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System Performance Evaluation for Tea Plants Replacing Sprinkler with Drip Irrigation using Water Uniformities in Dooars, India

Mantu Das, Subhasish Das* and Asis Mazumdar
School of Water Resources Engineering, Jadavpur University, Kolkata – 700032, West Bengal, India
✉ subhasish.das@jadavpuruniversity.in

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Abstract: Tea gardens are facing water scarcity; moreover, their irrigation utilises overhead sprinklers, which lack uniformities and controlled irrigation methods. Evaluating the performance of drip irrigation is an important research area for better water resources management. To address these issues different drip irrigation methods have been experimented with having different combinations of drippers. Two plots are online drip systems while the other two are inline systems operated at the same pressure on water application uniformity while other conditions remain similar. Earlier studies witnessed experimentation of drip irrigation with only the same emitter flow. While in this research, the uniformity coefficient, emission uniformity and performance index are calculated. It is found that due to various dripper discharges and systems the water application significantly changes. Extreme values of discharge variation of the emitters were observed during field operations under the same pressure and length of laterals. From the evaluation of the uniformities and investment cost, the performance of an inline system with a 4 lph dripper at 60 cm with 1-m lateral spacing is found to be the best model for tea irrigation under the specified conditions. Later stage and further research efforts should be aimed at the findings of the efficiencies and yield response of tea under the four drip systems.

Key words: Drip irrigation, uniformity coefficient, emission uniformity, performance, flow rate.

Introduction

In India, the first tea garden was established in Upper Assam in 1837 and commercial tea production began in 1840 (Barua, 2008). Currently, India holds the second-largest tea producer with 13,000 gardens with 2×10^6 people participating in the production. Total production stands at $1{,}208.78\times10^6$ kg covering 5,63,980 ha area throughout India out of which Assam contributes about 48.07% of production with 48.04% area coverage while Dooars contributes 14.71% of production with 12.93% of area coverage as per statistics 2013-14. During November-March the rainfall is low, hence, tea plants suffer from serious moisture stress while in April-October they receive excess water as annual rainfall of about 3500 mm (TTRI, 2012; Tea Board of India), which creates an imbalance in moisture. Most of the tea growers of Dooars tea gardens irrigate by portable sprinkler irrigation system during November-March while others depend on the rainfall. Normally, irrigation begins in November with slightly more rainfall than measured, followed by five more applications three weeks apart (TTRI, 2012).

Sprinkler irrigation in Dooars consists of a booster pumping unit with underground HDPE pipelines as main and portable *HDPE* pipelines as sub-mains and laterals, risers with tripod and rotating sprinklers. Sprinklers are usually spaced 30 m apart at Dooars

*Corresponding Author

List of notations

CU = uniformity coefficient
C_{pi} = total investment cost per ha
C_{vm} = manufacturer's CU
EU = emission uniformity
G_i, G_j and G_k = grade values
IP = Performance index
M = mean
N = emitter counts per plant
N_{ci}, N_{ui} and N_{Cpi} = net grade values
n = sample counts
Pi = i^{th} plot
q = dripper flow rate
R_i, R_j, R_k = ranges
$|X|$ = mean deviation

and exhibit low application uniformity, as expressed by Christiansen's uniformity coefficient (Christiansen, 1942) of CU = 31-55% (Knox, 1993) and CU = 58-72% (Cobban, 1995). In essence, the rotary head sprinkler is a widely used irrigation system for tea plants consisting of a head with one or two nozzles, turned slowly by the action of the water flowing through it. It irrigates a roughly circular patch of land around the sprinkler that requires a wide range of pressures and discharges to its rotating head. This study mainly assesses the uniformities of the designed and energy-efficient drip system and subsequently field implemented model.

Freeing the irrigation process from technical and field-level constraints that complicate furrow and sprinkler systems, introducing a drip system has the potential for micro-level water management and irrigating tea gardens. This consists of emitters or drippers in the form of a localised system mounted (in-line) or embedded (on-line) on lateral linear low-density polyethylene (LLDPE). The major advantages of drip – optimise water resources, a manageable and user-friendly system for users, and optimise power cost. The intelligent design practice of irrigation systems depends on the ease of operation and maintenance (O&M). In Tanzania, irrigation uniformities CU ranges from 85.9% to 96.7% (Moller and Weatherhead, 2007). Evaluation of drip irrigating systems accounts for one most frequently used parameters, namely, emission uniformity (EU) (Barragan and Wu, 2006). Moreover, the parameter is also recommended by the ASAE Standards in the course of EU of drip systems (ASAE, 1982).

Therefore, it is understood that not much work has been done on improving the drip system in India addressing its usefulness in tea plantations in terms of better uniformities and performance. Simultaneously, the latest research in drip systems experimented in Tanzania claimed a CU maximum of 96.7% in tea while in India such research has not been carried out extensively. Sprinkler irrigations are largely used in tea plantations which leads to high energy requirements and loss of water. With regard to the climate conditions in India, drip irrigation for tea plantation is believed to increase yield, which is more than sprinkler irrigation. This is still a notion that needs to be proved experimentally, while as per studies by Kigalu et al. (2008) in Tanzania, the quoted yield exceeds 50% of water savings and 85% of labour saving.

The main objective of the present work is to experiment with different drip systems in tea which is most commonly used in other crops in India under similar conditions in Dooars to establish the most appropriate drip model which provides the highest uniformities, cost-effectiveness and suitability for tea plantation. The four different drip systems used in the study are evaluated based on their field-level experience in terms of O&M, sustainability, cost involvement and level of execution in the field.

Materials and Method

Site Description

To investigate the potential and feasible alternatives for more proficient water use in commercial tea within the different drip irrigation systems, four drip systems were established in 2018 at Chuapara tea estate (CTE) in Dooars (Section-16, Upper Division) at N26°44′445″ and E 89°27′004″ with 166 m MSL (Figure 1). The total area under tea is 666.72 ha, of which Section–16 is 65 ha where the present models have been installed. Presently, the gardeners irrigate the entire estate by

Figure 1: Site selected at CTE to implement drip systems.

overhead impact sprinklers with portable *HDPE* pipes using the shifting method with ten sprinklers running at a time for 4 hours spaced 30 m apart ensuring at least 50 mm of precipitation described in Toklai Tea Research Institute (TTRI, 2012). The soil type is acidic, organic, with medium nitrogen content, low average potash, phosphate (P_2O_3, ppm =186), sulphur (S, ppm = 30) as per the 2018 soil analysis report by Tea Research Association (TRA), Nagrakata.

Data on temperature, humidity, radiation, precipitation, tank evaporation and wind speed are recorded daily at the station in the area supported by the TRA. The climate in Dooars is detailed by TRA where the average annual rainfall is 3900 mm. Total precipitation is high, however, the distribution of precipitation is really important for a high and sustainable yield of tea throughout the season. In Dooars, the distribution of precipitation is not uniform and excess precipitation occurred in the months of June-September, also causing drainage problems. During the months of November to March, the average monthly precipitation is less than the loss of evapotranspiration and causes a deficit of soil moisture which negatively affects the tea plants. During 2016-2020, from November to March (five months) it received only ~2% of its annual precipitation whereas from June-September (four months) it received almost 79% of its annual precipitation. The maximum and minimum temperatures were 31.8°C and 10.5°C in April and January, respectively. In general, the climate is hot and humid. The drier months of March and April are less humid with a relative humidity of 55-65% (DSR, 2021). Tea plants suffer severely if the dry period persists for a long time and production is impaired despite sufficient rains during monsoons. Therefore, adequate rainfall during the dry season is essential for high yield. Therefore, irrigation was highly necessary for profitable and successful tea cultivation during this period (Knox, 1993).

Model Development

The study is focussed on selecting the best drip system that can be used for tea cultivation. Therefore, four drip models were experimented at CTE with identical areas for the first time and the specifications of the systems are indicated in Table 1.

The study aims to evaluate the performance of the above models based on the CU, EU and total investment cost of the drip irrigation systems in tea crops.

The four drip irrigation models were installed and tested during March 2018 comprising several units at each section (Figure 2), LLDPE laterals and emitters (Figure 3). The system commissioned in the field consists of four sections having different combinations of drippers and labelled *P1-P4*. *P1-P2* plots have online drip systems while *P3-P4* are inline systems.

Table 1: Types and specifications of drip models

Model	*Plot (Pi)*	*Type*	*Emitter Specifications*		
			Flow (*lph*)	*Count per plant*	*Consecutive spacing* (*m*)
1	P1	online	8	2	0.75
2	P2	online	8	1	0.75
3	P3	inline	4	1	0.60
4	P4	inline	2	1	0.60

These four drip systems have been used to apply irrigation water and nutrients to different tea irrigation experiments in an attempt to bring the new drip patterns into line with water irrigation. traditional aerial spraying, which presents various opportunities and challenges. Uniformities and performance index were evaluated for all the on-line and in-line drip systems (Figure 2), the results of which were compared within the four drip models viz. *P1* contains two numbers of 8 litres per hour (lph) each emitter per plant, *P2* - one 8 lph per plant, *P3* - 4 lph in-line dripper spaced at 60 cm for each row and *P4* - 2 lph in-line dripper spaced at 60 cm for each row.

LLDPE laterals (outer diameter 16 mm) are installed on-surface with a spacing of 0.75 m serving each row of tea bushes for all four plots. Drippers with a design discharge of 8 lph are spaced 1.00 m apart for both online systems *P1* and *P2*. The four plots are operated and experimented with during March 2018 as per the designed flow and pressure duly adjusted by using a flowmeter at head controls and at the manifolds to evaluate the performance of the different systems (Das et al., 2019). Venturi (3/4″) is used for fertigation purposes for the application of liquid urea.

Measurements and Observations

Homogeneity tests were carried out to measure the distribution characteristics of the drip system in each experimental plot. While experimenting the discharge, pressure and soil moisture were recorded at the beginning and end of the experiments at *P1-P4*. Using mobile pressure gauge, pressures of the laterals were measured. At the same time using cans the discharge of the emitting nozzles was recorded. In each block, six laterals were selected – the first (L_1), fourth (L_4), seventh (L_7), tenth (L_{10}), fourteenth (L_{14}) and eighteenth (L_{18}) from the manifold while each lateral is 30 m in length.

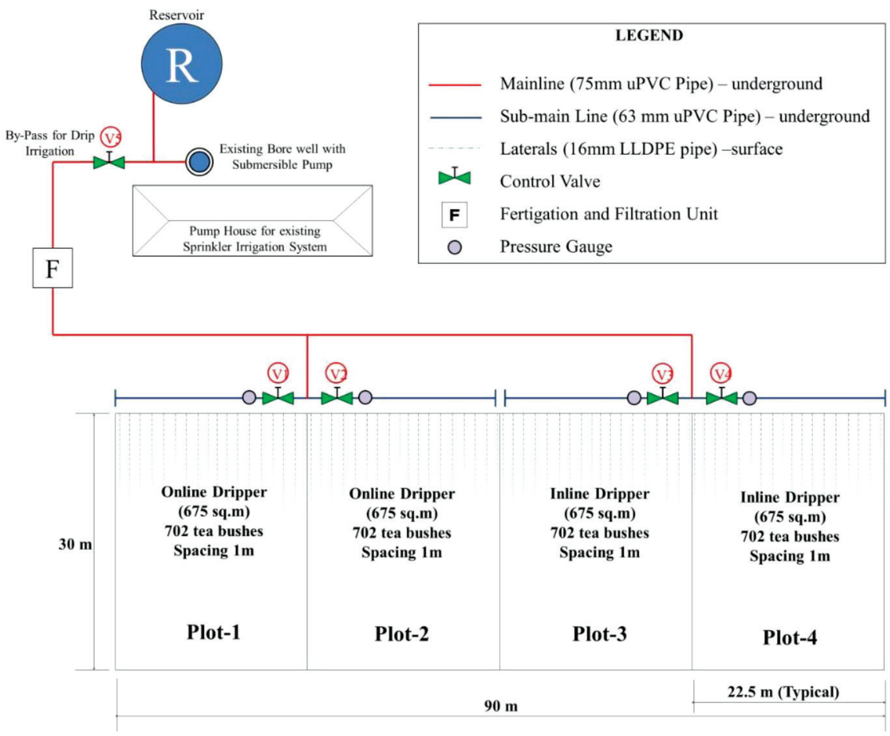

Figure 2: Model design and operation details of the plots.

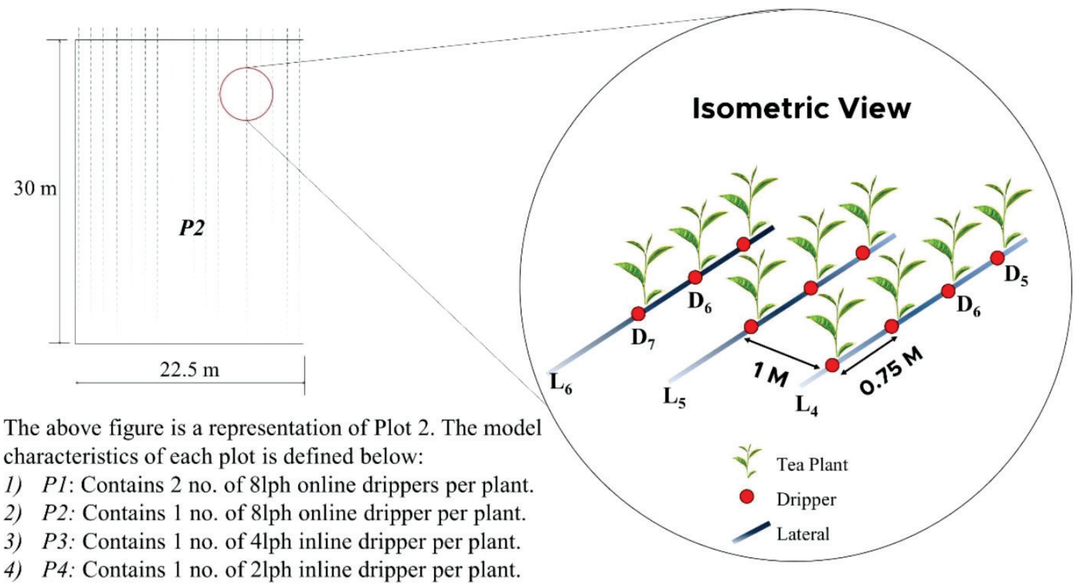

Figure 3: Laterals and drippers within the plots at CTE. Not to scale.

Two emitter positions at the beginning D_1 and the end D_{30} were sampled. As per the field conditions and some experimenting restrictions, 12 samples per plot have been identified for the flow collection.Therefore, a total number of 12 emitting points were considered as samples per block. From each emitting position, the volume of water discharged was fetched in each can for 60 seconds (Figure 4). The volumes (ml) of water were determined with the common measuring beaker. The application depth (mmh1) for each was evaluated by multiplying the volume measured by 0.06 and dividing by the area of the tea plantation irrigated by each dripper, i.e. 0.75 m^2 for the four blocks since the distance between the plants is 0.75 m and the lateral distance is 1.00 m.

Figure 4: Image showing water discharged from emitting position collected in a can.

As shown in Eq. (1), the Christiansen *CU* was calculated to quantify the uniformity of the dripper discharge rate in each experimental block.

$$CU = \left[1 - \frac{\sum|X|}{nM}\right] \times 100(1) \tag{1}$$

where $\sum|x|$ equals to the summation of the deviations from the mean, n =12 and M are sample counts and mean, respectively.

Since the development of micro-irrigation, the assessment of the *EU* has mostly been used as one of the design criteria for drip irrigating systems (Barrangan et al., 2005). It expresses the emitter discharge variation of the irrigating system which is mainly affected due to hydraulic variations, and variations due to manufacturing and dripper groups. In sprinkler irrigation, it is defined as the uniformity of distribution (DU) because it wets the whole patch to show the variation in the ratio between the minimum value and the average value. But as in drip, the water is not wetting the field completely so the EU as shown in Eq. (2), is expressed as the ratio of the minimum dripper flow rate to the mean dripper flow rate multiplied by a factor of the manufacturer's coefficient (Keller and Karmeli, 1974):

$$EU = \left[1 - 1.27\frac{C_{vm}}{\sqrt{N}}\right]\frac{q_{\min}}{q} \tag{2}$$

where C_{vm} implies the manufacturer's CU (dimensionless), N is emitter counts per plant, q_{min} and $\overline{q}$ is the minimum and average dripper flow rate in l ph. Field evaluation of the *EU* will be useful for improvement in the operational and management of the existing drip system. The data for the field evaluation of the uniformity test has been taken from the emitter discharge of four emitter positions at L_1, L_{10}, L_{14} and L_{18}. The sixteen data collection locations of each block include the extremes and uniformly spaced locations throughout the four blocks *P1-P4* of laterals. The discharge of the emitter was measured by selecting the first point, $(1/3)^{rd}$, $(2/3)^{rd}$ point and the last emitter on the corresponding laterals in each block. As there is more than one emitter per plant in *P1*, the data was collected for all emitters and the average value from two adjacent emitters at each location was considered.

The present work compares the four models with the parameters *CU*, *EU* and total investment cost per ha (in ₹ lakh), C_{pi} to determine the Performance Index (IP_i) out of 100 for each system as shown in Eq. (3). The purpose of formulating IP_i is to find the best system suited. Weightage indices W_c, W_u, and W_{cp} are given for performance factors *CU*, *EU* and C_{pi}. The same weightage i.e. 33.33% has been given to each performance factor as these three are equally important to decide the most appropriate model to bring three factors to the common platform and a final score can be derived to fulfil the objective.

The IP_i is given by Eq. (3).

$$IP_i = \sum(N_{ci} + N_{ui} + N_{cpi}) \tag{3}$$

where N_{ci}, N_{ui} and N_{Cpi} are the net grade values for *CU*, *EU* and investment cost indicated in equations (4), (5) and (6), respectively.

$$N_{ci} = G_i \times \left(\frac{W_c}{5}\right) \tag{4}$$

$$N_{ui} = G_j \times \left(\frac{W_c}{5}\right) \tag{5}$$

$$N_{cpi} = G_k \times \left(\frac{W_{cp}}{5}\right) \tag{6}$$

where G_i, G_j and G_k are grade values for *CU*, *EU* and C_{pi}, respectively.

Results and Discussion

In the four different designs and experiments of drip irrigation systems in tea representing four different blocks, the *CU* and *EU* are evaluated as presented in Figure 5. It is observed that the *CU* values ranged from 96.05% in plot *P4* to 98.80% in *P3*. The *CU* of all the blocks exceeded 96% (Letey et al., 1990) which can be academically possible and calculated by Moller and Weatherhead (2007) for Tanzania showed

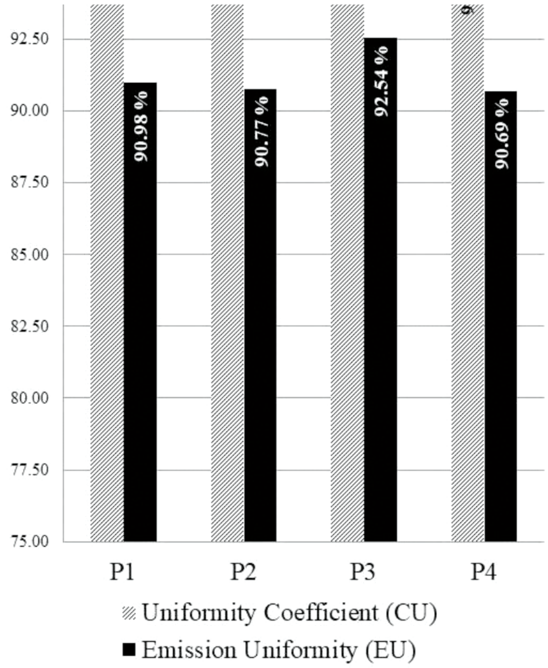

Figure 5: Uniformities of the four models.

CU exceeding 95% where the spacing was 1.2 m in a few cases and others 2.4 m between laterals. In the present study, the lateral spacing is kept the same i.e. 1.00 m for all the blocks and both on-line and in-line drip systems were experimented within the same field conditions to calculate the uniformities. From Figure 5, it is understood the value of *CU* is highest in *P3* which indicates the best suitable design among the other possibilities. At the same time, the *CU* of *P2* shows slightly less value. Extensive studies on sprinkler systems where *CU* between 31-55% and *CU* ranges within 58-72% were reported mentioning poor design, one of the main causes of low uniformity is due to high winds which are absent in drip.

Calculated *EU* in the 4 blocks ranged from 90.68% in block *P4* to 92.53% in block *P3* indicated in Figure 4. *EU* in *P1-P2* and *P4* are contributing almost the same while the *P3* shows the highest value among all four. *EU* has exceeded 90% which is quite encouraging and nearly matching to the statistical approach by Barragan and Wu (2006) explaining the combined effect of hydraulic variation and emitter manufacturer's variation for an emitter flow ratio. The pressure at the manifold for the four blocks is adjusted to 1.00 kg·cm^{-2} and the value of C_{vm} (Singh et al., 2006) are shown in Table 2 while calculating the uniformities. In most cases, the designers are mostly set arbitrarily where the high uniformity criteria can be viewed while designing a drip system.

Table 2: Manufacturer's coefficient of uniformity (C_{vm})

Plot	$\sum\|X\|$	$\frac{q_{min}}{\bar{q}}$	*Manufacturer's CU* (C_{vm})	*CU (%)*	*EU (%)*
P1	7.64	0.953	0.05	97.38	90.98
P2	8.23	0.969	0.05	98.38	90.77
P3	4.18	0.975	0.04	98.81	92.54
P4	4.11	0.919	0.01	96.05	90.69

Due to operational drawbacks and pressure adjustment at manifolds, it has been observed that in a few of the emitters flow rates increased by 2.388 lph block *P1* and in *P4* by 1.362 lph as the same pump has been operated in all four drip systems. Several sample readings were undertaken while experimenting and the adverse data were neglected considering the operational drawbacks. At the same time, some technical problems with the pumping system resulted in a decrease in the pressure and subsequently an increase in flow rates which caused the deviations.

It is understood that each plot setting was operated as per the application rate of the tea and irrigation water volumes. Thus, the flow rate in *P1*= 8 times the discharge rate for *P4* so the operating time has been considered inversely while irrigation scheduling and so irrigation efficiency need not be affected. However, some of the indirect effects in the operation have been observed i.e., increase in flow rates of the emitters, under and over-irrigation sometimes.

The investment costs for the four models of drip systems have been estimated provided by the manufacturers in an area of 675 m^2 for each plot while the pumping unit, underground mainline, filtration and fertigation units and operation cost remain the same for all the models and hence their costs are not considered while estimations. Material Costs of PVC sub-main, laterals, drippers, valves and fittings have been considered. In addition to the material other costs including the cost of installation i.e. labour cost, repair and maintenance (O&M) cost after observing for 1 year, energy costs are considered and the total investment cost per ha C_{pi} and the cost estimations for the four systems are shown in Table 3.

The Performance Index, IP_i, assesses the complete performance of the model, it is the combined score from the weightage of *CU*, *EU* and C_{pi}. To determine IP_i suitable grade value G_i ranging from 1 to 5 has been allotted as per Table 4. Score has been given in respect of CU, EU and the investment cost of the plots as per the ranges. *CU* in the range of (95-96) % scores

Table 3: Estimation of investment cost and C_{pi}

Costs (₹ lakh)	*P1*	*P2*	*P3*	*P4*
Material	10394.15	8246.03	8108.37	8246.03
Labour	4000.00	2000.00	1000.00	1000.00
O&M	420.00	210.00	0.00	0.00
Energy	4.57	2.28	1.46	0.733
Total	14818.73	10458.32	9109.80	9246.77
per ha	219536.79	154938.15	134960.05	136989.19
C_{pi}	2.19	1.54	1.34	1.36

minimum while (99-100) % is the maximum. Similarly, the *EU is* having a minimum value of 90.5% getting a score of 1 and a maximum of 93% will get 5 while in the case of C_{pi} the maximum point is for the lowest C_{pi} value i.e. 1.00 and the minimum for the highest 2.25 as shown in Table 4.

Using Eqs. (4-6) of net grade values, IP_i has been determined for all the drip models. It is observed that huge variations occurred ranging from 33.35 to 93.38 of 100 in the performance indices in the drip systems. The model *P1*, consisting of 2 drippers per plant online system, scores the least i.e. *IP1* = 33.35 while the inline system *P3* scores the most i.e. *IP3* = 93.38 as shown in Table 6.

Table 4: The ranges of performance factors

CU					
Grade Value (G_i)	1	2	3	4	5
Range (R_i)	(95-96)%	(96-97)%	(97-98)%	(98-99)%	(99-100)%
EU					
Grade Value (G_j)	1	2	3	4	5
Range (R_j)	(90.5-91)%	(91-91.5)%	(91.5-92)%	(92-92.5)%	(92.5-93)%
C_{pi}					
Grade Value (G_k)	1	2	3	4	5
Range (R_k)	(2.00-2.25)	(1.75-2.00)	(1.50-1.75)	(1.25-1.50)	(1.00-1.25)

Table 5: Determination of performance indices for four plots

Drip systems	N_{ci}	N_{ui}	N_{Cpi}	IP_i
P1	20.01	6.67	6.67	33.35
P2	26.68	6.67	20.01	53.36
P3	26.68	33.35	33.35	93.38
P4	13.34	6.67	26.68	46.69

Conclusions

In India where tea irrigation is concerned, it means the traditional overhead sprinklers so introducing drip irrigation in its place creates huge challenges and opportunities. The need for current research is to find the most appropriate design for a tea system that reflects not only the highest uniformities but also the investment and O&M costs. In this study, significant results were observed for the irrigation uniformities calculated separately on four different drip systems while all field conditions remained the same. System *P3* receiving 4 lph at 60 cm spacing represents the most efficient system under conditions 98.80% *CU* and 92.53% *EU*. The performance index of *P3* shows a considerably high value than the remaining three. It was identified that the 4 lph inline drip system with 60 cm spacing experienced the most efficient system.

The results are encouraging and exceeded those quoted for the sprinkler irrigation system by Cobban (1995) and Knox (1993). The major difference is the optimal water supply during the water stress period and nutrients directly to the root zone which is difficult for farmers to perform in sprinkler operations. Second, the sprinkler O&M is troublesome and the variable costs are high due to the shifting of sprinklers at each setting.

In tea plantations, approaches towards introducing drip irrigation for the first time at Dooars, India for experiment purposes and also conversion from the sprinkler to drip irrigation will be regarded as promising initiatives. Evaluated uniformities of drip indicate that the system is much better as compared to overhead sprinklers while the economy should be driven in terms of yield, investment, labour and O&M costs to reflect the overall performance of tested drip models. Therefore, tea industries can make decisions based on water-saving, yield, performance, labour and O&M costs.

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