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APPLICATION OF "SMART IRRIGATION" POROUS IRRIGATION FOR TOMATO (SOLANUM LYCOPERSICUM, L.) IN SWAMPLAND, SOUTH SUMATRA, INDONESIA

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Abstract

This study aimed to design and implement a subsurface irrigation system by using porous emitters of various materials such as bubblegum, flannel, cotton, and spandex. It was carried out using descriptive methods, namely designing, measuring, observing, calculating, and analyzing data quantitatively. The results showed that the soil conductivity ranges from 1.0 to 3.01 cm3/hour and the flannel material transmitter has a maximum hydraulic conductivity of 4.681 cm/hour. The largest and smallest porous irrigation discharges were found in flannel and bubblegum materials, with values of 2.4 l/hour and 0.59 l/hour, respectively. Emitter flannel had the best absorption capacity of 1.9348 l/hour, and the growth of porous emitter plants had the highest values of 228.6 cm, 158, 133, and 92 for height, leaves, flowers, and fruit. The daily water requirement in the vegetative phase was 112.15 ml/day and the flowering stage continued to increase by 211.95 ml/day, while the fruiting stage was 176.63 ml/day. Tomato water requirement decreased to 156.96 ml/day at the ripening stage, and irrigation application one day after the vegetative, flowering, fruiting, and vegetative stages required 118.33 ml/day, 141.30 ml/day, 194.28 ml /day. Day, and 264.93 mm/day, respectively. Furthermore, subsurface irrigation produced flannel optimally to meet the needs of plant growth, had no surface runoff and water loss due to percolation, with efficient use of water, and can reduce or prevent salinization.

Keywords: Subsurface Irrigation, Emitter Porous, Hydraulic Conductivity, Water Productivity, Crop Production

INTRODUCTION

Micro-irrigation technology and management are still being developed in Indonesia to address water scarcity and swampland use during the dry season. This technique distributes water throughout the root region of the plant to maximize the efficiency of water. Moreover, previous investigations have shown that the use of simple as well as cost-effective technology can be applied, developed, and tested by small and large-scale farmers. There is currently a reduction in the use of the micro-irrigation system (drip) due to the high capital cost of pressurized pipelines and pumps, as well as the energy cost of operation [1]. Subsurface irrigation is a simple, cost-effective, and practical system that increases crop production in arid regions [2]. Its advantages suggest that this method gives better water savings than surface drip irrigation systems [3]. Meanwhile, micro-irrigation techniques have high efficiency by direct flow of water into the soil (sub-irrigation). In this method, water can be absorbed by plant roots, there is no water loss (drainage), and moisture is maintained by the soil to break down the evaporation

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rate [4] The water flowing in the micro-irrigation system is known as an emitter and its design is important with deepest parameters that are used for operation. The correct design and selection of emitter materials minimize water loss and eliminate surface runoff as well as percolation. The use of an emitter protected by a filter has been found to improve the effectiveness of water flow in a subsurface irrigation system [5]. It was also discovered that fluctuating water pressure can change the distribution of flow rates until the blocking agent reduces the formation of blockage-producing substances in the emitter [6]. Pressure irrigation technology is very efficient in water use, but the cost of building is expensive beyond the ability of farmers on dry land. Although subsurface drip irrigation can drain water that does not follow the hydraulic conductivity of the soil, it is very efficient and often recommended to cope with water scarcity in arid and semi-arid areas. This method saves water, however, it requires a relatively high initial investment and quality of water hygiene.

A study on jug micro-irrigation systems was carried out using porous planting media as a temporary water reservoir. It was discovered that the system seeps water around the roots of plants due to hydrostatic pressure, suction of soil matrices, and permeability of irrigation jugs [7]. Meanwhile, Deficit Irrigation (DI) has been proposed as a valuable strategy to conserve water use, especially in arid and semi-arid water-scarce areas. The available literature also suggests that the right DI strategy can explain a large amount of water savings with some improvement in the quality of fruits such as tomatoes [8].

Micro-irrigation systems with soil conductivity control using porous material media in the ring transmitter can adjust conductivity values suitable for seasonal crops [9]. Furthermore, porous irrigation of textile materials was found to have a degree of permeability that can maintain water seepage and soil moisture. Enhanced water use efficiency (WUE) is the key to sustainable agriculture in arid regions. The installation of capillary barriers (CB) has been suggested as one of the potential solutions [10]. According to a previous report, a Sub-surface Drip Fertigation study (SSDF) can save and improve water, as well as crop productivity [11]. System conventional and water-saving irrigation was also developed as smart or automatic irrigation that uses microcontrollers to maintain irrigation time and soil moisture conditions [12]. According to a previous report, the experimental subsurface irrigation method of porous clay pipes is a water-saving technology compared to the surface method [13]. The result showed that subsurface irrigation systems by placing emitters below ground level can reduce emissions and increase crop production [14]. Therefore, this study aimed to produce a subsurface irrigation design using a porous transmitter to regulate the flow of water directly to the root area without percolation and evapotranspiration**.**

MATERIALS AND METHODS

This study was conducted by the Natural Resources Laboratory of the Agricultural Engineering Study Program, Department of Agricultural Technology, Soil Science Laboratory, Ministry of Land, Water Resources Engineering Laboratory, Department of Civil and Environmental Engineering, Bogor Agricultural Institute, and the greenhouse of the Faculty of Agriculture, Sriwijaya University, Indonesia. It was carried out using descriptive methods, namely

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designing, measuring, observing, calculating, and analyzing data quantitatively. The four types of emitter materials used for crop production using tomato plants include bubblegum (M1), flannel material (M2), spandex material (M3), and cotton material (M4). Meanwhile, the amount of water administered was 150 ml (R1), 200 ml (R2), and 250 ml (R3).

a. Materials

The emitter shaft is made of a flexible hose 11 cm long with a diameter of 15.875 mm. Furthermore, it is equipped with a hole where water enters from the lateral hose with a diameter of 0.4 cm and 0.2 cm as an outlet. Porous textile materials, such as bubblegum, flannel, cotton, and spandex, are installed to coat plastic hoses 15 cm long and 15 cm wide that control the flow of water out of the reservoir and seep into the walls of the emitter, as well as wet the soil around the plants. Porous emitters have little water flow and can maintain soil moisture around the roots without evaporation, infiltration, and percolation.

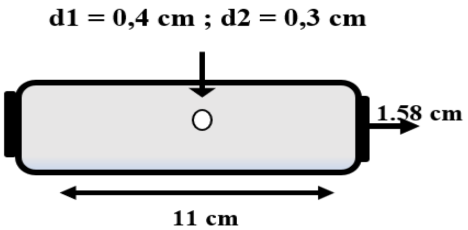

Figure 1. Porous Emitter

b. Porous Emitter Irrigation Design

Porous subsurface irrigation systems can seep water through emitters. The water is distributed into the soil around the plants with little discharge and maintains soil moisture around the roots without evaporation, infiltration, and percolation.

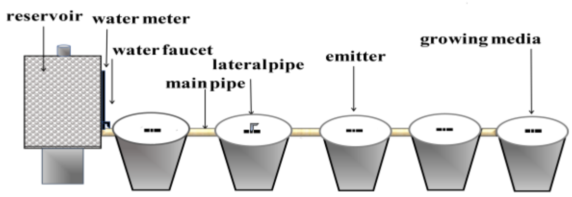

Figure 2. Porous Emitter Irrigation Design

c. Hydraulic Conductivity

The conductivity of unsaturated (dry) soils is calculated using the equation expressed below (Setiawan & Nakano, 1993):

$$K(\theta) = K_s \exp [-a1(\theta_s - \theta)^{b1}]$$

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Where K(θ) is the hydraulic conductivity and moisture content, is the soil moisture content ($catheter^3/cm^3$), K_s is the Permeability (cm/sec), and a1 and b1 are empirical parameters

d. Hydraulic Conductivity of Materials

Measurement of saturated hydraulic conductivity is carried out on soils and porous materials using the falling head method as follows.

$$K_{soil/material} = 2.3 \times (a \times l)/(A \times h) \log h1/h2$$

Where $K_{soil/material}$ is the hydraulic conductivity of the porous material (cm/second), a is the surface area of the cylinder (cm^2), l is the thickness of the material sample (cm), and A is the surface area of the porous material (cm^2), t is the time (seconds), h1 is the height of the initial height (cm), and h2 is the height at a certain time t (cm).

e. Crop Production

An emitter test was carried out using a house plant based on the assumption that there is no water supply only from vertical irrigation, equating precipitation with zero. Subsequently, plant growth including height, number of leaves, flowers, and fruits, as well as weight was observed. Statements are made once a week until harvest and the yield of production was expressed in cm for height, leaves, and weight of the fruit in kg. Plant height was measured from the base of the stem to the tip of the highest leaf in cm. The number of leaves was calculated, and white flowers, as well as fruits, were measured until harvest.

f. Water Consumption

Measurement of water requirements for tomato plants is carried out based on a daily balance without rain and percolation. Evapotranspiration heights use daily climate data from climate stations. The water requirements of plants such as evapotranspiration (ETc) are determined using the equation below (Doorenboos and Pruitt, 1977).

$$ETc = Kc \times ETo$$

Where ETc is the evapotranspiration of plants (mm/day), Kc is the factor of the planting coefficient, and ETo is the reference of evapotranspiration (mm/day).

RESULTS AND DISCUSSION

a. Application of Porous Emitter Irrigation

The porous vertical emitter irrigation system consists of (1) a water reservoir, (2) the main pipe, (3) a channeling pipe, (4) connecting valve, (5) a planting medium, and (6) an emitter. The water reservoir serves as a container with a capacity of 60 liters, equipped with a water droplet measuring device to identify the use of water during watering. The water flowed through the main pipe with holes to wet 5 planting media with a distance of 60 cm. Subsequently, the water is drained by opening the tap to enhance flow through the pipe to the porous transmitter.

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Figure 3. Irrigation System

The main pipe delivers water to the lateral one that fills the emitter through an intake hole of 4 mm diameter and discharges water using the 2 mm diameter drain hole. This is followed by the placement of porous emitters under the ground around the roots of the plant, draining water by wetting, seeping into the porous material, and moisturizing the soil around the roots. The experiment used 4 types of emitter materials, namely bubblegum, flannel, spandex, and cotton. Meanwhile, watering is carried out with 2 watering intervals, namely daily (R1) and one-day intervals (R2).

b. Application of Porous Emitter Irrigation

The hydraulic conductivity of the soil at a depth of 10 cm is 3.03 cm^3/h, and at 20 cm is 0.12 cm^3/h. Based on the soil's ability to drain water, the conductivity included in hydraulics ranges from 1.0 to 3.01 cm^3/h, and can still drain water effectively, especially during the dry season [15]. Therefore, the hydraulic conductivity of the marshland produces crops with a whole dry season for horticultural crops. This implies that the deeper the soil, the smaller the value of hydraulic conductivity. However, the greater the conductivity of the soil, the easier it is to pass water due to the large pore space or cavity.

Table 1: Hydraulic Conductivity of the Material

Soil depth (cm)	Soil conductivity (cm/hour)	Porous material	Material conductivity
10	3.03	Bubllegum	1.05
10	2.02	Flannel	4.68
20	0.12	Spandex	3.35
20	0.11	Cotton	2.98

The selection of this porous material is based on its proximity to the hydraulic conductivity of the soil. The result of flannel and bubblegum material has a value of 4.68 cm/hour and 1.05 cm/hour. The value of hydraulic conductivity is an illustration for estimating the dimensions of the soil wetting pattern with the uptake of water by the roots obtained from the soil conductivity value. A previous study stated that the conductivity of porous emitters is used to compare soils as a permeability approach [16]. The advantage of a porous emitter irrigation system can become a filter for running water and manure. This is because the presence of a porous emitter coated with textile media can filter the salinity of water and existing impurities. The filter is used to significantly remove turbidity, total solids, carbonates, and bicarbonates

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available in poor-quality water for irrigation. Moreover, investigation on emitters equipped with interaction filters has a significant effect on emitter blockage [17]. Field experiments were conducted to study the effect of the fertigation component on emission uniformity, emitter blockage, and soil infiltration rate [18].

c. Release of Porous Materials

The discharge is measured to determine the amount of water flowing in units of time, without using energy.

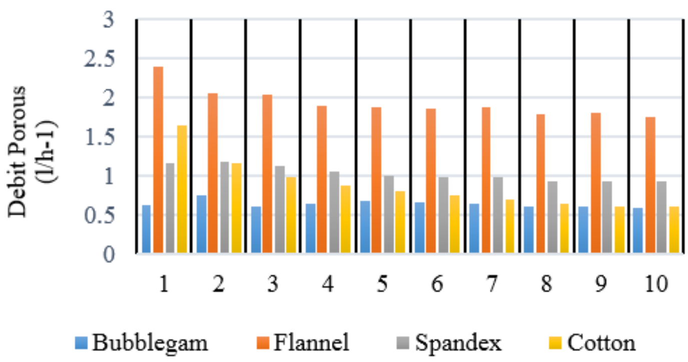

Figure. 4 Porus Material Discharge

The largest porous irrigation discharge in flannel material is 2.4 l/h, and the smallest in bubblegum material has a value of 0. 59 l/h. Furthermore, the flow discharge produced by porous vertical emitter irrigation is small, with a drip ranging from 1.98 to 2.80 l/hthe. This shows that the method is very efficient and all the water is stored in the root zone without wastage through percolation.

Flannel emitters have the highest flow discharge compared to other porous materials. This is equivalent to the 4,681 cm/h conductivity value of flannel hydraulics. The magnitude of the release of porous materials is influenced by the conductive value of the material hydraulics. A previous study stated that the water discharge on the emitter will increase linearly at low pressure to meet the soil moisture content [19]. It was also established that a greater conductivity value of the material means a higher rate of water discharge or seepage. This shows that it is easier for porous materials to escape from the water. However, the main factor in the smallness of water discharge is the improper application of pressure.

d. Uniform Release of Porous Material

Emission Uniformity is the uniformity of the working system of the material that seeps water.

Table 2. Uniformity of Porous Material

Debit Porous ($1/h^{-1}$)				
Sample	**Bubblegum**	**Flannel**	**Spandex**	**Cotton**
1	0.631	2.400	1.161	1.636
2	0.742	2.057	1.180	1.161
3	0.610	2.037	1.125	0.981
4	0.640	1.894	1.051	0.878
5	0.671	1.875	1.000	0.810
Total:	3.295	10.264	5.517	5.468
Average:	0.659	2.052	1.103	1.093
EU:	92.57%	91.33%	90.617%	74.136%

Based on the seepage freshness rate as classified by ASAE, EU with values 94-100% is excellent, while EU value 81-87%, 68-75%, 56-62%, and <50% represent good, quite good, poor, and not feasible, respectively. The observation of the uniformity of the 4 porous materials showed a good degree of uniformity, which is above 90%. Therefore, the flannel porous material can be applied because it has a good discharge uniformity value. Without proper design and placement of emitters, the number and type of emitters per plant will affect plant growth [20]. Emitter uniformity is an important parameter in irrigation systems because it affects the amount of water provided. The factor that determines the uniformity of the water flow of the emitter is the discharge. The vertical irrigation emitter porous has a good discharge that can drain water by seeping it in a continuous manner around the plant, without the help of pressure to remove water. The degree of uniformity of irrigation determines the ability of plants to produce well [21].

e. Emitter Seepage

Seepage on the walls of porous emitter material is the most important performance of a porous irrigation system. This is because it will determine the water needs of plants and the efficiency of irrigation water use. Based on the results, the flannel emitter has the best absorption of 1.9348 l / h, seepage of spandex material at 1.18624 l / h, seepage of cotton material at 0.8767 l / h, and bubblegum has the lowest seepage of 0.6135 l / h.

Table 3. Emitter Seepage

	Bubblegum (M1)		**Flannel (M2)**		**Spandex (M3)**		**Cotton (M4)**	
Volume	**Time (hour)**	**Debit (1/h)**	**Time (hour)**	**Debit (1/h)**	**Time (hour)**	**Debit (1/h)**	**Time (hour)**	**Debit (1/h)**
0.01	0.016	0.631	0.004	2.4	0.009	1.161	0.006	1.637
0.02	0.027	0.472	0.009	2.057	0.017	1	0.017	1.162
0.03	0.05	0.61	0.015	2.038	0.027	1.125	0.03	0.982
0.04	0.062	0.64	0.021	1.894	0.038	1.051	0.046	0.878
0.05	0.074	0.671	0.027	1.875	0.05	1	0.062	0.81
0.06	0.092	0.654	0.032	1.862	0.061	0.981	0.081	0.745
0.07	0.108	0.65	0.038	1.877	0.072	0.977	0.101	0.692
0.08	0.13	0.613	0.045	1.789	0.087	0.923	0.123	0.65
0.09	0.147	0.612	0.05	1.8	0.097	0.926	0.147	0.611
0.1	0.169	0.582	0.057	1.756	0.108	0.923	0.167	0.6

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Amount	6.135	19.348	10.247	8.767
Average	0.613	1.938	1.024	0.8767
Maximum	0.671	2.4	1.18	1.637
Minimum	0.472	1.756	0.923	0.6

The horizontal emitter of porous material can seep water into the roots of plants with a constant discharge in the absence of pressure to drain water, which is significantly affected by pressure. This is because as the pressure in the soil increases, the emitter discharge, soil moisture content, and uniformity of soil moisture content are also improved. The results show that the emitters of different porous materials and the placement around the roots of plants with good discharge significantly influence the yield and quality of tomatoes. The vertical emitter irrigation made from porous seeps water around the emitter to preserve the saturated root zone of the plant for some time after the incidence. Subsurface irrigation with the right emitter can also maintain soil saturation during and sometime after irrigation. The main advantage of emitters coated with porous material and the placement of emitters horizontally is to reduce salinity in the soil, especially in areas with salty moisture content. Moreover, emitters used in surface irrigation are susceptible to chemical blockages of emitters by salt water and soil cramming that interferes with growth [22].

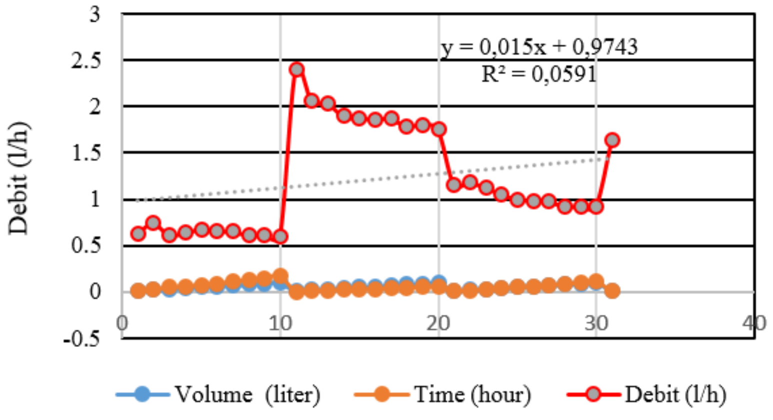

Figure. 5 Emitter Seepage and Accumulation Rate

The graph shows a decrease in the seepage rate that occurs after the soil is moist and becomes constant to obtain a balance between the height of the emitter wall and the surrounding soil. Porous flannel material is worth using because it has a good discharge uniformity value. The uniformity of emitter discharge is an important parameter in irrigation systems because it affects the amount of water supplied. According to a previous investigation, emitters with low discharges can cause irrigation for plants to be unfulfilled [23].

f. Plant Growth

The growth yield of subsurface irrigated plants with a variety of 4 materials, including porous emitter flannel has a plant height value of 228.6 cm, the number of leaves is 158 pieces, and flowers is 133, with a total harvest of 92 pieces. Tomato plant growth is the best flannel material

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because it has the most significant material conductivity value of 4.68 cm/hour, with a discharge material of 1.93 l/ hour. The lowest plant growth is observed in bubblegum with a hydraulic conductivity of 1.05 cm/h. The size of the porous irrigation discharge is influenced by the hydraulic conductivity value of the material. This value is directly proportional to the rate of water discharge or seepage. The plants respond to the water supply when the flannel emitter more easily seeps and drains water into the soil, and stress does not develop during growth. The yield rate of tomato crops is characterized by the level of harvest achieved for several indicators. Meanwhile, tomato crop production depends on the irrigation system, local climatic conditions, and the selection of a growing medium [24].

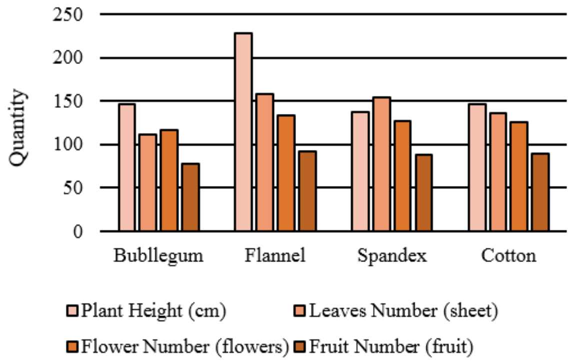

Figure. 6 Plant Growth

Porous irrigation has a degree of permeability that can maintain water seepage on the subsurface of the emitter and soil moisture. Generally, water-saving and agricultural activities can be adequately maintained with irrigation systems made of porous materials. Plants with high porosity soils can use emitters with a small discharge for a long time of application. Porous irrigation of textile materials has also been found to have a degree of permeability that can maintain water seepage and soil moisture. The selection of emitter type will determine the continuity of plant growth, and blockages that disrupt the water flow of plants [25].

g. Water Consumption

There is variation in the amount of water that tomato plants need during the vegetative period to harvest. The results show that the daily water requirement at the vegetative, flowering, and fruiting, stages is 112.15 ml/day, 211.95 ml/day, and 176.63 ml/day, respectively.

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Table 4: Water Consumption

Plant Growth Phase	Etc (mm/day)	A (mm^3)	Plant Water Requirement (cm^3 or mm/day)	Watering time (ml)	Total Water Needs (lt)
Vegetative	1.59	70650	112156	70	7.85
Flowering	3	70650	211950	70	14.83
Fruitful	2.5	70650	176625	70	12.36
Harvest	2.25	70650	158.962	70	11.13
Vegetative	1.68	70650	118.338	70	3.55
Flowering	2.	70650	141.30	70	4.239
Fruitful	2.75	70650	194.288	70	5.828
Harvest	3.75	70650	264.937	70	7.948

There is variation in the amount of water that tomato plants need during the vegetative period to harvest. The results show that the daily water requirement at the vegetative, flowering, and fruiting, stages is 112.15 ml/day, 211.95 ml/day, and 176.63 ml/day, respectively. Meanwhile, in the ripening stage, the need for water decreases to 156.96 ml/day. The administration of water one day after the vegetative stage is 118.33 ml/day, while the flowering, fruiting, and maturation phases are 141.3 ml/day, 194.28 ml/day, and 264.93 mm/day, respectively. The amount of water that tomato plants need per day is very efficient compared to other emitter subsurface irrigation systems. The results indicate that the water requirements of the emitter cube subsurface irrigation system require water ranging from 0.24 liters to 0.73 liters per day [26]. Since the number of emitters per plant does not have a significant effect, the values obtained are the quality of the plant's fruits, fruit yields, and the efficiency of water use. Subsurface irrigation also causes water loss by drainage in the planting medium. A previous report on irrigation systems has shown that the use of porous material can hold water in the upper and underground layers. It was discovered that soil hydraulic parameters can be used to predict groundwater dynamics in relatively complex soil profiles with porous emitters.

The exact calculation of the water requirements of plants or daily evapotranspiration during a certain period flowing into the soil is essential for sustainable agriculture [27]. This is because the increase in requirements affects the growth of fruits, size, quantity, and color. The amount of water needed by plants using porous material per day is more efficient than conventional planting. The need for tomatoes in traditional fields aged from 1 to 3 weeks is 200 ml, and at 4 weeks, it is 300 ml. At the age of 7 to 10 weeks, the need for tomatoes is 400 ml but decreases by 300 ml after planting. Different levels of water and nitrogen are considered to have significant effects on yields in arid regions [28]. The interval and amount of water application greatly determine the yield of crop production on water content, water use efficiency, and plant growth. The application of water below the surface with a shallow installation depth can wet the soil quickly without any water loss due to evaporation [29].

The value of evapotranspiration in tomato plants is smaller compared to conventional cultivation in the field due to temperature, humidity, and solar radiation. A previous study showed that full irrigation (100% ETc) increases plant growth and tomato yield but produces more small and late fruits. Meanwhile, the subsurface irrigation method does not lose water to the atmosphere, percolation, and infiltration but stores and seeps water using absorbent materials. The above-ground irrigation method is lost to the atmosphere due to emissions. This shows that the selection of irrigation methods with a more accurate estimation of plant evapotranspiration is an important factor for efficient water management [30]. The sub-surface irrigation method of water is directly applied to the root zone of the plant [31]. Emitters are one of the most important parameters considered in designing, implementing, and managing subsurface irrigation systems [32]. During the 70-day watering period from the vegetative phase to harvest, the plant waters need varies from 7 to 11 liters after planting. Therefore, the provision of irrigation water at intervals of one day requires 3.5-8 liters of water. Water productivity is the amount of water used to produce evapotranspiration in an open environment [33].

CONCLUSION

Based on the hydraulic conductivity analysis, the emitters made of flannel materials have the highest value, which is 4.68 cm/hour, while bubblegum has the lowest value, namely 1.05 cm/hour. Plants producing flannel and spandex grow to a height of 228.6 cm and 137 cm. The best number of leaves is watered daily with flannel material of 287 strands, a day interval of 267 strands of spandex material, and a watering time of two days of 132 strands using the production of flannel producing. Furthermore, the growth rate of plants at one-day watering intervals yields 1687 grams. The number of fruits is 57 pieces, weighing 322 grams, which is watered once every two days using a spandex transmitter. The daily water requirement for the vegetative phase is 112.15 ml/day. The successive stages of flowering, fruiting, and ripening are 211.95 ml/day, 176.63 ml/day, and 156.96 ml/day. The need for water for one day in the vegetative phase is 118.33 ml/day, with successive flowering, fruiting, and maturation phases of 141.30 ml/day, 194.2875 ml/day, and 264.93 mm/day. Therefore, flannel materials have the highest water productivity of 1.37 kgm^3, while bubblegum has the lowest value, which is 0.78 kg/m^3.

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