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Assessment of wetted irrigation patterns for inline and online emitters in different soil textures

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Abstract

Selection of a suitable emitter type is one of the main design parameter which significantly affects the performance of drip irrigation system. Emitters can change wetting pattern under different soils, and may cause water stress if proper emitter spacing is not maintained. The major objective of this study was to investigate the wetting pattern of two generally used emitter types (inline and online) on different soils (loamy sand, sandy loam, silt and clay) of Peshawar valley and compare the observed values with model simulation using Drip Irrigation Water Distribution Pattern Calculator (DIPAC) and Drip-Irriwater models. Experimental trials were conducted of inline and online emitters (n=30) having 60 cm spacing and a discharge of 4 liters per hour. The trials were replicated twice for each soil type. The vertical and lateral infiltration of each emitter and water applied were recorded at 30 minutes and 60 minutes intervals. The wetted depth and width were measured manually by digging and through visual measurements. The results showed an increasing tendency in vertical and lateral infiltration with increasing wetting time for both emitter types, evidenced by 70-80% larger wetted area at one hour wetting time when compared with 30 minutes wetting time. However, the sandy soil showed greater (40-50 %) vertical infiltration when compared to clayey soil. Conversely, the lateral infiltration was identified larger (5-10%) for clay soil than sandy soil. Dripper's wetting pattern comparison was independent of the emitters type. Drip-Irriwater simulations were in close agreement with the observed values when compared to the empirical model DIPAC. The finding in this study has the potential to improve the decision support system for selecting a suitable emitter type for different soil types. In addition, the results of this study may be effectively utilized to obtain increased application efficiency by using the appropriate emitter type under limited water conditions.

Keywords: Drip irrigation; Wetting bulb; Water distribution in soil; Wetting front in soil.

1. Introduction

Approximately 94 percent of Pakistan's water resources are used in the agriculture sector (FAO, 2011). The prevailing water scarcity and large amount of water used in agriculture is prompting the adoption of more efficient irrigation practices. Drip irrigation, which allows water application at a low rate, achieves high efficiency in terms of water use and low energy requirement compared to sprinkler irrigation, and is being used on cash crops in Pakistan (World Bank, 2012). But the success of this irrigation system depends on some critical parameters; particularly drip emitters' selection – key component of drip irrigation systems (Wei et al., 2006). Among these parameters' selection other than agronomic factors the soil texture, dripper discharge, and the number of drippers per plant are important and critical to achieve optimum irrigation efficiency (Arbat et al., 2013).

The presence of water and wetted parameter in the root zone is vital for plants and has major impact on crop growth (Raoof and Pilpayeh, 2013). Different studies have been conducted to investigate the emitters wetting pattern. Sheng et al. (2007) examined the wetting pattern in three overlapped layered-textural soils in different combinations from drip irrigation under different application rate and applied volume. Their results showed that wetting patterns are affected by application rate, volume of water applied and the sequence of soil overlapped layers and their thickness. The results also showed that a fine layer over coarse layer or coarse layer over fine have less wetted depths and wider wetted widths. It was also noticed that wetted patterns were affected by application rate when the soil is uniform and wetted depth is increasing with low flow rates. However, in multilayered soils the role of application rate was not significant. The irrigation frequency also plays a vital role in wetting pattern. The increase in frequency shows an increase in vertical wetting front compared to continuous irrigation (Elmaloglou and Diamantopoulos, 2007). Similarly, Zhang et al. (2012) compared single emitter wetted patterns with multi emitters and it was noticed that wetted depth was significantly greater in multi emitters than single emitter. The wetting pattern has a shape of the rotating projectile with a maximum horizontal distance in the range 3-6 cm distance from medium surface. Zhigang et al. (2015) showed that as the volume of applied water increases the wetting body increases. Similarly, Cabrera et al. (2016) investigated the soil moisture distribution under drip irrigation and seepage irrigation for potato production in sandy soil. They reported that the drip irrigation increased the moisture distribution uniformity in the potato ridge and the majority of the root system was concentrated in the upper 0.30 m soil layer.

Field test for the wetted pattern, of digging a pit under an emitter is considered the most reliable method of emitter discharge and spacing (Keller and Bliesner, 1990; Battam et al., 2003), however, field tests are costly, time consuming, and difficult to implement under certain field conditions and are rarely conducted. Use of empirical or mathematical models could be a viable alternative. The researchers have applied different modelling tools (Kandelous and Simunek, 2010; Amin and Ekhmaj, 2006; Cook et al., 2003; Sheng et al., 2007; Arbat et al., 2013) to simulate the wetting pattern of drip emitter in certain soil textures.

In Pakistan, drip irrigation system is gaining popularity where considerable savings in energy and water consumption can be achieved. Mathematical models can save time and cost if used for different drip emitters wetting patterns, but to the best of our knowledge, no filed experiment is carried out to validate the model's simulations under local soil conditions. The field results often do not match with those provided by these mathematical models (Subbaiah and Mashru, 2013). This study aims to investigate the effect of drip emitters type on wetting pattern in different soils of Peshawar valley and to compare the observed values with Drip Irrigation Water Distribution Pattern Calculator (DIPAC) (Amin and Ekhmaj, 2006) and Drip-Irriwater models simulation.

2. Materials and methods

The experiment was consisted of two parts; field experiment at multiple site with different soil textures and model simulation. Field experiments were carried out in between the Indus and Kabul rivers at District Swabi, Khyber Pakhtunkhwa, Pakistan (Fig. 1). A reconnaissance survey was carried out to select different classes of soil, 42 different sites in the study area were visited. Using the Touch and Feel method (Vos et al., 2016), twelve (12) sites were chosen for collecting soil samples. These soil samples were tested in the Soil Laboratory of Agricultural Engineering Department, University of Engineering & Technology Peshawar, Khyber Pakhtunkhwa, Pakistan for initial moisture, soil texture analysis, and hydraulic conductivity following protocol outlined in Elliott et al. (1999). The laboratory results revealed four different soil textural classes in the study area based on International Society of Soil Science classification system. These soil classes are loamy sand, sandy loam, silt and clay.

Before the installation of irrigation system, these sites were cultivated at 0.30 m depth and the large size clods were broken manually. The clean water was applied for inline and online drip irrigation systems to eliminate chances of clogging. For field experiment a potable drip irrigation kit was fabricated in the Agricultural Machinery Workshop of Agricultural Engineering Department, University of Engineering & Technology, Peshawar. The major components of this setup include a water source, pump, delivery pipe, emitters and flow control valve. Plastic canes of 1 m^3 volume each were used as a water source. While 746 watt, single phase motor with 25 mm × 25 mm pump was used as a pumping unit. The unplasticized polyvinyl chloride (uPVC) pipe (confirming DIN 8063) of 32 mm size used as a main pipe for irrigation. Inline and online Pressure Compensating (PC) drippers/emitters with a discharge of 4 liter per hour (lph) each were selected in this study as shown in Figure 2. While the lateral pipe (drip tube) on which the online drippers were installed was 16 mm Low-density polyethylene (LDPE). One meter spacing between the emitters were kept so that the wetting parameters didn't overlap. As per the requirement, the pressure and flow of pumping unit was controlled by the installed flow control valves, which would route the excess flow back to the water tank.

Thirty Pressure Compensated (PC) drippers inline and online each were installed in two rows for evaluation per run. The discharge of each dripper was tested at one bar pressure in the laboratory. After evaluating the performance of drippers, the setup was installed at each site for checking the wetting patterns of drip irrigation as shown in figure 3.

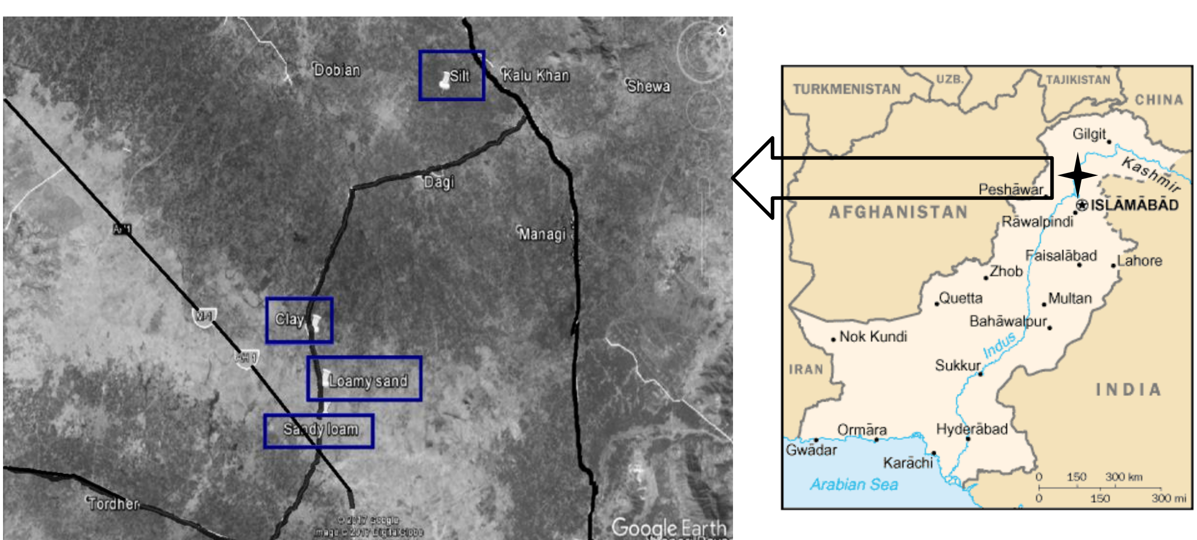

Fig. 1. Map of Pakistan showing study area.

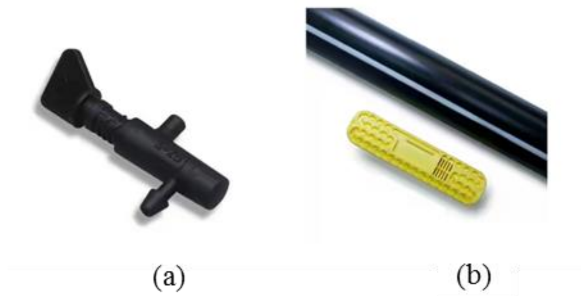

Fig. 2. (a) Online emitter, and (b) and inline emitter.

Fig. 3. Various pictures of sites.

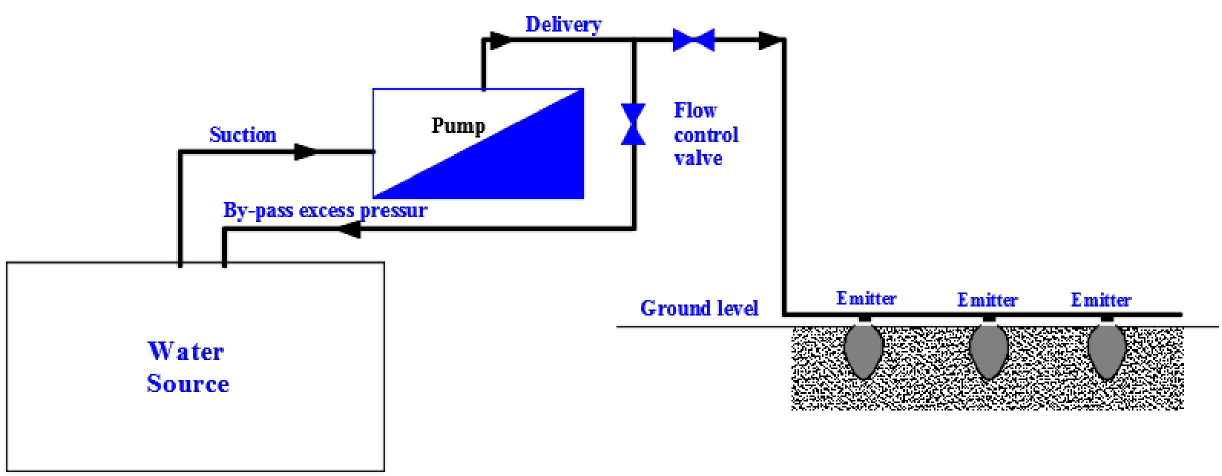

Fig. 4. Conceptual sketch of the installed drip irrigation system.

During 30 minutes irrigation, total applied volume of water was 120 liters/emitter and for one hour irrigation it was 240 liters/emitter. The soil samples from each site were collected for determining the initial moisture, bulk density and particle density as shown in Table 1. The particle density values vary from 2.10 to 2.65 g/cm^3

Table 1. Soil tests of selected sites.

S. No.	Soil type	Sand (%)	Clay (%)	Silt (%)	Particle density (g/cm^3)	Bulk density (g/cm^3)	Initial Moisture content (%)	Hydraulic conductivity (mm/h)
1	Loamy Sand	77	11	12	2.60	1.40	1.98	1.2078
2	Sandy loam	67	15	18	2.65	1.51	4.14	0.7074
3	Silt	11	08	81	2.10	1.12	17.09	0.0654
4	Clay	20	70	10	2.50	1.07	10.95	0.00924

For the comparison of results, the Drip-Irriwater (Arbat et al., 2013) was used in this study. This model is giving the wetted parameters under single emitter discharge. Drip-Irriwater determines soil wetting patterns by solving Richard's equation using finite difference method. The input parameters required for Drip-Irriwater are discharge of dripper, irrigation time, initial moisture content and total simulation time. The inputs for each soil were calculated and the results were derived from software for the purpose of comparing with the field results. Similarly, an empirical model DIPAC was also used for the purpose of comparing the results (Amin and Ekhmaj, 2006). The inputs required for this model are hydraulic conductivity, volume of water applied, the average change in moisture content and the discharge of the dripper. The empirical model DIPAC was developed after several field experiments. It is the modified form of the empirical model (Schwartzman and Zur, 1986) and estimating the wetted patterns by nonlinear regression.

3. Results and discussion

3.1. Loamy sand soil

Figure 5 shows the results derived for wetted width and wetted depth for 30 minutes irrigation. The average value of inline wetted depth is 23.38 cm with standard deviation of 1.75 cm and the coefficient of variation was 7.5 % while the average value of online wetted depth is 23.84 cm with standard deviation of 1.79 cm and the coefficient of variation was 7.49 %. Similarly, the average value of inline wetted width is 27.27 cm with standard deviation of 1.88 cm and the coefficient of variation was 6.89 %. The average online wetted width is 27.87 cm with standard deviation of 1.94 cm and the coefficient of variation was 6.97 %, due to which the two average lines are very close to each other. The average lines are significantly closer to each other for both inline and online drippers. For 30 minutes irrigation in the case of loamy sand, both the inline and online drippers exhibited approximately similar results.

Figure 6 shows the average lines of the derived results for wetted width and wetted depth. Similar results were obtained for online emitters with slight variation in the wetted width and depth compared to the inline emitter data. On one hand, the average value of inline wetted width is 33.03 cm with standard deviation of 0 cm and the coefficient of variation was 0 % while average value of online wetted width is 32.95 cm with standard deviation of 0.23 cm and the coefficient of variation was 0.69 %. On the other hand, the average wetted depth of inline is 35.57 cm with standard deviation of 0 cm and the coefficient of variation was 0 % and the average wetted depth of online is 34.98cm with standard deviation of 0.39 cm and the coefficient of variation was 1.10 %. The results for one hour irrigation showed that inline drip system has less variation in the results for both the wetted depth and width. Also, the wetted depth rapidly increased in size compared to the wetted width.

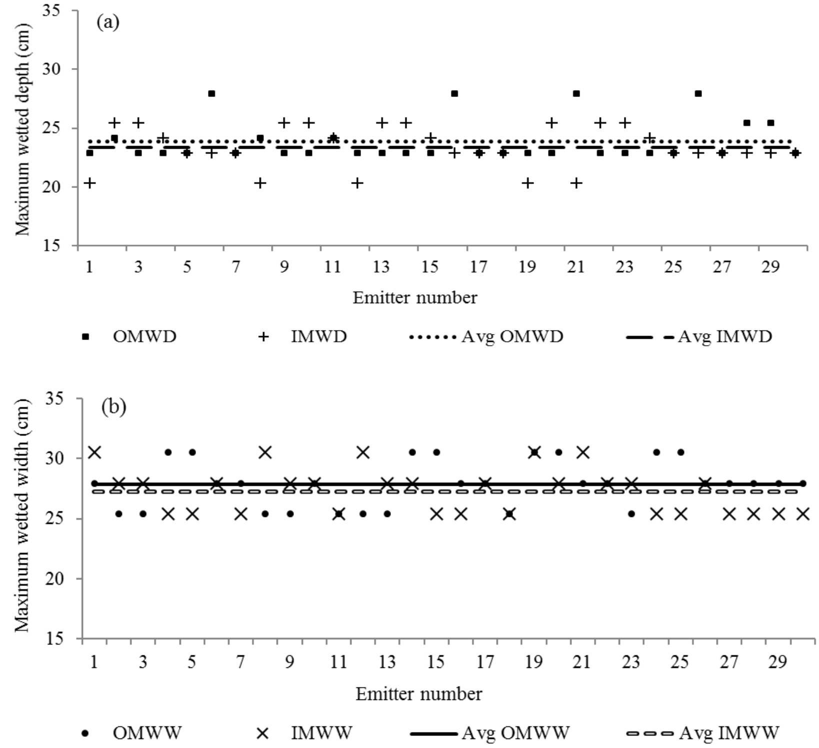

Fig. 5. (a) Thirty minutes irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for loamy sand.

Note: OMWD= Online Maximum Wetted Depth; OMWW= Online Maximum Wetted Width; IMWD= Inline Maximum Wetted Depth; IMWW= Inline Maximum Wetted Width

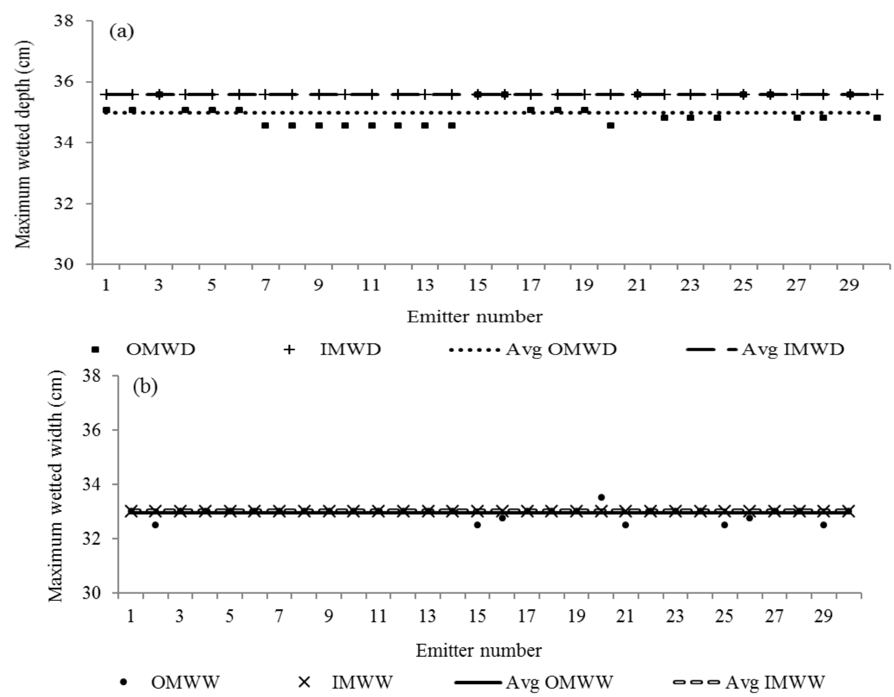

Fig. 6. (a) One hour irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for loamy sand. For abbreviation see figure 5a.

3.2. Sandy loam soil

Thirty minutes irrigation demonstrated that both the inline wetted width and depth values are very scattered and the individual emitter's did not give the same results as shown in Figs. 7. The average wetted depth of inline is 26.56 cm with standard deviation of 1.46 cm and the coefficient of variation was 5.82 % and the average witted depth of online is 26.85 cm with standard deviation of 1.41 cm and the coefficient of variation was 5.26 %. More or less similar results were found for online drip system. On the other hand, the average value of inline wetted width is 25.16 cm with standard deviation of 1.46 cm and the coefficient of variation was 5.82 % while average value of online wetted width is 25.75 cm with standard deviation of 0.77 cm and the coefficient of variation was 2.99 %. Individual results of inline and online drippers showed some variations, but the average wetted depth lines for thirty minutes irrigation for inline and online drippers is almost the same.

The one hour irrigation demonstrated comparatively better and invariable results than 30 minutes irrigation. It can be seen that in case of one hour irrigation, all the emitters showed the same results compared to 30 minutes irrigation and the wetted width size increased rapidly compared to wetted depth (Fig 8). On one hand, the average wetted depth of inline is 27.32 cm with standard deviation of 0.98 cm and the coefficient of variation was 3.58 % and the average witted depth of online is 27.27 cm with standard deviation of 1.1 cm and the coefficient of variation was 4.02 %. On the other hand, the average value of inline wetted width is 31.90 cm with standard deviation of 1.58 cm and the coefficient of variation was 4.94 % while average value of online wetted width is 33.13 cm with standard deviation of 1.48 cm and the coefficient of variation was 4.48 %. Approximately, similar results were found for the online drip system.

3.3. Silt soil

The behavior of wetted depth and width of the silty soil was almost similar to the loamy sand and sandy loam soil types. Thirty minutes irrigation demonstrated that both inline and online drip systems have much variations in the wetted depth and width (Fig. 9). The average wetted depth of inline is 12.58 cm with standard deviation of 1.51 cm and the coefficient of variation is 11.97 % and the average wetted depth of online is 13.73 cm with standard deviation of 1.72 cm and the coefficient of variation is 12.55 %. On the other hand, the average value of inline wetted width is 30.64 cm with standard deviation of 1.18 cm and the coefficient of variation is 3.86 % while average value of online wetted width is 30.96 cm with standard deviation of 1.35 cm and the coefficient of variation was 4.38 %.

For one hour irrigation, it was noticed that the wetted width of an inline drip system increased but the increase was slow compared to 30 minutes irrigation (Fig.10). While the increase in size of wetted depth was almost negligible. The same results were found for the online drip system. The average wetted depth of inline is 14.53 cm with standard deviation of 0.98 cm and the coefficient of variation is 6.77 % and the average witted depth of online is 13.42 cm with standard deviation of 1.88 cm and the coefficient of variation is 13.99 %. On the other hand, the average value of inline wetted width is 37.86 cm with standard deviation of 1.68 cm and the coefficient of variation is 4.44 % while average value of online wetted width is 38.03 cm with standard deviation of 2.26 cm and the coefficient of variation is 5.95 %. The average lines wetted width is showing that inline and online drippers show similar results for silt.

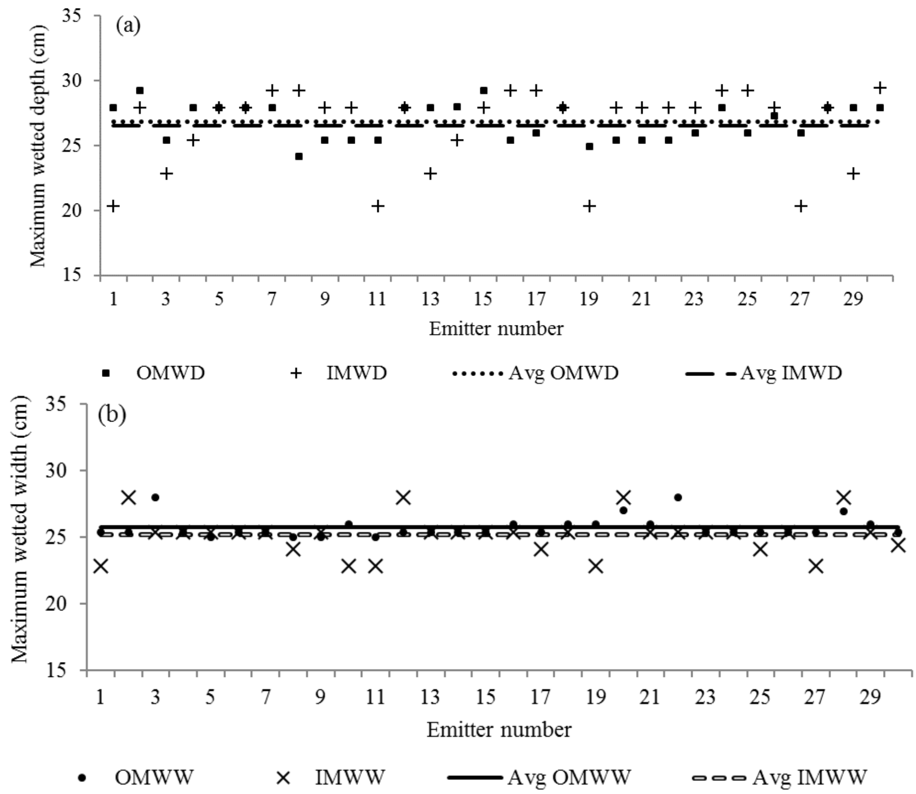

Fig. 7. (a) Thirty minutes irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for sandy loam. For abbreviation see figure 5a.

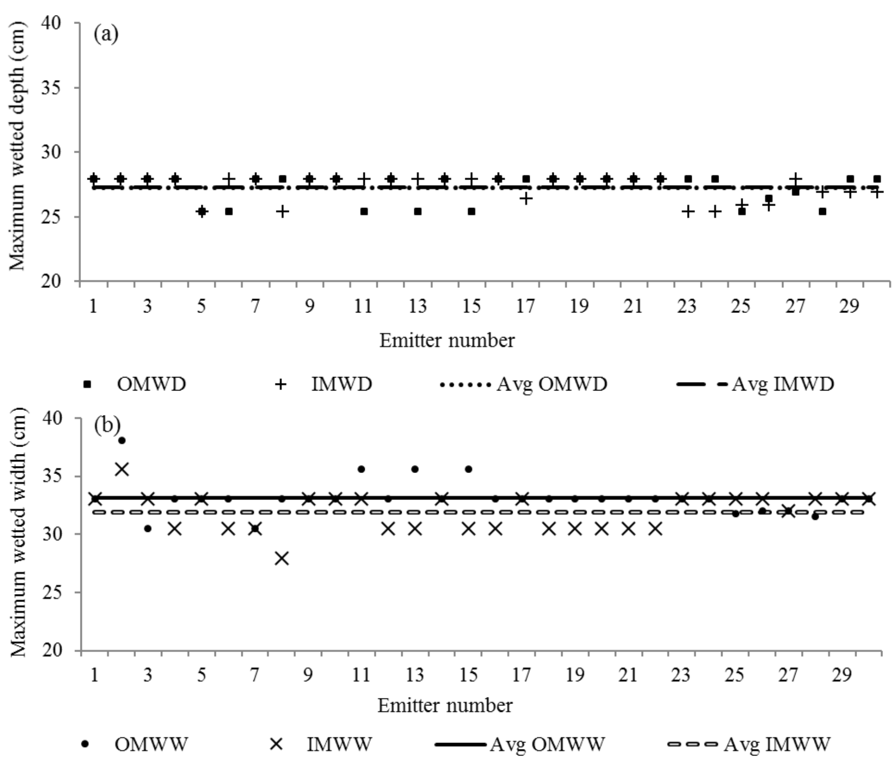

Fig. 8. (a) One hour irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for sandy loam. For abbreviation see figure 5a.

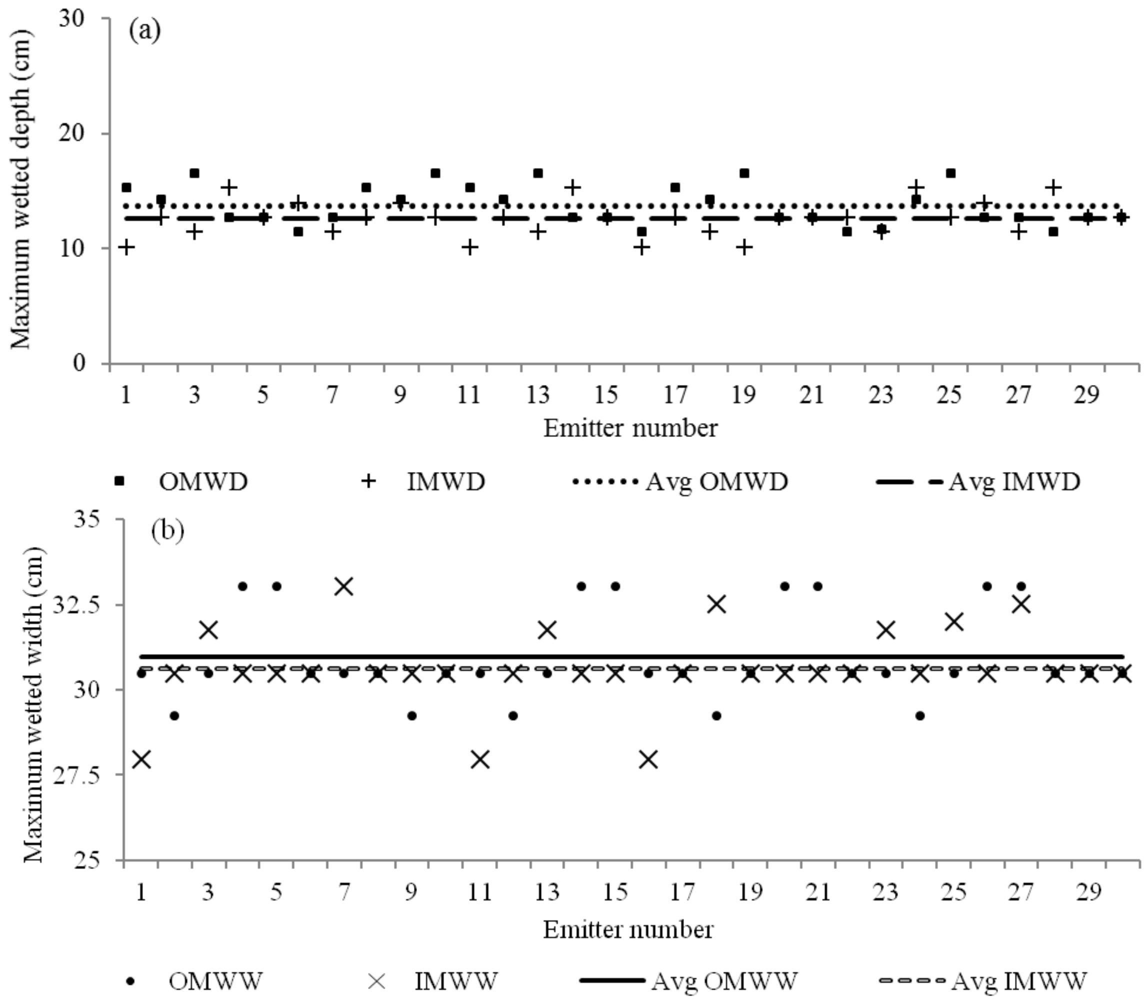

Fig. 9. (a) Thirty minutes irrigation maximum wetted depth, and (b) and maximum wetted width of 4 lph drippers for silt. For abbreviation see figure 5a.

3.4. Clay soil

Figure 11 shows larger variations both in wetted depth and wetted width. The wetted width of online drip irrigation was 10% more than the inline wetted drip irrigation. The average wetted depth of inline is 10.91 cm with standard deviation of 0.58 cm and the coefficient of variation is 5.33 % and the average wetted depth of online is 12.11 cm with standard deviation of 1.46 cm and the coefficient of variation is 12.02 %. While the average value of inline wetted width is 28.80 cm with standard deviation of 1.22 cm and the coefficient of variation is 4.23 % while average value of online wetted width is 28.54 cm with standard deviation of 1.59 cm and the coefficient of variation is 5.57 %. The average lines of wetted width are almost same while the wetted depths showed a slight deviation.

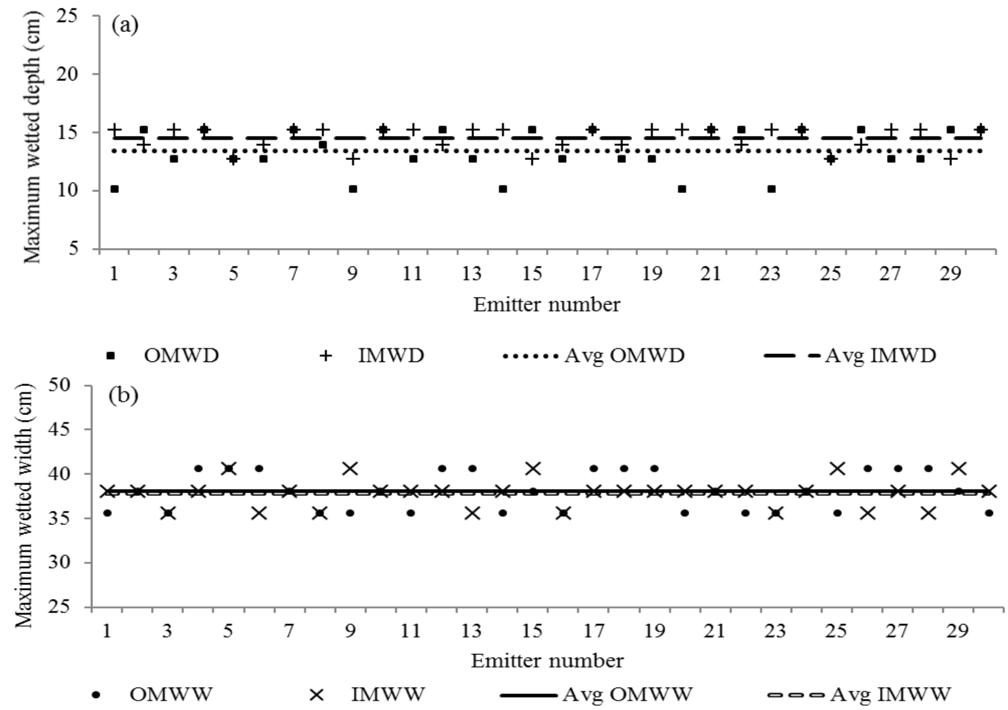

Fig. 10. (a) One hour irrigation maximum wetted depth, and (b) and maximum wetted width of 4 lph drippers for silt. For abbreviation see figure 5a.

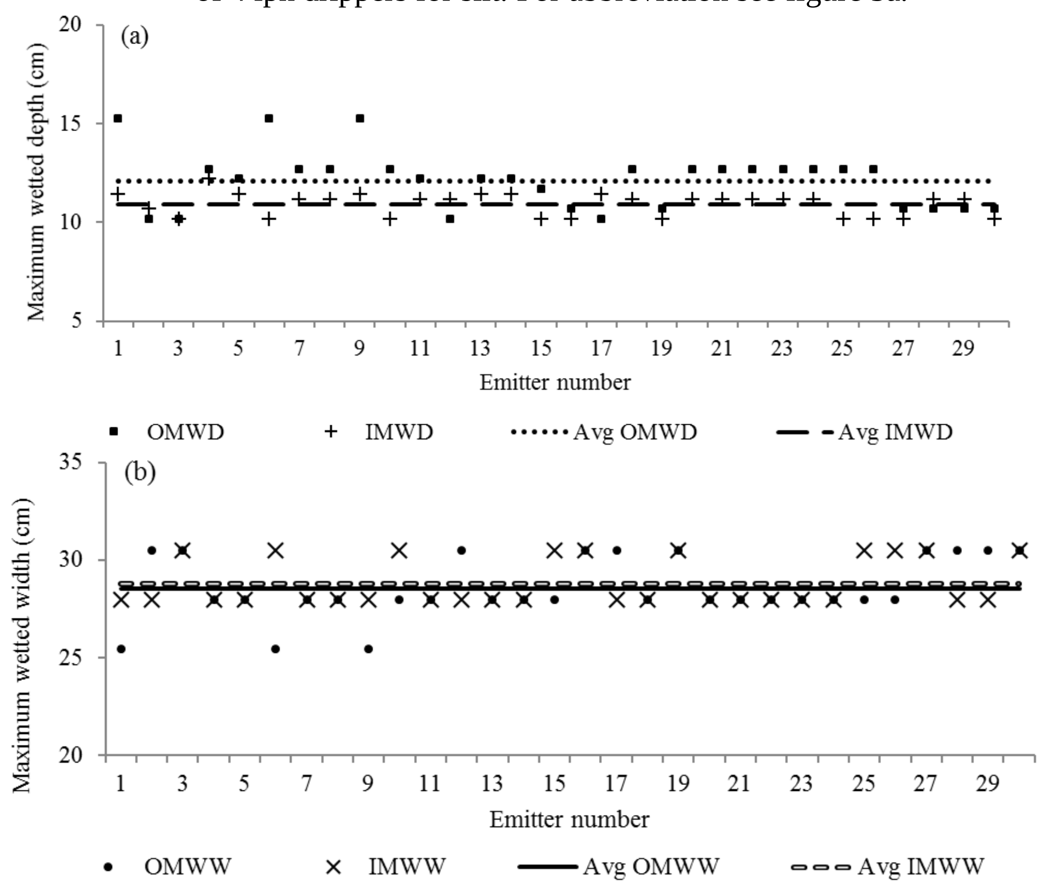

Fig. 11. (a) Thirty minutes irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for clay. For abbreviation see figure 5a.

The average lines showed that wetted depth and wetted width were almost same for both inline and online drip irrigation systems (Fig.12). The average wetted depth of inline is 13.68 cm with standard deviation of 0.17 cm and the coefficient of variation is 1.22 % and the average witted depth of online is 13.74 cm with standard deviation of 0.12 cm and the coefficient of variation is 0.85 %. The average value of inline wetted width is 37.14 cm with standard deviation of 0.85 cm and the coefficient of variation is 2.29 % while average value of online wetted width is 36.77 cm with standard deviation of 1.41 cm and the coefficient of variation is 3.85 %.

4. Overall discussion

Two dimensional view for the four types of soil is given in figure 13. The overall wetted width is 14% larger in size than the wetted depth in loamy sand. The average depth and wetted width and model simulation results are given Table 2. It was noticed that with an increasing irrigation time, the wetted patterns became more regular in shape, which results almost constant wetted depth and width. It was also noticed that the wetted depth showed a greater increase in size after 30 minute irrigation compared to the wetted width. The wetted depth was 7% larger in size for one hour irrigation than the wetted width. The wetted patterns were found to be increasing in size rapidly in the first 30 minute irrigation application compared to further irrigation. The wetted bulb of inline and online drippers showed that as the irrigation time increases the wetted bulb increases, but the increase in wetted depth is more rapid as compared to the width in the case of loamy sand. Similar results were observed by Zhang et al. (2012) in their study. They further stated that irrigation time for any soil may be decided by keeping in view the root depth and plant spacing. From comparison of inline and online emitters, it was found that the latter depicted variable results for emitters. These outputs are compared with the Drip-Irriwater (Arbat et al., 2013) and another empirical model (DIPAC) (Amin and Ekhmaj, 2006) as shown in Table 2. The Drip-Irriwater exhibited similar results as the empirical model both for 30 minutes and one hour irrigation experiments.

In sandy loam, the wetted depth was 5% larger in size than the wetted width for 30 minutes irrigation. The comparison showed that as the irrigation time increases the wetted patterns became more regular in shape and curves became straighter. It was also noticed that as the irrigation time increases the wetted width increases more in size compared to the depth. It is evident from Table 2 that during the first 30 minutes the increase in wetted patterns was much quicker compared to further irrigation. The results from Drip-Irriwater and the current study were in good agreement, both for 30 minutes and one hour irrigation duration. One hour irrigation results showed that inline drip system has 14% larger wetted width compared to the wetted depth. The wetted bulb of inline and online drippers showed that as the irrigation time increases the wetted bulb increases. The increase in wetted width is more rapid as compared to depth in the case of sandy loam. Similar results were reported by Zhang et al. (2012) for sandy loam under drip irrigation.

In case of silt soil, the comparison showed that the wetted patterns, increasing rapidly for the first 30 minutes irrigation and for further irrigation the increase in wetted depth and wetted width was much slower. However, the increase in wetted depth was negligible for both drip systems. The outputs were compared with the Drip-Irriwater model. In both the cases, the results were found consistent for 30 minutes irrigation, whereas one hour irrigation results showed 37% variation. The results were also compared with the empirical model (DIPAC) where Drip-Irriwater was found more accurate (Table 2).The wetted bulb of inline and online drippers exhibited that as the irrigation time increases the wetted bulb increases, but with the passage of time the increase in parameters slowed down. Also, the wetted width increased rapidly compared to the depth.

The comparison of inline and online drip systems indicated that the results in clay soil were similar, and the wetted width was almost double in size to the wetted depth. The results obtained using the Drip-Irriwater was more reasonable compared to the empirical model DIPAC. The wetted bulb of inline and online drippers showed the same behavior with time and as the irrigation time increased the wetted bulb increased. But with the passage of time the increase in parameters slowed down significantly, especially in the case of depth. The 28% increase in wetted width occurred when irrigation time increased from 30 minutes to 60 minutes.

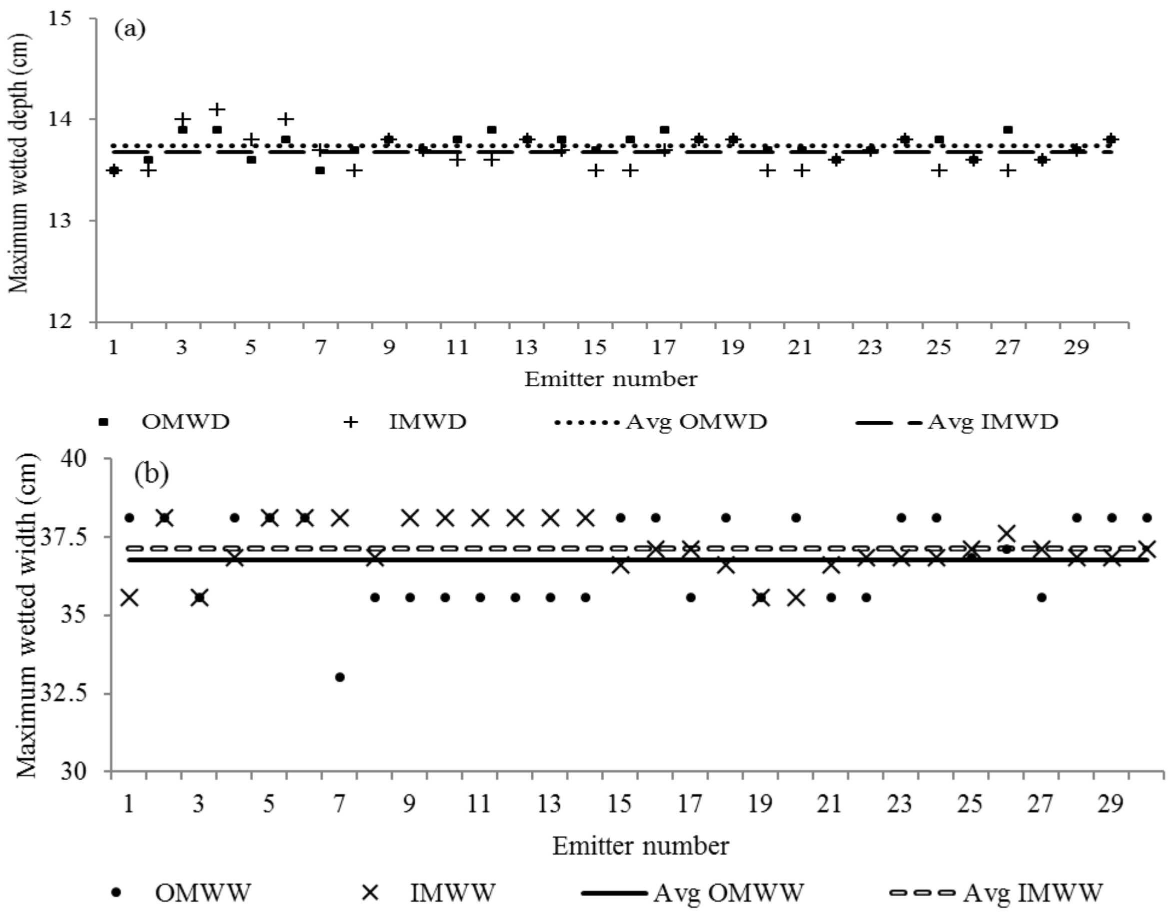

Fig. 12. (a) One hour irrigation maximum wetted depth, and (b) maximum wetted width of 4 lph drippers for clay. For abbreviation see figure 5a.

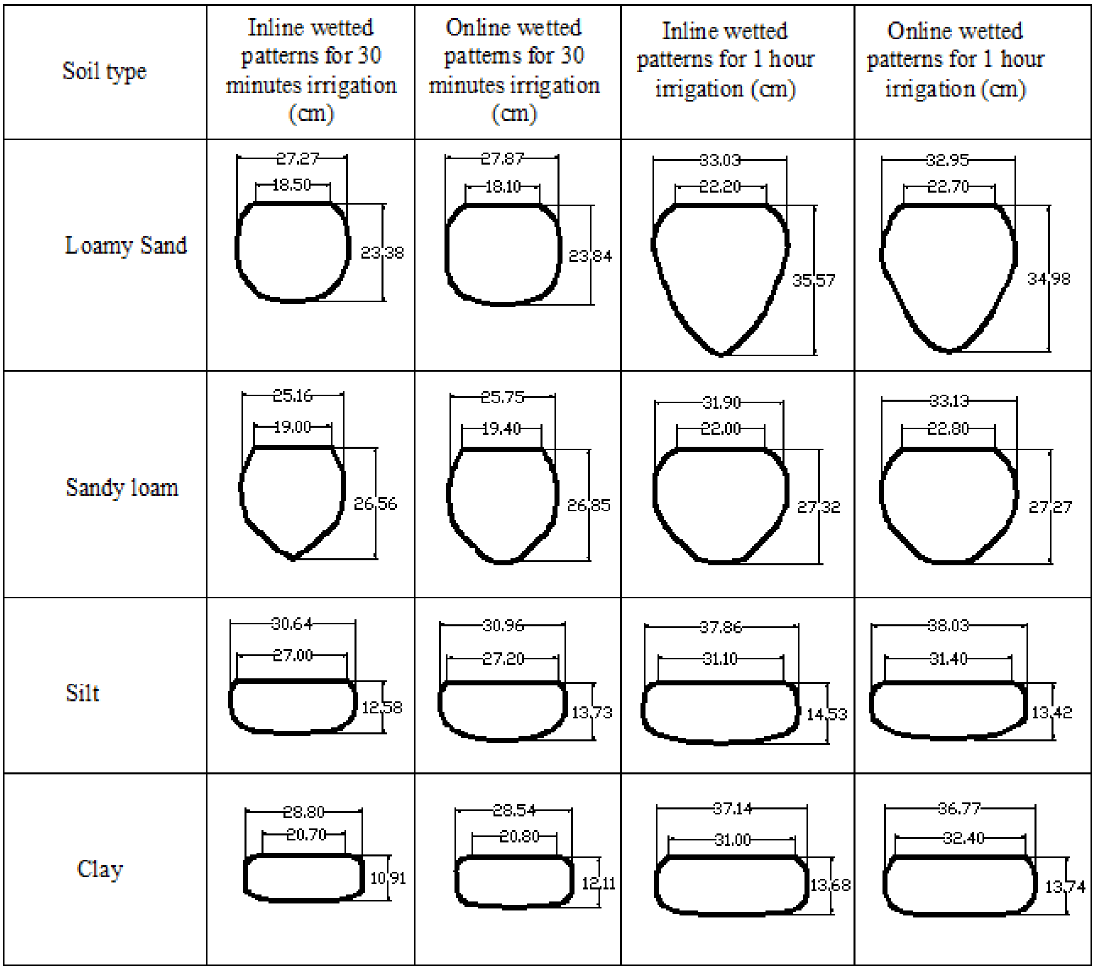

Fig. 13. Wetted bulb with maximum depth, maximum width and top width.

Table 2. Comparison of observed Wetted depth and Width with other two models.

Soil Class	Irrigation time (minutes)	Volume applied (liters)	Observed of inline and online average		Drip-Irriwater		Empirical model (DIPAC)	
			Avg. wetted depth (cm)	Avg. wetted width (cm)	Avg. wetted depth (cm)	Avg. wetted width (cm)	Avg. wetted depth (cm)	Avg. wetted width (cm)
Loamy Sand	30	120	23.61	27.57	25.2	25.1	77.17	45.91
	60	240	35.27	32.99	35.3	35.2	99.38	55.31
Sandy loam	30	120	26.70	25.45	25.6	25	97.87	77.29
	60	240	27.29	32.51	30.6	30.5	126.04	93.1
Silt	30	120	13.15	30.8	20.3	30.2	64.19	89.31
	60	240	13.97	37.94	20.4	35.2	82.68	107.58
Clay	30	120	11.51	28.67	15.5	30.7	34.77	67.97
	60	240	13.71	36.95	15.7	35.2	44.77	81.88

5. Conclusion

In this research, the effects of inline and online drip irrigation with 30 minutes and one hour irrigation time were investigated on four different soil classes. The observations showed that inline and online drip irrigation systems demonstrated almost similar results with slight variations (less than 10%). The wetted patterns of online drip irrigation system depicted scattered values compared to inline drip irrigation system for short time (less than 30 minutes) irrigation intervals. The results also showed that when the irrigation time increased beyond 30 minutes, the variation in results was less for both the online and inline emitters.

In addition, increase in the sizes of wetted patterns was very rapid for the first 30 minutes irrigation and after that these became slower for further irrigation. It was also noted that in first 30 minutes irrigation, the wetted patterns indicated 70 to 80% increases in size compared to one hour irrigation. Therefore, it is concluded that optimal irrigation time is critical for maximum water saving. For each soil type, the wetted patterns were also compared with Drip-Irriwater (Arbat et al., 2013) and empirical model DIPAC (Amin and Ekhmaj., 2006). About 5 to 15 % difference was observed in the results derived from Drip-Irriwater and the present study. Thus it can be concluded that the Drip-Irriwater model results were in good agreement with the observed results from the current study.

Authors' contribution

Muhammad Shahzad Khattak was project principal investigator and developed the research idea. Waheed Ali involved in field work and primary data collection. Muhammad Ajmal assisted in compilation and presentation of results. Tariq Mahmood Khalil contributed in improving the write up of the paper, improved methodology, and data analysis. Jamil Ahmad assisted in selection of various materials types used in experimental setup. Abdul Malik reviewed the manuscript and improved its readability. Ghani Akbar reviewed the manuscript and provided useful inputs.

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