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Evaluation and testing of machine installed subsurface drip laterals

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Abstract
The placement depths subsurface drip laterals installed by developed machine are uniform as compared to manual installation, yet it may vary. To assess on the uniformity of installation, the placement depth with respect to the soil surface has been accessed and analysed for recently developed tractor operated subsurface drip lateral laying machine. A field experiment was laid at the ICAR-Central Institute of Agricultural Engineering, Bhopal, India. Two types of drip laterals, pipe and drip tape, both of 16 mm diameter, were installed while each of them were placed at two depths of 15 and 20 cm by using the sub-surface drip lateral laying machine. Each lateral and placement depths were thus considered as treatments which were replicated three times. Each lateral was considered as one treatment. A week after laying of experiment, the soil around the lateral pipe has carefully been dug without disturbing the lateral pipe and the depth from the surface was recorded by vertically placing a measuring scale. The observations so obtained were analysed using Christiansen's Coefficient of Uniformity (CCU) and other similar parameters like Wilcox-Swailes Coefficient of Uniformity (WSCU), Statistical Coefficient of Uniformity (SCU) and Low Quarter Distribution Uniformity (SDU_{lq}). In the study conducted, a widely used Christiansen's coefficient of uniformity has been computed to be 0.95 and 0.87 for the drip pipes placed at 15 and 20 cm depth respectively. The same coefficients have been worked out at 0.93 and 0.92 respectively for 15 and 20 cm depths for a drip tape.

Keywords: Subsurface drip irrigation, drip lateral, placement depth, distribution uniformity, mechanized lateral laying

1. Introduction

Water is the prime and most precious natural resource as well as basic needs of life. Agriculture in future has to produce ever increasing quantities of food and fiber with decreasing water availability for irrigation. Availability of fresh irrigation water is getting inadequate. Therefore, a sustainable management option and judicious use of water is present day challenge before the country. The share of water for agriculture may likely to reduce from present level of 84 to 69 per cent by 2025 with increasing demand from other sectors but on the other hand, demand of water for agricultural purposes would increase to produce more food and fiber to feed the increasing population (Sivanappan, 2016) [1]. Micro-irrigation had fast spread during the 90s when its coverage touched 0.3 Mha, while present coverage in India is estimated at about 3.4 Mha (MIDH, 2017) [2]. Both the surface and sub-surface drip irrigation systems are getting popular in areas of acute water scarcity and places where commercial cultivation of cash or horticultural crops is in vogue (IASRI, 2018) [3]. Per capita land and water resources are decreasing at a fast rate. Per capita land resource has decreased from 0.34 ha in 1961 to 0.12 ha in 2015 (World Bank, 2018) [4]. On the other hand, per capita water availability assessed at more than 5300 m^3 in 1951 had decreased to 1588 m^3 in 2010, and is likely to be less than 1500 m^3 by the year 2025 (Gautam, 2016) [5]. The challenge of present day agriculture is to make it profitable, and can only be addressed by reducing the cost of cultivation through enhanced input use efficiency and by higher returns to the farmers through quality production (Saxena *et al*., 2018) [6]. However, the adoption of drip irrigation has remained low in spite of several proven benefits mainly due to high initial cost, improper system design and faulty maintenance (Rao *et al*., 2018; Waghaye *et al*., 2018) [7, 8].

It has been assessed that with engineering interventions like mechanization and use of water saving technologies like micro-irrigation an increase of 15 per cent in productivity and a reduction of 20 per cent in cost of cultivation can be achieved which needs extension over wide range of crops (Saxena and Gupta, 2004; Saxena and Rao, 2018) [9, 10]. Keeping these issues in view, government of India has taken a conscious decision to promote drip irrigation through National Horticulture Mission and as a result, India is now in the top three nations in terms of area coverage under drip irrigation. Limited studies conducted in India have indicated a great potential of subsurface drip irrigation (SDI) in horticultural and vegetable crops for enhanced crop yield and water saving (Singh *et al*., 2008; Patel and Rajput, 2009; Saxena and Rao, 2018) [11, 12, 10]. An important aspect of planning and management of the SDI system is uniformly laying the lateral at crop specific desired depth as per soil moisture movement pattern under it. The SDI is rather suitable for other mechanized operations such as weeding, intercultural operations as well as harvesting. Presently, there is no indigenous commercially available mechanized system for easing out the cumbersome process of laying the laterals for sub-surface drip irrigation systems. Machine laid lateral pipes could be placed at more uniform depth as well as can save time and avoid manual labour. Although, many studies have been conducted on surface or sub-surface drip irrigation in different soils for their evaluation of hydraulics, wetting, spatial and temporal distribution of water within the system (Saxena and Gupta, 2006 a; Pandey et al., 2010; Saxena et al., 2013; Saxena et al., 2015; Kishore et al., 2016) [13, 14, 15, 16, 17]. Soil water distribution patterns for different types of soils and emitter discharge rates can be taken as a guide for efficient design, operation and management of irrigation system (Zur, 1996; Saxena and Gupta, 2006 b; Bajpai and Saxena, 2017; Saxena et al., 2017) [18, 19, 20, 21]. Yet very meager information is available to evaluate a SDI system on the basis of placement of laterals. Like that of irrigation uniformity, which is an important indicator for such evaluation, the machine laid SDI system could be assessed similarly through placement depth at different places within the field. Therefore, an SDI system was installed by using a subsurface drip lateral laying machine (SSDLLM) that was designed and developed by the same authors. The laid out SDI system was tested through evaluation of machine's ability to place the sub-surface laterals at the desired depth suiting to the various horticultural crops.

2. Material and methods

The experimental set up was established at the farm of ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal, Madhya Pradesh, India (at about 23° 18' 35" N latitude and 77° 24' 10" E longitude). The climate of Bhopal is pleasant throughout the year. During winter, ambient temperature varies between 10°C and 25°C and in summer between 25°C and 44°C. The annual rainfall in the region is about 1200 mm. The texture of the soil and basic physical properties were determined using standard practices and given in Table 1 (Saxena *et al*., 2018) [6]. The soil of CIAE farm is vertisols that have a low infiltration rate of approximately 11.2 $mm.h^{-1}$.

Table 1: Experimental soil physical properties

S. No.	Properties	Value
1.	Soil texture	
	Clay, %	51.9
	Silt, %	29.1
	Sand, %	19.0
2.	Bulk density, $kg.m^{-3}$	1600
3.	Porosity, %	38 - 40

2.1 Experimental Set-up

The field experiment has been planned with the major objective to evaluate the sub-surface drip irrigation system installed by using the SSDLLM. For this purpose, two types of laterals of 16 mm size were considered as treatments.

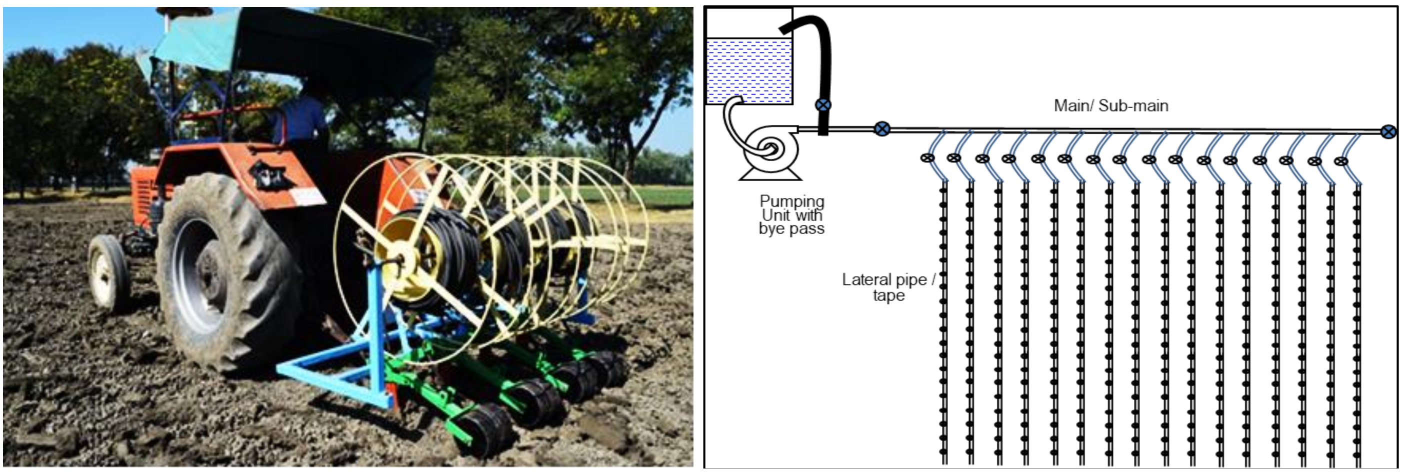
1. Drip pipe lateral
2. Drip tape lateral

Both type of laterals had 30 cm inline emitter spacing with 4 lph emitter discharge. Each of the above types of laterals were planned to be laid at 15 and 20 cm beneath the soil surface as sub-treatments. All the treatments were replicated four times as factorial RBD. The lateral to lateral spacing has been kept as 1.2 m. Each lateral was considered as one treatment. In the field layout, there are 12 laterals. The system has been equipped with a supply and storage tank apart from filtration and fertigation units. The size of main, sub-main and lateral lines were 75 mm, 63 mm and 16 mm respectively.

2.2 Evaluation of field layout drip irrigation

A week after laying of experiment, the soil around the lateral pipe has carefully been dug without disturbing the lateral pipe and the depth from the surface was recorded by vertically placing a measuring scale.

Performance evaluation of the machine laid sub-surface drip irrigation system was carried out by digging the soil carefully around each laterals laid at a minimum of 12 places on each lateral across the entire length which were connected to sub-main. The digging of soil was carried out after a week of laying the experiment. The depth of lateral placement was measured as the vertical distance from the soil surface till the top side of laid lateral as shown in Fig. 1.



(a) Developed Sub-surface drip lateral laying machine (b) Experimental layout laid by the machine

(C) Removal of soil over the lateral length at diiferent places (d) Observation of lateral placement depth

Fig 1: Details of the experiment

2.3 Estimation of uniformity of placement

Several coefficients of uniformity have been described and used by several researchers to appreciate the distribution of irrigation within the field (Christiansen, 1942; Bralt and Kesner, 1983; Burt *et al.*, 1997; Solomon, 1984; Saxena and Gupta, 2006 b; Bajpai and Saxena, 2017; Saxena et al., 2017) [22, 23, 24, 25, 19, 20, 21]. The distribution uniformity of the placement depth could be evaluated as similar to the application of irrigation. Main uniformity parameters used in this paper are as following.

Christiansen's Coefficient of Uniformity

Christiansen (1942) [22] described the coefficient of uniformity as the ratio of absolute difference of each value from the mean and the mean. The Christiansen's Coefficient of Uniformity (CCU) can be expressed as

$$CCU = \left[1 - \frac{\sum_{i=1}^{n} \left| D_i - \overline{D} \right|}{\sum_{i=1}^{n} D_i} \right] \qquad (1)$$

Where,

D_i is the discharge or depth of irrigation of an emitter,

$\overline{D}$ is the mean discharge of all emitters (or plants in case of plant wise determination of CCU),

n is total number of observations/emitters (total number of plants in case of plant wise determination of CCU).

This parameter considers deviations by magnitude alone without reflecting on excess or deficit. In practice, one of the two may be more critical.

Wilcox-Swailes Coefficient of Uniformity

Wilcox and Swailes (1947) [26] proposed a uniformity coefficient, Wilcox-Swailes Coefficient of Uniformity (WSCU) based upon the coefficient of variation, which can be expressed as:

$$WSCU = (1 - CV) \qquad (2)$$

Where,

CV is Coefficient of Variation expressed in fraction, as the standard deviation divided by mean value of emitter discharges (or the mean and the standard deviation of the sum of discharges of all emitters at each plant for plant wise WSCU). This parameter has the same limitation as the CCU.

Statistical Uniformity

Hart (1961) [27] described the uniformity of irrigation through the terms Statistical Coefficient of Uniformity (SCU) and Low Quarter Distribution Uniformity (SDU_{lq}), which are expressed as:

$$SCU = (1 - \sqrt{2/\pi}\; CV) \qquad (3)$$

$$SDU_{lq} = (1 - 1.27\, CV) \qquad (4)$$

The reason for the use of term 1.27 in Eq (4), as explained by Hart (1961) [27] is due to the fact that in a normal distribution, the mean of the low quarter of the values occurs approximately 1.27 times the standard deviation below the mean. These parameters were used by many workers (Solomon, 1984; Burt *et al.*, 1997; and Ascough & Kiker, 2002) [25, 24, 28]. While SCU has the same limitation as the CCU, SDU_{lq} reflects on the deficit of water in the lower quarter of the area if each dripper represents the same area.

3. Results and Discussion

The summary of the statistical parameters of the values of placement depths for different treatments within the field are presented in Table 2. Statistical parameters of mean, mode and median of placement depths among each treatment have found to be very close and the value of standard deviation and the coefficient of skewness have been less which clearly indicated that the placement depths were rather uniformly distributed; in other words, the variability in placement depth was minimal. Since the values of the mean and the median are quite close and the values of standard deviation and coefficient of skewness are low, it seems that the data follow a nearly normal distribution (Saxena and Gupta, 2016 b) [19]. The variation of lateral placement has been smaller for shallower depth of 15 cm as compared to 20 cm.

Table 2: Treatment wise statistical parameters for the depth of installation have been summarized in the following table.

Parameter	Pipe		Tape	
	15 cm	20 cm	15 cm	20 cm
Mean	15.10	22.35	14.31	20.71
Standard Error	0.18	0.76	0.28	0.45
Median	15.20	23.75	14.55	20.50
Mode	14.30	24.50	13.80	21.50
Standard Deviation	0.86	3.73	1.35	2.22
Sample Variance	0.74	13.95	1.83	4.92
Kurtosis	-1.07	3.10	1.30	3.96
Skewness	0.03	-1.55	-0.08	1.41
Min at 95% Confidence Level	14.84	22.17	13.98	19.56
Max at 95% Confidence Level	15.56	25.33	15.12	21.44

The laying performance of the developed machine for the SDI system was assessed by the coefficients of uniformity and compared (Table 3). It could be observed from Table 3 that the values of the CUC, WSUC, SCU, SDU_{lq}, have remained very good to excellent in the installation field. The CUC computed from the observed values of installation depths in the experimental system have remained between 0.87 to 0.95 for the lateral pipes installed at 20 and 15 cm depths respectively. It could also be noticed from Table 3 that the parameters of uniformity estimated using different approaches have followed similar trends among each treatment.

Table 3: Various distribution uniformities for different depths of installation among pipe and tape laterals

Uniformity coefficient	Pipe		Tape	
	15 cm	20 cm	15 cm	20 cm
Christiansen's Coefficient of uniformity (CCU)	0.95	0.87	0.93	0.92
Wilcox-Swailes Coefficient of Uniformity (WSCU)	0.94	0.84	0.91	0.90
Statistical Coefficient of Uniformity (SCU)	0.95	0.87	0.92	0.91
Low Quarter Distribution Uniformity (SDU_{lq})	0.93	0.79	0.88	0.87

Near close values of the CCU and SCU among the treatments have revealed that the placement depths were normally distributed. The results of which were in agreement to Ascough and Kiker (2002) [28] and Saxena and Gupta (2006 b) [19], who have reported that the CU values for various irrigation systems varied between 17.4 to 95.2 per cent and while the same were close to 81.2 per cent for drip and micro spray discharge rates. However, a widely used Christiansen's coefficient of uniformity has been computed to be above 0.90 except in 20 cm placement depth of pipe laterals.

The rating criteria values for the statistical uniformity in case of emitter discharge of drip irrigation system is considered to be excellent when it is more than or equal to 0.90 (Pitts, 1997) [29]. Therefore, it could be considered to be an excellent system for 15 cm depth installation for both the tape and lateral pipes (Table 3). Whereas, for the higher depths of installation at 20 cm, the system could be assessed between very good to excellent for drip pipe and tape. Similarly, the Wilcox-Swailes Uniformity Coefficient (WSUC), and Statistical Coefficient of Uniformity (SCU) were found to be 0.94 and 0.95; and 0.91 and 0.92 respectively for drip lateral pipe and drip tape.

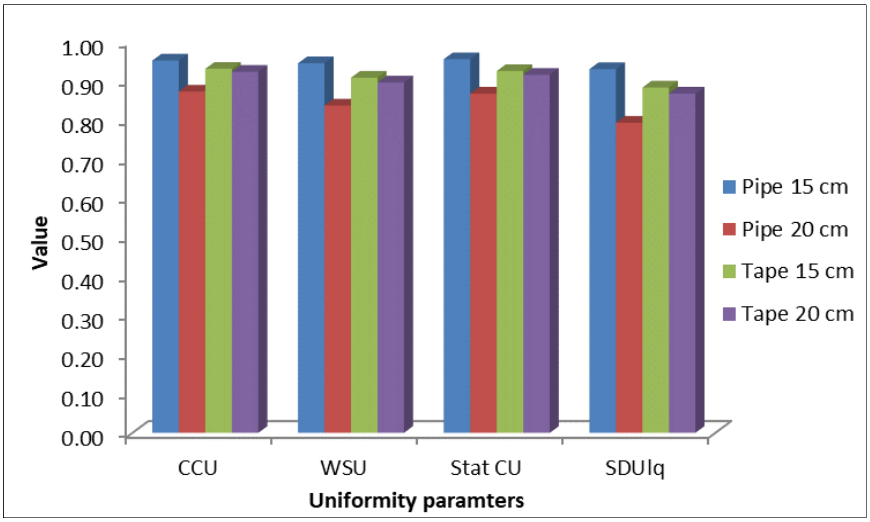


Fig 2: Graphical representation of the uniformity coefficients for lateral placement depths

The graphical representation of the various coefficients of uniformity for the machine laid lateral pipe as well as tape for different depths of placement at 15 and 20 cm may be seen in Fig.2. It is clear from Fig. 2 that in general the uniformity of placement irrespective of parameter has remained quite high, yet the pipe laterals laid at 20 cm depth did not show higher uniformity. As reflected by Table 3, the Low Quarter Distribution Uniformity (SDU_{lq}) has been evaluated to be

0.93 to 0.79 and 0.88 to 0.87 for pipe and tapes installed at 15 and 20 cm respectively. It could be seen from Fig. 2 that the lowest values of SDU_{lq} were observed in higher depths of 20 cm among both treatments. The low values of SDU_{lq} revealed that at least 25 per cent of the area suffered due to uneven placement from the desired depth. The computed values of SDU_{lq} were observed for 15 cm depth of placement for lateral pipes and lateral tapes at 93 and 88 per cent respectively. However, under the field conditions, a SDU_{lq} of around 0.70 is considered quite good (Ascough and Kiker, 2002) [28].

4. Conclusions

On the basis of the evaluation and field installation studies conducted on subsurface drip lateral laying machine, following conclusions could be drawn:

1. The placement performance of the laterals for a SDI system installed by using sub-surface drip lateral laying machine has been evaluated to be excellent to good during the tests as revealed by the various uniformity parameters.
2. The Christiansen's Uniformity Coefficient (CUC) of the drip irrigation system in SSDLLM field was 0.95 and 0.87; similarly, the Wilcox-Swailes Uniformity Coefficient (WSUC), and Statistical Coefficient of Uniformity (SCU) were found to be 0.83 and 0.64; and 0.87 and 0.72 respectively for drip lateral pipes and tapes placed at 15 and 20 cm depth repectively. While the Low Quarter Distribution Uniformity (SDU_{lq}) was evaluated to be 0.93 to 0.79 and 0.88 to 0.87 for pipe and tapes installed at 15 and 20 cm respectively.
3. The coefficient of variation of sub-surface drip lateral placement remained between 5.7 and 16.7 per cent in the installed system. For the shallower placement of 15 cm, the CV was found to be lesser than that of higher depths.

On the basis of the present study it may be concluded that the developed sub-surface drip lateral laying machine has found to place the sub-surface drip laterals at excellent uniformity and hence it can be used to install sub-surface drip laterals in the field.

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