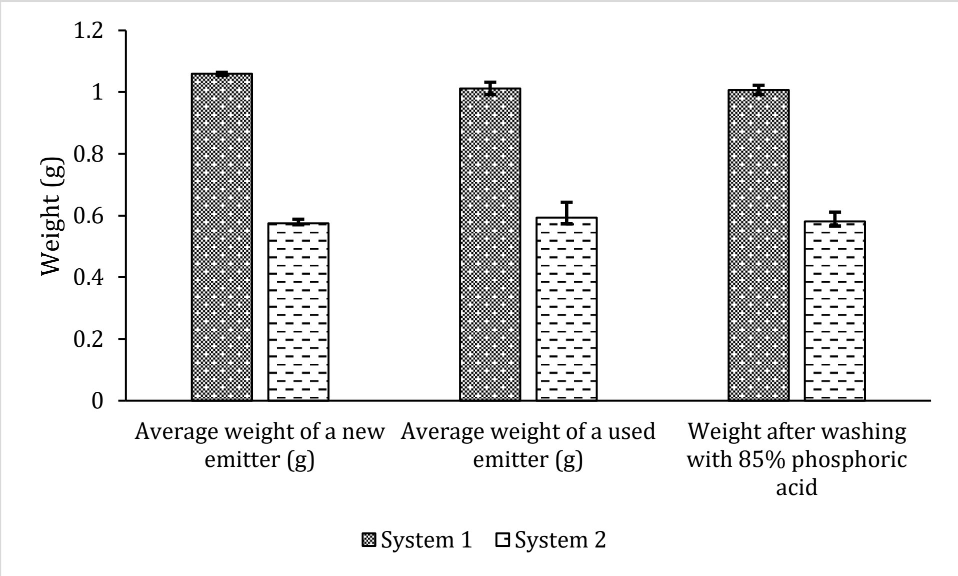

Figure 5: Variation in weights before and after the treatment for drippers and mini sprayers

Table 9: Emitter flow variation in MIS with existing emitters and new emitters

System	Emitter Flow Variation (%)			
	Subunit 1		Subunit 2	
	With existing emitters (Mean±SD)	With new emitters (Mean±SD)	With existing emitters (Mean±SD)	With new emitters (Mean±SD)
1	27.13±0.85	20.58±1.70	52.36±1.15	15.80±0.18
2	55.19±0.91	46.46±1.20	64.41±1.33	61.17±1.09

*SD – Standard Deviation

Emitter flow variation

The emitter flow variation of two subunits of each MIS is shown in Table 9. The emitter flow variation of all the subunits was at unacceptable level (Table 3) with the existing emitters. Only the subunit at the distal end of the drip irrigation system could achieve an acceptable emitter flow variation with new drip emitters. However, all the other subunits of both systems showed unacceptable emitter flow variation even after the replacement of the emitters. The ultimate objective of the proper hydraulic design of a micro-irrigation system is to minimize the emitter flow variation, and it is possible to design the system to maintain emitter flow variation within 10-20% (Perea et al., 2013).

CONCLUSION

The results of the emission uniformity test in the system with drippers showed a good Emission Uniformity (EU) for the subunit at the inlet and a poor EU for the subunit at the distal end while both subunits of the system with mini sprayers showed poor EU values. In the drip irrigation system, the increase of EU after the replacement of the drippers in the subunit at the inlet was about 5% and the increase of EU in the subunit at the distal end was approximately 33%. The increase of EU in both subunits of the system with mini sprayers after the replacement of the mini sprayers was nearly 4-6%. The system with drippers showed severe clogging risk for EC level and the system with mini sprayers showed minor clogging risk for all the evaluated parameters. The percent weight reduction of a mini sprayer due removal of clogging substances after washing with 85% phosphoric acid was the highest (2%) even though the water quality was classified as the low clogging risk category. The percent weight reduction of a dripper due to the removal of clogging substances after washing with 85% phosphoric acid was 0.5%. The emitter flow variation of all the subunits was at unacceptable level with the existing emitters. Only the subunit at the distal end of the drip irrigation system could achieve an acceptable emitter flow variation with new drip emitters. The low performance, emitter clogging, wear of the emitters, poor hydraulic design, unavailability of essential components and lack of maintenance were observed as reasons for failures in both micro-irrigation systems.

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