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Influence of wicking bed system characteristics on tomato (*Solanum lycopersicum* L.) growth and yield

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Abstract

Wicking bed systems have gained significant attention in the context of small-scale and urban horticulture as a result of their capacity to effectively mitigate water constraint and promote sustainable crop output. To further our comprehension of these systems, a research study was conducted during the summer of 2020-21 to evaluate the efficacy of tomato plants (*Solanum lycopersicum* L.) in a wicking bed system. The experimental design followed a Completely Randomized Design (CRD) with a total of eight different treatments, replicated three times. The treatments consisted of several arrangements of wicking bed systems, which involved variations in reservoir depths (100 mm and 150 mm), soil bed depths (200 mm and 300 mm), and the inclusion of coir geotextile as interlayers. Based on the conducted experiments on the results of various wicking bed configurations, it is advisable to utilize a reservoir depth of 150 mm and a soil bed depth of 300 mm, together with the inclusion of a geotextile interlayer, in order to maximize tomato yield inside a wicking bed system. The aforementioned study enhance our understanding of urban agriculture, sustainable water management and crop cultivation techniques.

Key words: Geotextile, reservoir depth, soil bed, tomato, wicking bed, yield

Introduction

With the ongoing growth of the world population and the looming worries over food security, there is an escalating urgency for the development of creative strategies to enhance food production (McDougall *et al.,* 2019). Urban agriculture presents a viable alternative that has the potential to enhance the world food supply by planting crops within urban settings. Nevertheless, the exponential expansion of urban populations in developing nations has imposed significant pressures on urban food supply systems, frequently resulting in food scarcities during periods of emergency (Bhat and Paschapur, 2020). This highlights the imperative for implementing transformative strategies in urban agriculture that prioritize sustainability and resilience.

The importance of irrigation in agriculture has been widely acknowledged, and its application in urban environments poses distinct issues. The utilization of traditional irrigation practices, which involve the use of municipal water delivery infrastructure, has been recognized as a significant obstacle in the advancement of urban agriculture. This method not only places significant pressure on local water resources but also has the potential to cause negative environmental consequences, hence worsening problems related to water scarcity and pollution. In order to tackle these issues, the implementation of intelligent irrigation practices is identified as a promising approach for urban agriculture.

An example of an innovative irrigation technique is the wicking bed (WB) system, which operates on the principle of capillary rise from a subterranean reservoir filled with coarse materials, allowing plants to autonomously obtain water (Semananda *et al.,* 2018). In contrast to traditional surface irrigation techniques, wicking beds have notable benefits, such as the potential for a substantial augmentation in agricultural yield while concurrently mitigating water usage. According to Austin (2010), research has indicated that the implementation of wicking bed systems can result in a reduction of water use by up to 50% in comparison to conventional methods of irrigation. The huge decrease in water demands can be attributed to the reservoir's capacity to store large volumes of water, hence reducing the frequency of water applications.

Therefore, the objective of the study was to understand how does the depth of the reservoir in a wicking bed system affect the growth parameters, yield attributes, and yield of tomato plants. and what is the impact of different soil bed depths with coir geotextile interlayers on the growth and yield of tomato plants when cultivated in a wicking bed system compared to surface irrigation methods?

Materials and methods

The experiment was carried out from December 2020 to April 2021 in farmer's field at Chemmaruthy Panchayath in the Varkala block of Thiruvananthapuram district situated at 8° 77' 29.9'' N latitude and 76° 74' 06.7'' E longitude. A total rainfall of 223 mm was received during the growing season. The mean maximum temperature recorded was 33.2 ºC and the minimum temperature of the period was 23.7 ºC. A mean maximum relative humidity of 90.34 per cent and a minimum relative humidity of 73.89 per cent were recorded. The mean evaporation recorded was 3.78 mm.

The experiment was laid out in a completely randomised design with 8 treatments replicated thrice. The treatments were T_1 – Gravel Wicking bed (WB) 100mm + Geotextile inter liner (GT) + Soil bed (SB) 200 mm; T_2 - Gravel WB 150mm + GT +SB 300 mm; T_3 - Coconut shell WB 100 mm + GT + SB 200 mm; T_4 - Coconut shell WB 150 mm + GT + SB 300 mm; T_5 - Gravel + Coconut shell (1:1) WB 100 mm + GT+ SB 200 mm; T_6 - Gravel + Coconut shell (1:1) WB 150 mm + GT + SB 300 mm; T_7 - SB 200 mm Conventional irrigation; T_8 – SB 300 mm Conventional irrigation. Soil bed was prepared by mixing soil, coir pith compost and FYM in the ratio 2:1:1. Nutrition was provided as per the organic package of practices (KAU, 2017). One-month-old tomato seedlings of the variety Vellayani Vijai from Kerala Agricultural University were used for transplanting.

Plastic pots of dimensions 20 cm, 30 cm and 45 cm heights were used for the experiment. Gravel (Granite chips, 0.75 inches) purchased locally were used for the experiment. Coconut shell halves collected from households were cracked into 3 to 4 pieces to fill reservoir. Coconut shell or gravel or a mixture of both was filled up to the reservoir height in the pots. PVC pipes of 2 inches were purchased locally and cut into 35 cm and 50 cm lengthwise for 100 mm and 150 mm reservoir heights and holes were drilled in the PVC pipe up to the reservoir portion in wicking bed treatments for inflow and outflow of water in the reservoir.

Based on the treatments, reservoir heights were marked in the pots and a drainage hole was drilled just above the geotextile layer to permit the overflow of water. Then PVC pipes of suitable heights were inserted at the central portion of the pots. Above this setup, a geotextile inter liner was inserted through the pipe and fixed over the reservoir. Soil beds of 200 mm and 300 mm height were filled with potting mixture above the geotextile inter liner as per the treatments.

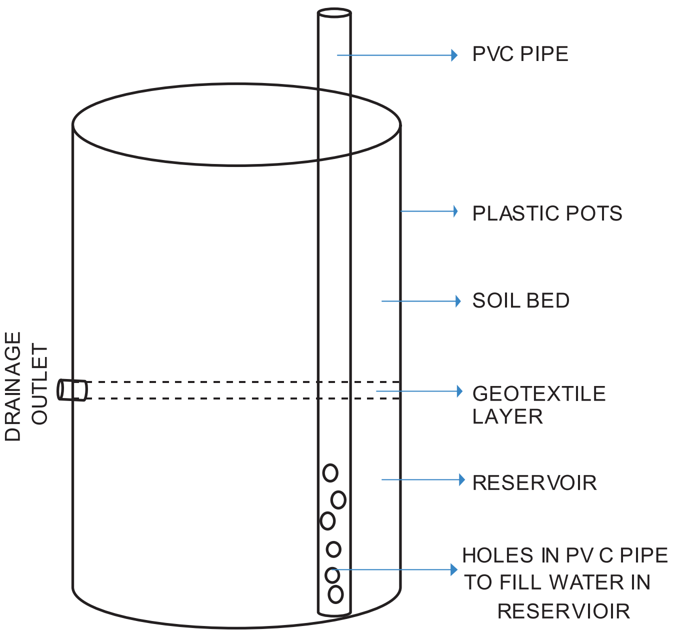

Fig. 1. Schematic representation of the wicking bed

After transplanting, all treatments were surface irrigated to field capacity for two weeks. After that, the irrigation scheduling was done as per the treatments. In the wicking bed, irrigation was given based on the water level in the reservoir. A pointer was inserted to demarcate the water level in the reservoir of wicking bed treatments. The measured volume of water applied to the reservoir upto the premarked geotextile interlayer in wicking bed treatments. The data generated from the experiment were statistically analysed using the Analysis of Variance technique for Completely Randomised Design (CRD) (Panse and Sukhatme, 1985).

Result and discussion

The observations on growth parameters, *viz.* plant height, number of primary branches per plant, stem girth and leaf area, were taken at the vegetative stage, flowering stage and at harvest. Dry matter production was taken at harvest. The first harvest was conducted from 73 days after transplanting when approximately 80 percent of fruits became ripe.

The coir-based mix would be able to supply plant water demands during high periods ofevapotranspiration due to its increased hydraulic conductivity (Londra, 2010). This could indicate that coir would be a useful addition to a wicking bed substrate mix. A capillary rise rate of 5mm per day has been used as an indicator of the suitability of a substrate to supply water to growing plants (Schindler *et al.,* 2017).

Effect of wicking bed irrigation on growth parameters: The results clearly indicated the reservoir height of 150 mm had more wicking action than 100mm height. Thus, resulted in more plant height when compared to reservoir height of 100 mm. This may due to the maintenance soil moisture at field capacity for more days so the roots get soil moisture continuously over longer period. When compared to wicking bed irrigation, surface irrigation treatments (T_7 and T_8) recorded lower plant height.

The stem girth of tomato is an indicator of water stress in plants. At flowering stage, T_7 recorded the lowest stem girth due to moisture stress (Fig. 3).

The number of branches in tomato is an important growth attribute contributing to yield of tomato. The data on primary branches

Fig. 2. Field view of experiment

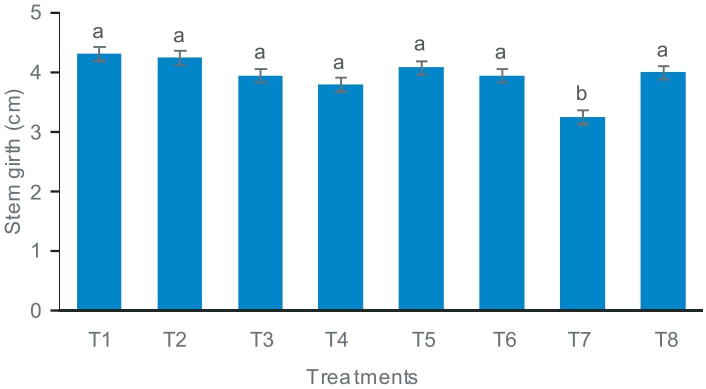

Fig. 3. Effect of wicking bed irrigation on stem girth at flowering stage

showed that coconut shell WB 150 mm + GT+SB 300 mm (T4) recorded more branches in all growth stages when compared to surface irrigation treatments. This lead to more flowers per branch, contributing to final yield.

However, the leaf area was not influenced during the early stages of growth. At harvest the higher leaf area was recorded by gravel-filled medium of 100 mm and 150 mm height (Fig. 4.).

The dry matter production per plant at different growth stages as influenced by differentwicking bed and soil bed treatments. Coconut shell WB 150 mm + Geotextile inter liner + SB 300 mm (T4) recorded significantly higher dry matter production per plant (180.84g) at harvest (Fig. 5).

Effect of wicking bed irrigation on root parameters: The study of root parameters revealed that all root parameters (root length, root weight and root volume) were significantly affected

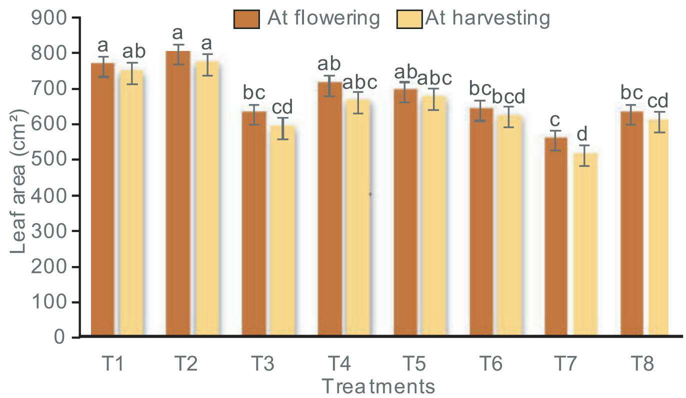

Fig. 4. Effect of wicking bed irrigation on leaf area at flowering and at harvest

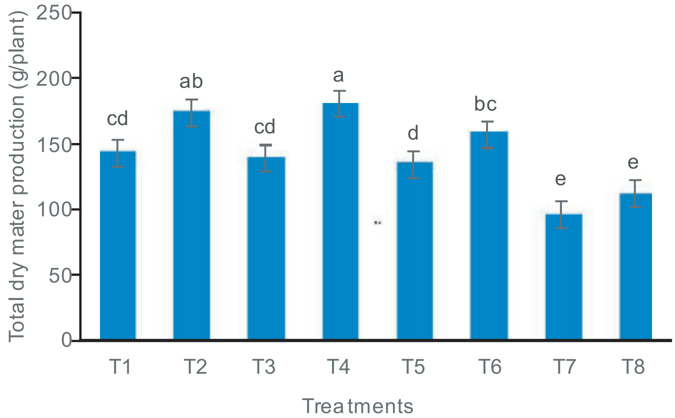

Fig. 5. Effect of wicking bed irrigation on dry matter production

by the treatments. The longest roots were observed in the larger reservoir depth of 150 mm with 300 mm soil bed. This was due to the more volume of soil available in the treatment.

Harris (1992) reported that root length serves as an indicator of a root's capacity to absorb water. Our experimental findings align with this concept, as the longer roots observed in T4 suggested the superiority of this treatment over others. Additionally, the root weight and volume were greater for wicking bed treatments in comparison to surface irrigation treatments. Man *et al. (*2016) opined that moderate soil water content increases root distribution over soil layers. This matches with our results in which longer and heavier roots were observed with wick bed irrigation compared to surface irrigation.

Effect of wicking bed irrigation on yield and yield parameters: In tomato, flower clusters per plant and flowers per cluster are the important yield-attributing characters. The coconut shell + gravel and gravel medium at 100 and 150 mm height recorded more flower clusters per plant. But the coconut shell medium recorded higher flowers per cluster. The surface irrigation treatments recorded lower flower clusters per plant and flowers per cluster. Other yield attributes *viz.,* days to first harvest, fruit per truss and fruit set percentage, were not significant (Table 1).

In tomato, fruit length, fruit diameter and average fruit weight are the important parameter contributing to yield. The fruit length and fruit diameter were higher in gravel and coconut shell-filled medium at reservoir depths 100 and 150 mm, respectively (T1, T2, T3 and T4). The result on average fruit weight showed that coconut shell-filled media of 150 mm (T4) recorded higher value.

Table 1. Effect of wicking bed irrigation on yield and yield parameters

Treatments	Flower clusters per plant	Flowers per cluster	Days to 50% flowering	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Yield per plant (g $plant^{-1}$)	Number of pickings	Harvest index
T1	25.33	8.93	39.83	3.83	10.70	36.50	732.69	8.67	30.89
T2	31.67	8.35	38.83	4.13	10.50	40.50	1114.46	9.33	38.46
T3	11.00	8.51	40.17	4.35	11.08	36.42	724.88	9.00	31.60
T4	23.33	10.67	37.83	4.13	11.20	41.53	1152.94	10.33	38.30
T5	25.33	8.33	38.17	3.07	7.03	35.33	640.57	9.00	28.68
T6	27.33	7.67	37.83	3.72	11.63	38.67	950.14	10.00	36.28
T7	6.33	6.68	41.83	3.07	8.15	34.33	359.58	5.00	22.43
T8	21.33	7.33	45.17	2.95	9.70	35.17	451.14	5.50	24.19
SEm (±)	2.62	0.60	1.16	0.26	0.69	1.17	29.81	0.36	1.52
CD (0.05)	7.86	1.81	3.47	0.78	2.07	3.51	89.35	1.09	4.55

Sullivan *et al.* (2015) reported that capillary-based sub-irrigation systems may have a higher yield and require less maintenance when compared to other methods. Plants grown on wicking beds would use water more efficiently than those grown in pots that were irrigated from the surface (Semananda *et al.,* 2019).

In the present study, the growth and yield attributes of tomato were significantly superior in tomato grown in larger soil volume. This in conformity with finding of Gupta *et al.* (2015). The analysed data on yield showed that higher yield per plant was recorded with T_4 which was on par with T_2 and the lowest yield was recorded with T_7 (Fig. 6). The yield increase percentage were 220 and 210 in T_4 and T_2, respectively over surface irrigation pots of 200 mm soil bed depth (Fig. 7.). This may be due to larger reservoir depth which contributed higher capillary rise to the soil bed over longer period of time. Larger volume of soil bed sustains constant soil moisture and greater access to the soil moisture for the roots over long period.

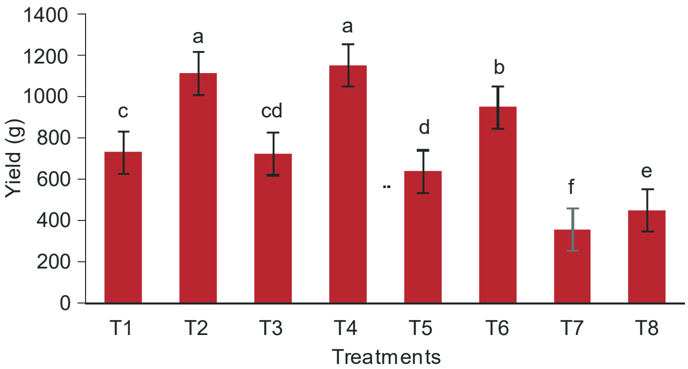

Fig. 6. Effect of wicking bed irrigation on yield per plant

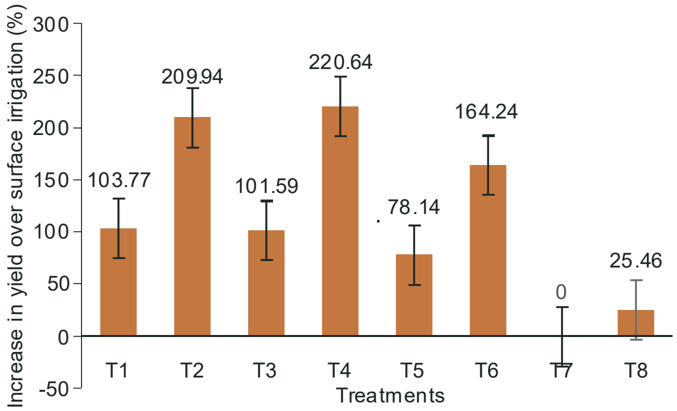

Fig. 7. Percentage increase in yield over surface irrigation

Effect of wicking bed irrigation on quality attributes: The quality of tomatoes is determined by various attributes including color, fruit shape, and size. Additionally, the quality assessment includes parameters such as ascorbic acid content, total soluble solids (TSS), and titratable acidity. While TSS and titratable acidity remained unaffected by both wicking bed and surface irrigation treatments, the ascorbic acid content was influenced by these treatments. Among the treatments, all were comparable except for T7 and T8.

From the study, it can be concluded, that tomato can be successfully cultivated in wicking bed system. Among the wicking beds, reservoir depth of 150 mm and soil bed depth of 300 mm with geotextile inter liner can be recommended for higher yield under wicking bed system.

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Feasibility study on Lepton 3.5 in terms of accuracy for measuring leaf temperature of crops

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Abstract

The precise monitoring of leaf temperature is becoming more important as crop leaf temperature is utilized more frequently for different uses such as irrigation, disease and pest detection. This study aims to explore the potential usage of a cost-effective Lepton 3.5 camera to measure the crop canopy temperature. The accuracy of the Lepton 3.5 will be compared to a FLIR E8-XT thermal camera and an MLX90614 infrared thermometer. With the usage of three devices: a custom Lepton 3.5 camera, an Implexxio LT-1T thermistor and an MLX90614, the temperature of the target leaf of a laboratory plant was automatically measured every five minutes. The data would then be recorded on a private cloud server and manually measured with a handheld FLIR E8-XT. The performance of these three devices was evaluated to the standard of a highly accurate Implexxio LT-1T thermistor using the mean absolute error and root mean squared error. Among the non-contact sensors- MLX90614, Lepton 3.5 and FLIR E8-XT- the MLX90614 sensor showed the highest accuracy. However, the Lepton 3.5 module had an accuracy of less than ±2°C, which was similar to FLIR E8-XT and much better than the error value specified for the Lepton. The low-cost Lepton 3.5 can be used to periodically measure leaf temperature with an accuracy comparable to that of an intermediate-level thermal imager.

Key words: Leaf temperature, CWSI, Accuracy, Lepton 3.5, FLIR E8-XT, MLX90614

Introduction

Leaf temperature is defined as the surface temperature of a crop leaf. It influences the photosynthesis and transpiration of crops and is also a critical indicator for determining crop moisture status and health. Insufficient soil moisture hinders the crops to transpire, causing stomatal closure and increased leaf temperature. Research in the past (Su *et al.,* 2020; Yang *et al.,* 2021; Ballester *et al.,* 2013; Berger *et al.,* 2010; Chaerle *et al.,* 1999) used crop canopy temperature to assess the stomatal conductance/closure, drought and pest stress. Like such, accurate monitoring of leaf temperatures during crop cultivation is becoming more important.

Leaf temperature can be measured through either contact or non-contact methods. Contact methods (Blad *et al.,* 1976; Pieters *et al.,* 1972) such as thermocouples and thermistors provide high accuracy but require multiple sensors to measure canopy temperature. On the other hand, Non-contact methods such as infrared thermometers (Kumar *et al.,* 2021; Luus *et al.,* 2022; Jones *et al.,* 2018; Martinez *et al.,* 2017; Sui *et al.,* 2012; O'Shaughnessy *et al.,* 2011; Dhillon *et al.,* 2012) and thermal imaging cameras (Su *et al.,* 2020; Leinonen, 2004; Blaya-ros, 2020) provide lower accuracy, with infrared thermometers limited to measuring broader areas and thermal imaging cameras having even lower accuracy than infrared thermometers. Handheld infrared thermometers are mobile but not practical for regular monitoring. In the past, thermocouples, thermistors, and handheld infrared thermometers were commonly utilized despite each having its own limitations. Nowadays, fixed infrared thermometers and thermal imaging cameras have become the prevailing methods for measuring leaf temperature.

Infrared thermometers measure thermal radiation emitted by the surface and can determine the temperature of the detector within a certain range of its actual temperature. They commonly use a spectral band of 8 to 14 µm. In some studies, (Hatfield; 1990; Alves *et al.,* 2000; Ahi *et al.,* 2015; Kumar *et al.,* 2021), portable infrared thermometers have been used to measure leaf temperature and calculate the Crop Water Stress Index (CWSI). Thermal infrared imaging cameras detect and measure infrared energy emitted by objects, then visualize the data. Each pixel in the sensor array has a temperature value that creates a color map when focused on an object.

Many studies have used handheld thermal cameras to measure leaf or canopy temperature. Sui *et al.* (2020) used a handheld thermal infrared camera to measure forest canopy temperature, while Luus *et al.* (2022) used the same camera to measure the grapevine leaf temperature. However, fixed thermal imaging cameras can be very expensive. As a substitute, the low-cost FLIR Lepton module has been used to replace a fixed thermal camera. Some studies (Arcosi *et al.,* 2020; Baker *et al.,* 2019) have utilized the Lepton 3.5 module to monitor canopy temperature.

In general, the CWSI is computed using Equation:

$$\mathrm{CWSI} = \frac{(T_c - T_a) - (T_c - T_a)_u}{(T_c - T_a)_{ul} - (T_c - T_a)_u}$$

T_c measures canopy temperature, T_a stands for air temperature, $(T_c - T_a)_u$ and $(T_c - T_a)_{ul}$, each are the lower bound and upper limit, respectively (Idso *et al.,* 1981; Jackson *et al.,* 1981, 1988).

Canopy temperature is a crucial variable in calculating a CWSI. If the device used for measuring the canopy temperature has low accuracy, the results of the CWSI value will be full of errors as well. Therefore, it is crucial to use accurate and reliable measurement devices when calculating the CWSI.