

Original Research Article

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## Calculation of Uniform Coefficient, Soil Moisture Distribution and Analysis of Level of Biofilms Strategy under Sub Surface Drip Irrigation

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### ABSTRACT

Water logging and low application efficiency are main problems inherent with surface irrigation. The methods were surface, surface drip and subsurface drip irrigation with three level of irrigation 100, 80, 60% of potential evapo-transpiration were compared and contour map of soil moisture patterns were analysed for corn in two times; one before irrigation, and other at 48 h after irrigation. The distribution of water in soil profile for potato crop by subsurface drip irrigation system (SDI) studied and it was observed uniform and more yield for all treatments. Therefore, the results can be concluded that under subsurface drip, the water available in root zone was enough for plant growth. The study indicated that soil moisture content under subsurface drip irrigation was more uniform as compared with surface drip. It was found that plant height, yield and water use efficiency of potato crop increased due to subsurface placement of laterals at 10 to 15 cm as compared to that under surface drip. The wetted depth was observed larger than surface wetting radius due to more water moves below soil due to gravity force as compared to capillary forces (elliptical shape at depth of 10 to 15 cm). In this paper, wastewaters reclaimed biological aerated filter (BAF) process were chosen as the experiment objects then the effects of the average growth and topography of biofilms attached to the irrigation laterals and quantitative relationship between biofilms components were studied. The results showed that emitter clogging degree and biofilms components revealed an increasing trend with the drip irrigation system running, which could be regarded as the 'quick-slow-quick-slow' increasing trend. During the initial 540 h of the system running, DWs, PLFAs, and EPS of attached biofilms had obvious negative linear correlation with emitter discharge ratio variation (Dra) and coefficient of uniformity (CU).

#### Keywords

Root zone density, Soil moisture distribution, Sub surface irrigation and Uniform distribution and biofilms.

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### Introduction

Subsurface drip irrigation is defined as application of water below the soil surface through emitters, with discharge rates generally in the same range as surface drip irrigation. SDI is defined as application of water below the soil surface through the emitters (Merriam and Keller 1978), with discharge rates generally in the same range as surface drip irrigation (Gilbert *et al.*, 1981).

Subsurface Drip Irrigation (SDI) is similar to surface drip irrigation but the emitters located below the soil surface and thus the water is applied directly into the root zone. It has been used for the last 40 years and is suitable for most crops, particularly for high value fruit and vegetable as well as for turf and landscapes (Autovino *et al.*, 2016). A drawback is that its irrigation uniformity can

be severely affected by the obstruction of an emitter, although some field evaluations have shown uniformity coefficients similar to or even higher than those from drip irrigation (Merriam and Keller, 1978; Autovino *et al.*, 2016).

The first field experiment in the United States with a subsurface drip irrigation system was established on a lemon orchard at Pomona, California in 1963 and on an orange orchard near Riverside, California in 1964. The first research and demonstration study on a private grower's trees was in an avocado orchard in San Diego, California in 1969 (Hassanli *et al.*, 2010). About the same time trials were started using drip irrigation and plastic mulch on strawberries and tomatoes also in and around San Diego (Hills and Brenes, 2010; Chouhan *et al.*, 2015) stated that in 1984 cotton farmers installed the first SDI equipment in Texas HP.

The drip irrigation system with lateral lines laid on soil surface is the most popular application method in India (Hermes *et al.*, 2015). SDI offers many advantages over surface drip irrigation such as; reduced evaporation loss and precise placement and management of water, nutrient and pesticides leading to more efficient water use, greater water application uniformity, enhanced plant growth, crop yield and quality (Ives, 1980; Hassanli *et al.*, 2010). The other advantages of SDI include less interference with cultural operations and improved cultural practices; allows field operations even during irrigation; less nutrient and chemical leaching and deep percolation; reduced weed germination and their growth; reduced pest and diseases; damage due to drier and less humid crop canopies; warmer soils; reduced exposure of irrigation equipment to damage; no soil crusting due to irrigation; well suited to widely spaced crops; and advantages of freedom from necessity of anchoring laterals at the beginning and removing (Bernadette

and Ontermma, 1994) it at the end of the season, and thus longer economic life, high application efficiency of 80-90% (Adin and Sacks, 1991; Hermes *et al.*, 2015). The National Water Policy of India stresses that water is a prime natural resource, a basic human need and a precious natural asset. It is vital for realizing full potential of agricultural sector in order to get food self-sufficiency and security (Robles *et al.*, 2016). The demand for water is increasing both in agriculture and in particular in municipal sector at significant rates (Bush *et al.*, 2016). Indian agriculture in future has to produce ever-increasing quantities of food, fiber and fuel for increasing population of the country with decreasing quantities of water available for irrigation (Chouhan *et al.*, 2015). Therefore, optimum and efficient utilization of water in agriculture for irrigation assumes great significance. Several methods of irrigation from traditional surface flooding to modern drip irrigation systems have been evolved (Jha *et al.*, 2016). The traditional surface irrigation methods pose numerous problems of soil, water and environmental degradation (Aiello *et al.*, 2007). These methods are supply driven rather than crop demand driven, which cause mismatch between the need of crop and the quantity supplied. A large part of irrigated agriculture employ surface application methods, which results in low water application efficiency.

The use of wastewater in agriculture minimizes a potential contamination source for ground and surface water, especially in arid regions where the shortage of water implies the use of every available water source. Emitter clogging, a phenomenon commonly seen in reclaimed wastewater drip irrigation systems (Ravina *et al.*, 1992; Hassanli *et al.*, 2010), is a severe obstacle to the wide applications and popularization of the irrigation technology. Their sensibility depends on their characteristics (Ravina *et al.*,

1977) and on the water quality characterized by its physical, biological and chemical properties (Nakayama *et al.*, 2007). The constituents of reclaimed wastewaters are suspended particles, salinity ions, nitrogen, phosphorus, and organisms and microbial community clog emitters (Puig *et al.*, 2005). The nutrients, organic substances, and trace elements contained in the reclaimed water after secondary or even tertiary treatment could sustain the growth of microorganisms. Microorganisms including various bacteria, fungi, protozoa, with large quantities, multiple types, and fast growth rates in natural water play an important role in the ecosystem. In fact, over 90 % of microbes adhere to the substrate surface and exist in the form of biofilms (Li *et al.*, 2015; Bush *et al.*, 2016). Biofilm is a 3D heterogeneous and functional aggregation containing microbial community (bacteria, protozoa and fungi, etc.), solid particulates, extracellular polymers (EPS) secreted by microorganisms and other substances (Yang *et al.*, 2000). Microorganisms and nutrients can pass through the filter and enter the drip irrigation system and then form biofilms following the “attachment growth-detachment-decay” process (Li *et al.*, 2015; Nakayama 2007).

The emitters are among the most important parts of drip irrigation systems, but the narrow labyrinth path is easily clogged by pollutants, such as, suspended particulates, chemical precipitates, organic matter (OM), and microorganisms. Emitter clogging has become the major problem limiting more widespread use of drip irrigation, because it can reduce the service life and benefits of a drip irrigation system (Torabi *et al.*, 2013). In the present research the level and characteristic of biofilms formed in the drip laterals were studied.

The evaluate how different irrigation depths applied with SDI affected the distribution of soil moisture pattern, placement of laterals to

get maximum yield and water use efficiency for onion and potato crops (Jha *et al.*, 2016; Patel and Rajput 2007). The maximum yield is recorded at 10 to 15 cm depth in sandy loamy soil as compared with other depths. To see the response of subsurface drip irrigation on potato yield, a study was conducted at Water Technology Centre filed (Abbott, 1985; Kandelous and Simunek, 2010). Potato crop was cultivated in three sub-plots with four treatments of drip lateral depths viz. on the surface, and at depths of 5, 10, 15 cm below the soil surface (Duran *et al.*, 2009). Crop was irrigated as per irrigation schedule to fulfil its water requirement. The observations were recorded on growth parameter, soil moisture content and yield of crop (Nakayama *et al.*, 2007).

## **Materials and Methods**

### **Experimental site**

In order to achieve the objectives set for the present study, experiments were carried out in the laboratory as well as in the field of Precision Farming Development Centre (PFDC), Water Technology Centre (WTC), ICAR-Indian Agricultural Research institute (IARI), New Delhi. (Latitude 28°37'30" - 28°30'0" N, Longitude 77°8'45" -77°10'24" E and AMSL 228.61 m) during October to February two years (2013-14, 2014-15).

### **Soil analyses and data collection**

Soil samples were taken from different locations of the field to determine the physical and chemical properties. Experimental soil was sandy loam soil. Soil samples were collected from different depths up to 60 cm using tube auger and were analysed to determine its physical properties such as particle size distribution, bulk density, field capacity, permanent wilting point, soil moisture, soil matric potential and hydraulic conductivity. Methodologies adopted for

analysis of different soil parameters are listed in Table 1. Soil samples from surface down to 30.0 cm at 15.0 cm interval were collected. Hydrometer method was followed to determine the sand, silt and clay percentage of soil. The soil of the experimental area was deep, well-drained sandy loam soil comprising 67.5 % sand, 12.5 % silt and 20 % sandy loam for depth 0 to 15 cm and other details were presented in Table 1. The soil is sandy loam with mean basic infiltration rate as  $8.14 \times 10^{-6} \text{ ms}^{-1}$ . Average bulk density and saturated hydraulic conductivity of soil were found to be  $1.53 \text{ Mg m}^{-3}$  and  $3.08 \times 10^{-6} \text{ ms}^{-1}$ , respectively.

### System installation and experimental treatments

A field plot of size 25.0 m x 50.0 m was selected for experimental studies. The field plot was divided into three equal plots of 9.0 m x 50.0 m. Plot of 9.0 m x 50.0 m size was divided into 15 equal plots of 0.60 m x 50.0 m, representing a single treatment (Li *et al.*, 2015). The experiment was laid out following the randomized block design (RBD) with 15 treatments and 3 replications (R1, R2 and R3) of each treatment with drip laterals were installed at different depth, were presented in Table 2. Installation of the SDI system commenced in September, 2002 according to the standard guidelines. The layout of SDI system is shown in figure 1(a-d).

Tubers of 30 g weight of potato were sown at the depth of 15.0 cm in the raised ridges prepared during the first week of October at a plant to plant and ridge to ridge spacing of 30.0 cm x 60.0 cm. The base and height of ridges were kept 60.0 cm and 30.0 cm, respectively. Drip tape of 12.0 mil was buried manually at depths of 0.0, 5.0, 10.0, 15.0 and 20.0 cm in the middle of ridges formed for sowing of potato under different treatment. Three different irrigation levels of 60, 80 and 100% of the crop evapotranspiration and five

depth of placement of drip tape were maintained in the crop. The SDI system installed had drippers spaced at 30.0 cm, each with an application rate of 0.72 lph. One drip tape was installed for each row of potato. Time Domain Reflectometry was used in this study for determination of soil water content. Three access tubes, one at the mid of ridge and two at 15.0 and 30.0 cm away from the middle of ridge were installed. Access tubes were placed at the middle of the row up to a depth of 45.0 cm and water content (volumetric) were measured in all treatments. The total 135 access tubes made of PVC were installed in the experimental field.

### Estimation of uniformity of SDI system

The uniformity of water application of the SDI system was carried out for two year. For each testing, 54 drippers were selected from head, middle and tail ends of drip tape, randomly. Collecting the outflow in cans placed below the dripper for a known duration, uniformity of water application was determined. The uniformity of water application was calculated from the statistical distribution of dripper flow rates (Payero *et al.*, 2008) in terms of coefficient of variation (CV), distribution uniformity (DU) and statistical uniformity (SU).

The statistical coefficients CV, DU and SU were determined by using the equations 1, 2 and 3 and the data were presented Table 3.

$$CV = \left( \frac{s}{q} \right) \quad (1)$$

$$DU = \left( \frac{q_{iq}}{q} \right) \times 100 \quad (2)$$

$$SU = \left( 1 - \frac{s}{q} \right) \times 100 \quad (3)$$

Where,

s = Standard deviation of drippers discharge, lph

$q_{1q}$  = Mean of lowest one- fourth of drippers discharge, lph

q = Mean dripper flow rate, lph

n = Number of drippers taken for observations

Five micro irrigation uniformity classifications, ranging from excellent to unacceptable, recognized by the American Society of Agricultural Engineers were used to evaluate the SDI system (Pramanik *et al.*, 2014).

### Discharge ratio variation

The Discharge ratio variations (Dra) of drip irrigation emitter were calculated by equation 4.

$$Dra = \frac{\sum_{i=1}^n q_i}{N\bar{q}_{new}} \times 100 \quad (4)$$

Where,  $q_i$  indicated the outflow rates of drip emitter number. i tested (l/h),  $\bar{q}_{new}$  indicated the rated outflow rates of emitters offered by manufacturer (l/h), and N was the total number of experimental emitters in each treatment.

### Coefficient of uniformity

The coefficient of uniformity (CU) of drip irrigation emitters was calculated by equation 5.

$$Cu = \left(1 - \frac{\sum_{i=1}^n |q_i - \bar{q}|}{N\bar{q}}\right) \times 100 \quad (5)$$

Where,  $q_i$  indicated the outflow rates of drip emitter number. i tested (l/h),  $\bar{q}$  was the

average emitter outflow of emitters tested in each treatment (l/h), and N was the total number of experimental emitters in each treatment.

### Root zone and wetting pattern under sub surface drip irrigation system

The major design parameters controlling shape and position of the wetting zone beneath a SDI system are application rate, dripper depth, dripper spacing and irrigation application time (Fig. 4). Normally, SDI system is placed at the shallowest depth possible, consistent with avoiding damage from operations such as cultivation. The wetting patron of potato crop, root zone distribution and lateral depths showed in figure 2 and 3. However, if the lowest available dripper rate is greater than the soil intake rate, water surfacing can often result from irrigation. This can be reduced by burying the SDI system deeper in the soil (Mailhol *et al.*, 2011; Pramanik *et al.*, 2014; Patel and Rajput, 2008). The shallowest effective depth of placement can be found by keeping the drip tape at varying depths. Drip tapes were placed at five depths of 0.0, 5.0, 10.0, 15.0 and 20 cm below the soil surface. The depth at which potato yield was found maximum was taken as the correct depth for placement of drip tape. The drip emitter was calibrated based on standard procedure (Patel and Rajput, 2008).

### Estimation of water requirement and irrigation application

The weather data were collected from an automatic weather station located at 30 m away from the experimental field, WTC, ICAR-IARI. Reference crop evapotranspiration ( $ET_0$ ) was calculated on a daily basis by using Penman-Monteith's semi empirical formula (Robles *et al.*, 2016). Potato is a 130 days duration crop and may be divided in to four stages namely initial of 25

days, developmental of 30 days, middle of 45 days and tuber maturity of 30 days. The actual evapotranspiration was estimated by multiplying reference evapotranspiration with crop coefficient ( $ET = ET_0 \times K_C$ ) for different months based on crop growth stages. The crop coefficient during the crop season 2013-14, 2014-15, was adopted as 0.50, 0.65, 1.15 and 0.75 at initial, developmental, middle and tuber maturity stages, respectively (Payero *et al.*, 2008; Torabi *et al.*, 2013). During the initial and developmental growth stages, until tuber formation, it is essential, that soil should be kept constantly and uniformly wet to a depth of at least 10.0-15.0 cm. The water productivity was presented in Table 3 was calculated for different years by using SSD Irrigation.

### **Potato yield and water productivity**

Manual digging of matured potato was done on February 15. Yield of potato of each treatment was recorded. The water productivity under different treatment T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> was presented in the Table 4. Statistical analysis was done by using standard analysis of variance (ANOVA). Two-probability levels 0.01 and 0.05 were considered for determination of significance.

### **Level of biofilms and its characters**

According to standard methods for water and wastewater monitoring and analysis edited by National Environmental Protection Agency (2002), the water quality parameters of the two types of reclaimed wastewaters were shown in Table 5 and the measured parameters (including TN, TP, and pH, Ca<sup>2+</sup> and Mg<sup>2+</sup>) in reclaimed water treated by FBR method and BAF method (Puig *et al.*, 2005). The wastewaters reclaimed biological aerated filter (BAF) process were chosen as the experiment objects and then the effects of the average growth and topography of biofilms

attached to the irrigation laterals and quantitative relationship between biofilms components were studied (Ravina *et al.*, 1992; Tripathi *et al.*, 2014).

The biofilms attached on emitters revealed a gradual increasing trend with the increased running time of reclaimed water drip irrigation system. Dra and CU revealed a linear decrease in the early stage and a faster reduction in the 2<sup>nd</sup> year, which was closely correlated with biofilm growth.

## **Results and Discussions**

### **Uniformity of SDI system**

The operating pressure of system was kept 1.0 kg cm<sup>-2</sup> during all the three crop seasons. The coefficients of variation of flow rates were found 0.045, 0.042 and 0.058 during 2013-14, 2014-15 respectively. The lesser values of CV indicated good performance of the system. CV estimated (Tripathi *et al.*, 2014) for the in line labyrinth type drippers was reported to be 0.077 and CV values from 0.045 to 0.058 considered for good performance of system. The values of SU and DU were found more than 92% during all the three cropping seasons. SU and DU are more than 91 % and 88 % of the SDI system; the system was functioning excellent.

### **Soil water distribution**

Water distribution in the soil around a buried dripper mainly depends on soil texture, dripper discharge and root water uptake (Wang *et al.*, 2014). Soil samples were collected from the six points selected randomly from the experimental field at a depth of 0.0-15.0 cm, 15.0-30.0 cm and 30.0-45.0 cm. Statistical test (Friedman's test) was revealed that the sand was significantly different at different depths ( $P < 0.01, 0.05$ ) but sand, silt and clay content are not

significantly different at different locations of the experimental field ( $P < 0.01, 0.05$ ). Soil moisture distributions at different growth stages of potato at different depths of placement of drip tape are shown in figure 5.

Wetting of the soil surface started appearing in case of surface placement of drip tape and also in case of depth of placement of 5.0 cm. When dip tapes were buried at depths of 10.0, 15.0 and 20.0 cm soil depth, the soil surface remained relatively dry. Soil surface appeared moist but did not get saturated when depth of placement of drip tape was more than 5.0 cm at all growth stages of potato. In the treatments T1, 2 and T3, soil moisture at the soil surface was found 16.5, 17.2, 14.9, 14.4, 15.5, 15.9, 14.5, 14.0, 12.0, 13.0, 12.9 and 12.3 %, at initial, developmental, middle and maturity stage of crop, respectively (Patel and Rajput, 2007).

When drip tape was placed at the surface, more than 18.0 % moisture was found at the soil depth of 15.0 cm. But at 30.0 cm soil depth soil moisture was found about 12.0 %. When drip tape was buried at a depth of 5.0 cm, then moisture at the surface was vary from 20.5 to 22.5 % at different growth stage of crop. Upward movement of water takes place and surface soil become moist and adequate amount of moisture was found at the surface and at the 15.0 cm soil depth (av. 21.5 %) at different stages of potato. In treatment

T3, when drip tape was placed at depth of 10.0 cm, it was found that the water movement due to capillary forces was not sufficient and soil moisture at the surface decreases significantly (av. 15.5%) in comparison to treatment T1 and T2. It was observed that more than 16.0% moisture was found available in the ridge at all points in treatments T1, T2 and T3. Wetted soil bulb of 20.0 cm in width and 25.0 cm depth was having more than 18.0% moisture was observed in treatments T1, T2 and T3. This is very conducive for good tuber formation resulting in higher yields in treatments T1, T2 and T3.

It was observed that irrigation water should be applied in short duration and in the soils immediate vicinity of the drippers to prevent the surfacing. Roots of a plant, uses the water adjacent to them and plant needs to wait for the soil to replenish the water and plant uptakes the water from different zone. To increase the production and to achieve the higher yield, maintaining relatively high water content where replenishment of drying soil easily occurs can create conditions conducive to good plant growth therefore shallow placement of drip tape was recommended. The high water content of the soil around the drippers maintains relatively high soil hydraulic conductivity and good replenishment of water taken up by roots.

**Table.1** Soil physical properties of different layers

Soil layer depth (cm)	Particle size distribution (%)			Soil texture class	BD* (g/cc)	FC* on gravimetric basis (%)	PWP* (%)
	Sand	Silt	Clay				
0-15	67.5	12.5	20	Sandy loam	1.32	30.5	9.8
15-30	66.1	13.1	20.8	Sandy loam	1.38	30.1	9.3
30-45	65.9	12.8	21.3	Sandy loam	1.47	29.8	12.8
45-60	64.9	13.3	21.8	Sandy loam	1.48	30.1	16.8

\*BD= Bulk density, FC= Field Capacity, PWP= Permanent Wilting Point

**Table.2** Depth of placement of drip lateral

Water balance components (%)	Depth of placement of drip lateral, cm					
	0 cm	5 cm	10 cm	15 cm	20 cm	30 cm
Soil evaporation	12.3	13.1	10.8	7.5	4.5	4.2
Root water uptake	85.7	85.8	88.5	90.2	91.3	78.1
Drainage	8.3	5.2	4.2	3.2	8.9	12.5
Total	100	100	100	100	100	100
Root zone storage	-5.4	-5.2	-1.6	-3.8	-5.8	-5.1

**Table.3** Uniformity coefficient, distribution uniformity and application efficiency

Lateral position, cm	Uniformity Coefficient (%)		Distribution uniformity %		Application efficiency %	
	Smooth	Spiral	Smooth	Spiral	Smooth	Spiral
<b>0</b>	80.1	89.0	71.8	89.5	86.2	90.4
<b>5</b>	82.5	85.9	71.3	76.9	83.4	91.4
<b>10</b>	85.2	88.3	81.2	80.5	79.8	88.3
<b>15</b>	80.7	86.5	74.9	84.0	88.4	89.3

**Table.4** Water productivity of potato crop under sub surface drip irrigation system

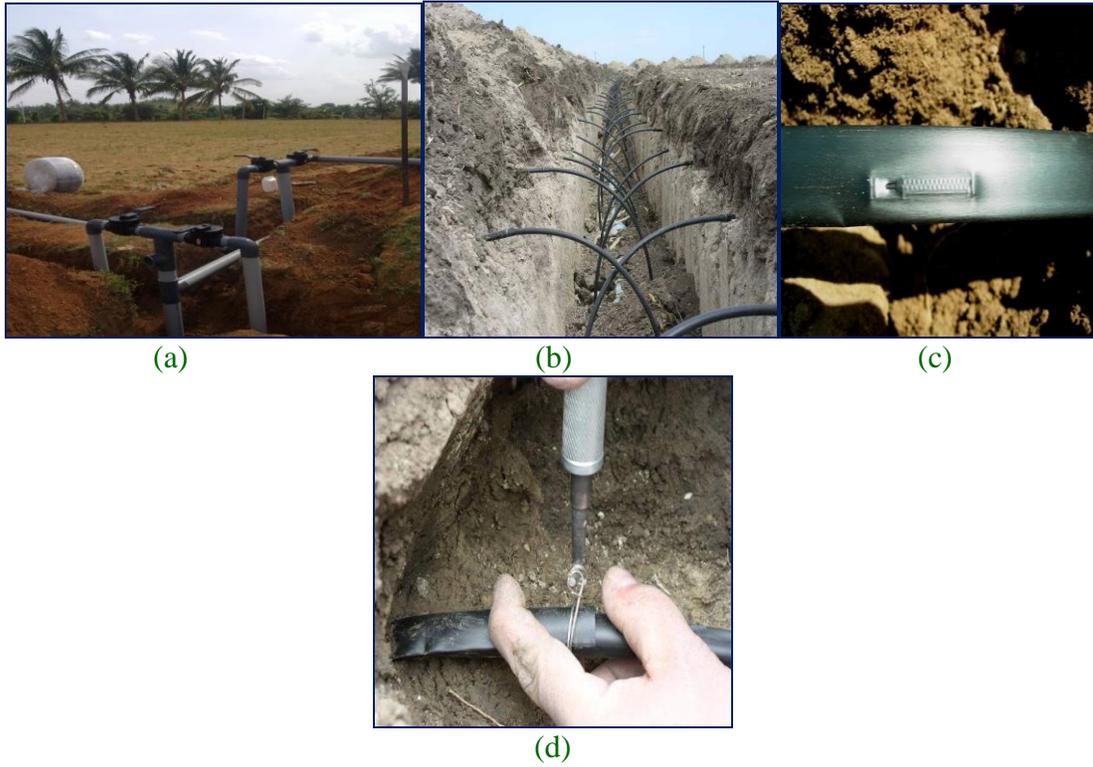
Lateral depth, cm	Water productivity in different years					
	T1		T2		T3	
	2013	2014	2013	2014	2013	2014
0	40.8	47.8	41.8	51.5	44.1	51.7
5	42.8	49.0	43.6	50.2	40.1	54.9
10	40.4	52.6	46.9	55.0	48.7	58.0
15	40.8	51.7	44.1	53.0	47.8	55.7

**Table.5** Average water quality characteristics of reclaimed water used during the experiment

Parameter	BAF	FBR	Parameters	BAF	FBR
COD	48	32	P <sup>H</sup>	7.20	7.21
SS	12.5	24	TSS	23	75
NH <sub>3</sub> -N	0.33	0.7	CA <sup>2+</sup>	68.7	65.8
NO <sub>2</sub> -N	0.2	1	Mg <sup>2+</sup>	10.9	7.1
NO <sub>3</sub> -N	0.5	2	Fe <sup>3+</sup>	0.15	0.41
TN	7.0	7.4	Mn <sup>2+</sup>	0.05	0.11
TP	1.7	2.8	DO	3.7	1.3

COD: Chemical Oxygen Demand; SS: Suspended Solid; TN: Total Nitrogen; TP: Total Phosphorus; DO: Dissolved Oxygen

**Fig.1** Installation of sub surface drip irrigation (main and sub mine lines and laterals) in the field



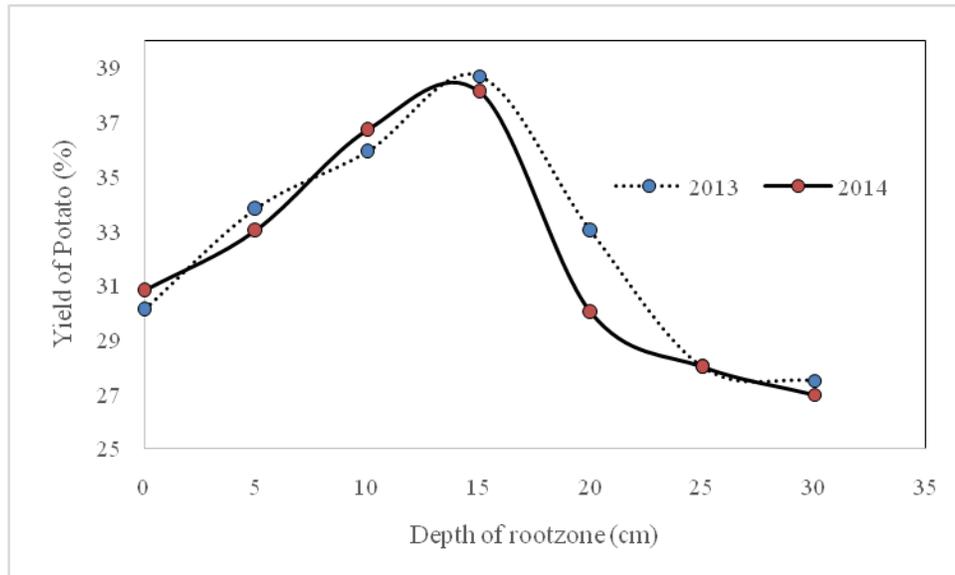
**Fig.2** Root zone distribution under sub surface drip irrigation methods



**Fig.3** Wetting pattern distribution under sub surface drip irrigation methods



**Fig.4** Average observed potato yield under sub surface drip irrigation system for 2013-14 and 2014-15



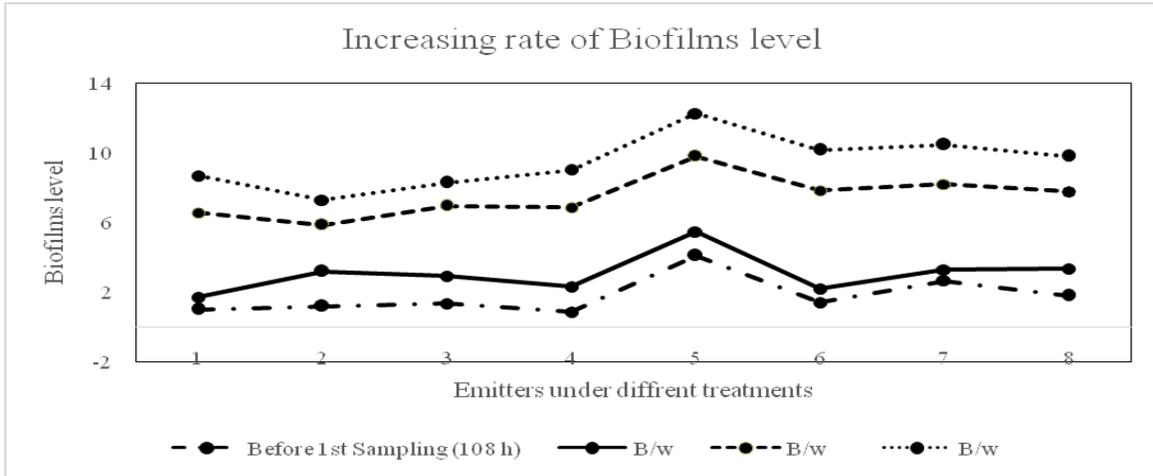
**Fig.5** Partially accumulation of the biofilm inside and outside the laterals and online emitters



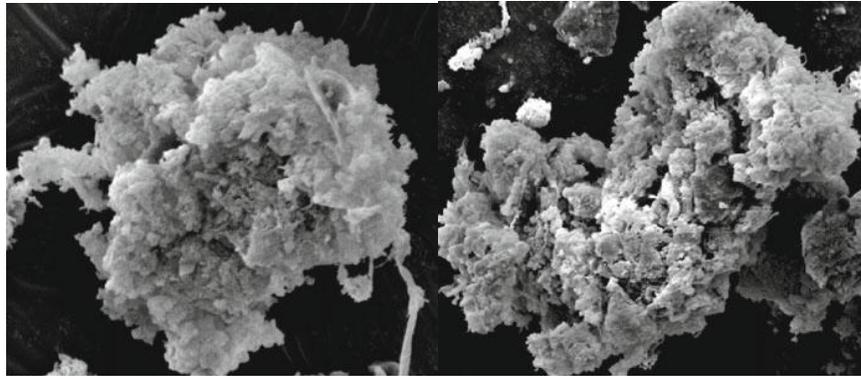
**Fig.6** Full accumulation of the biofilm inside and outside the laterals and online emitters



**Fig.7** Increased level of biofilm inside and outside the laterals and online emitters for a different durations



**Fig.8** SEM images of suspended particulates in BAF reclaimed wastewater



**Effect of depth of placement of drip tape on potato yield**

Maximum yield of potato was recorded during the year 2013-14 and 2014-15. The highest yield was recorded in treatment T3 (37.3 t ha<sup>-1</sup>) and lowest in case of 0.6T1 (18.5 t ha<sup>-1</sup>) as shown in Figure 3. Potato yield was higher under SDI than surface drip irrigation system during two years of experimentation. Potato yield was significantly affected by the placement of drip tape and maximum yield was obtained by placing the drip tape at 10.0 cm soil depth (P<0.05). It was observed that the drip tape could be buried either at 10.0 or 15.0 cm depth without significantly affecting

the yield (CD at 5% are 0.6, 0.55 and 0.66). It was recommended that to achieve the higher yields, drip tape should be buried at 10.0 cm depth. Levels of irrigation and depth of placement of drip tape significantly affected the mean yield of tuber in all three years (P<0.05).

**Relationship with emitter clogging**

As shown in Table 5, biofilm showed an increasing trend as the increase in running time of drip irrigation system (Figure 4). The average rate biofilms attached on pressure compensating and non-pressure compensating emitters were 18.4884 µg and 19.55 µg after

204 h, and they reached 63.81  $\mu\text{g}$  and 90.48  $\mu\text{g}$  after 540 h, respectively. On the other hand, the increasing rates of attached biofilm showed the fast-slow-fast-slow trend during different periods, which were 0.14, 0.02, 0.30, and 0.11  $\mu\text{g/h}$ , respectively.

During the initial fast-growth stage the biofilms thickness increased linearly and the biofilms accumulated. Increased level of biofilm inside and outside the laterals and online emitters for different durations was presented in Figure 5. During the later period the biofilms grew slowly and its thickness fluctuated because there was a dynamic procedure of growth, detachment, and re-growth (Fig. 7). There was a unimodal type of relationship between velocity and thickness of biofilms attached to two reclaimed wastewater laterals during the fast growth period and the SEM images of suspended particulates in BAF reclaimed wastewater image were presented in figure 6. Yan *et al.*, (2009) concluded that a close relationship with the processes of attachment growth, and detachment decay of biofilms in drip irrigation system (Fig. 8).

The coefficient of variation of flow rates was found 0.045, 0.042 and 0.058 during 2013-14, 2014-15 respectively. The lower values of CV indicated good performance of the SDI system. The values of SU and DU were found more than 92.0% during all the three cropping seasons. Soil moisture distribution at different growth stages of potato at different depths of placement of drip tape was monitored. When drip tape was buried at 5.0 cm soil depth, upward movement of water takes place and surface soil become moist and at the 15.0 cm soil depth about 21.5 % moisture was found at different growth stages of potato. Drip tape buried at the depth of 10.0 cm, it was found that the water movement due to capillary forces is not sufficient particularly in sandy loam soil and soil moisture at the surface decreases. When drip tapes were buried at the

depths of 15.0 and 20.0 cm, the soil surface remains relatively dry and moisture increases at the 30.0 cm soil depth at all growth stages of crop and water moves beyond the ridge base. In potato, the tubers formation was confined within the ridges, therefore water moves beyond the ridge base was not available for plants at any stage of growth.

Potato yield was higher under SDI than surface drip irrigation system during all years of experimentation. Highest yield was recorded in treatment T3 (33.3 t ha<sup>-1</sup>) and lowest in case of 0.6T1 (18.5 t ha<sup>-1</sup>). Higher yield potential can be achieved at 10 cm and 15 cm depth of placement laterals for Onion and Potato respectively. Cost of Subsurface drip irrigation is more as compared to other irrigation system. The growth and detachment of biofilms were the main reason of the clogging of drip irrigation system. The biofilms attached on emitters showed an increasing trend with the increased running time of reclaimed water drip irrigation system, while the increasing rates represented the fast-slow; fast-slow trend in different periods as head, middle and tail end.

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