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By KH Iskandar

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COMPOSITION OF CLAY AND SAND IN POROUS CERAMIC EMITTERS FOR DRIP LINE OF SUBSURFACE DRIP IRRIGATION SYSTEM

K.H. ISKANDAR [1]*, MOMON SODIK IMANUDIN [2], BAKRI [3] and S.J. PRIATNA[4]

[1] Lecturers in Department of Agriculture Technology, Faculty of Agriculture, Sriwijaya University Indonesia.
[2, 3, 4] Lecturers in Department of Soil Science, Faculty of Agriculture, Sriwijaya University Indonesia Jl. Raya Palembang-Prabumulih KM 32, Kampus Unsri Indralaya Kabupaten Ogan Ilir Sumatera Selatan Indonesia.
Email: [1]kh.iskandar@fp.unsri.ac.id (*Corresponding Author), [2]momon_unsri@yahoo.co.id

Abstract

This research objective was to develop the best composition of clay and sand for prous ceramic emitter by considering its wetting pattern characteristic. This research had done at Hangar of Soil and Water Laboratory, Agricultural Engineering Study Program, Agricultural Faculty of Sriwijaya University. The main ingredients for ceramic emitter are mixture of sand and clay in this study. Clay material has function as cementing agent, whereas sand has function as strengthening agent. Randomized Block Design had used in this research. Clay and sand composition are as follows: P_1 (1.5 part of clay and 1 part of sand), P_2 (1.25 part of clay and 1 part of sand), P_3 (1 part of clay and 1 part of sand), P_4 (1 part of clay and 1.25 part of sand) and P_5 (1 part of clay and 1.5 part of sand). Each treatment has three replications. Clay and sand composition for developing porous ceramic emitter has effect on horizontal wetting direction (H), vertical direction (V_a and V_b) and wetting ration below *drip line* (H/V_b). Emitter with 1 part of clay and 1.5 part of sand composition (P_5) showed the highest distance in term of horizontal direction wetting, vertical wetting above drip line and below drip line with magnitude 13.95 cm, 10.52 cm and 13.21 cm respectively. However, it had the lowest ratio of horizontal wetting distance toward wetting distance below drip line (H/V_b) with average value of 1.06. The increase of sand composition only had effect on wetting ration below *drip line* (H/V_b). Results of simulation showed that all treatments had horizontal wetting toward vertical wetting higher than 1.0 as one of criteria to indicate relatively good wetting pattern. In term of wetting width in horizontal direction, the best treatment is (P_5) having composition 1 part of clay and 1.5 part of sand.

Keywords: Ceramic Emitter, Drip Line, Horizontal Wetting, Vertical Wetting, Vertical Wetting Ratio.

1. INTRODUCTION

The use of *subsurface drip irrigation*) which is hereinafter referred to SDI is increasingly widespread from year to year due to significant production increase as well as water use saving with water application efficiency can achieve 50% up to 95% (Ayars *et al*., 1999; Cao *et al*., 2021). In case of limited water supply especially during dry season, this method is very proper for water application (Payero, *et al*., 2016; Patra *et al*., 2020). Therefore, sustainable agriculture is highly depend on water supply effort and increasing farmer knowledge in term of water application that is efficient and saving without decreasing yield (Jafari *et al*., 2021). Method of direct irrigation water application into root zone area is the best water application method in order to increase yield. This method had applied on grape plant resulting in 10% production increase (Xiaochi *et al*., 2020). It also showed that this production level increase is relatively higher than that of sprinkler irrigation application. Results of sweet corn crop can be increased 12% to 14% higher than that of by using sprinkle irrigation (Phene & Sanders, 1976;

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Firouzabadi et al., 2021) and about 20% higher than that of by using furrow irrigation (Bogle *et.al*., 1989; Khamees et al., 2023). SDI in China combined with medium dose fertilizer application was capable to achieve maximum yield for corn crop (Haiyang *et al*., 2020). Application of SDI with fertilizer capable to increase production by 12% and decrease evapotranspiration by 15% (Li *et al*., 2021). SDI model is using *drip line* set made of *polyethylene* pipe which is buried below soil surface and installed parallel with crop rows. Series of emitter are installed on drip line with certain distance. For application example, installation at depth of 0.2 m and distance between line of 0.6 m had successfully applied on alfalfa crop (Cai *et al*., 2018).

The emitter depth buried in land for horticultural crops having shallow root system is about 0.1 m to 0.2 m (Devasirvatham, 2008; Hamad *et al.,* 2022) even up to 0.45 m below soil surface (Davis *et al*., 1985). *Drip line* is located 0.05 m in land for sweet corn crop ((Phene & Sanders, 1976) up to 0.45 m (Onken *et al*., 1979). The best application depth for sugarcane crop is at depth of 0.2- 0.3 m (Dashteghol *et al*., 2021). Research result for alfalfa crop planted at 0.7 m depth showed production increase of alfalfa by using SDI system (Hutmacher *et al*., 1996). Optimization of drip line placement depth for Bombay's onion crop had been conducted and it is concluded that result for SDI is better than that of SD because SDI has less water loss due to evaporation (Evett *et al*, 1995; Biswas *et al*., 2015) and subsequently it was reported that *drip line* placement (lateral) 15 cm and 30 cm below soil surface is capable to store water with magnitude of 5.1 cm and 8.1 cm, respectively. Apart from the PE hose type *drip line*, other *drip line* or *emitter* made of porous ceramic had been developed such as emitter in form of pitcher or pot (Naik *et al*., 2013; Tripathi et al., 2017), porous ceramic tube (Liu et al., 2000; Cai *et al*., 2018). System design parameter generally should determined through infiltration experiment at different working operation condition in order to determine infiltration characteristics of subsurface drip irrigation emitter (cumulative infiltration, wetting front and soil water content distribution (Assouline, 2019; Sahim, 2023).

Emitter infiltration characteristics are affected by some factors such as soil texture, bulk density, initial water content, emitter placement, immersion depth and emitter characteristics (structural size, discharge design and operational pressure head (Sakaguchi *et al*., 2019; Kalashnikov et al., 2023). Water released from emitter will spread in horizontal and vertical directions within the root zone. Therefore, emitter capability in spreading water should be take into account in water management within root zone in order to increase water use efficiency, minimize evaporation, percolation and irrigation cost.

Emitter discharge is one of the most important parameter that should be take into account in design, operation and management of *subsurface drip irrigation systems* (Nogueira *et al*., 2021; Rambabu *et al*., 2023;). Moreover, emitter discharge is depend on working pressure head and ceramic hydraulics conductivity (Ashrafi et al., 2002; Patel *et al*., 2007; Rasheed, 2023). In addition to working pressure head, discharge of porous ceramic emitter is also affected by soil texture especially clay and sand composition (Payero *et al*., 2016; Nogueira *et al*., 2021).

This research objective was to develop the best composition of clay and sand for prous ceramic emitter by considering its wetting pattern characteristic.

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2. MATERIALS AND METHOD

This research had done at Hangar of Soil and Water Laboratory, Agricultural Engineering Study Program, Agricultural Faculty of Sriwijaya University. The main ingredients for ceramic emitter in this study are miture of clay and sand. Clay material has function as cementing agent, whereas sand has function as strengthening agent.

Randomized Block Design had used in this research. Clay and sand composition are as follows: P_1 (1.5 part of clay and 1 part of sand), P_2 (1.25 part of clay and 1 part of sand), P_3 (1 part of clay and 1 part of sand), P_4 (1 part of clay and 1.25 part of sand) and P_5 (1 part of clay and 1.5 part of sand). Each treatment has three replications.

Clay and sand materials for each treatment is homogenously mixed, moisturized and formed using manual pressure method. Porous ceramic could be made through several procedures, including compression method and extrusion technique (Cai et al., 2018; Vaghei et al., 2022).

The resulting emitter has diameter of 9 mm and length of 12 mm. Subsequently, the moist emitter is air dried for one week. Then emitter burned by using Mapple Furnace gradually until maximum temperature of 900^{o}C for 2 x 24 hours. The increase of sintering temperature from 900 ^{o}C up to 1100 ^{o}C produced porous ceramic with decreasing porosity although its mechanical strength is increasing (Mouiya *et al*., 2019).

Observation of water distribution from emitter done by using air dried soil which is placed within transparent acrylic box with size of (LxWxH) 60 cm x 40 cm x 45 cm. *Drip line* was located at longitudinal direction toward acrylic box that is buried 10 cm below soil surface. Soil media used in this experiment has air dried condition having water content about 13.5%, average mass density of 1.12 g/cm^3 and classified as sandy loam texture with sand content of 72.88%, loam content of 19.57% and clay content of 7.65% (Novyanti, 2013).

Observation of wetting front for each treatment done at inlet pressure of 15 psi. Because emitter discharge differences as a results of different clay and sand composition, then not all treatments have the same operational time. Operational time for P_1 is 90 minutes, P_2 is 60 minutes, whereas P_3, P_4 and P_5 treatments are only 30 minutes.

The observed parameters are width or distance of horizontal wetting (H), vertical wetting distance above *drip line* (Va), vertical wetting distance below *drip line* or wetting depth (Vb), ratio of H/Va and ratio of H/Vb (Figure 1).

The supporting data is consisted of emitter discharge for each treatment, emitter hydraulics conductivity measured by using *falling head* method and initial water content of soil measured by using gravimetric method.

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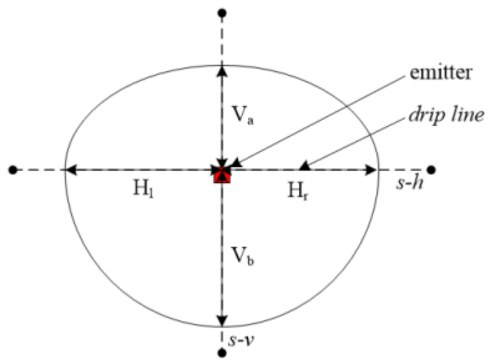

Figure 1: Two dimension of wet surface scheme for measurement of water distribution from emitter

After irrigation application, wetting pattern plotted in normal graphic paper. Wetting width or horizontal wetting distance (**H**) measured from intersection point which pass emitter vertical axis into wetting perimeter point (end). If wetting width at left and right from emitter vertical axis is not symmetrical, then average value of horizontal wetting width (**H**) is used. Vertical wetting distance above *drip line* (V_a) is measured from intersection point of horizontal axis and vertical axis towards wetting perimeter peak, whereas wetting distance below *drip line* (V_b) or wetting depth is measured from intersection point of horizontal axis and vertical axis of emitter toward wetting perimeter base.

3. RESULTS AND DISCUSSION

Each parameter values of treatment result could not compared directly because of different irrigation time. Data from prediction result for 60 minutes by using polynomial regression pattern used for all parameters because their patterns generally resemble a semicircle (Skaggs *et al*., 2004; Appels, & Karimi, 2021).

3.1. Horizontal and Vertical Wetting Front

Wetting width or water spreading from emitter at horizontal direction is diverse because differences of emitter discharge which related to different clay and sand composition as treatment. Emitter made from 1 part of clay and 1.5 part of sand composition had produced the highest discharge with magnitude of 10 ml/min. However, discharge for all treatments are still low although operational pressure up to 15 psi is applied. In addition to operating pressure in porous ceramic emitter, emitter discharge can also be affected by clay and sand composition (Patel *et al*., 2007; Cai *et al*., 2018).

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After irrigation, water slowly infiltrate into soil in horizontal direction, vertical direction below drip line and part of water seep in vertical direction into soil surface. If air humidity in atmosphere is lower, then part of water mass will move into atmosphere in form of moisture (evaporation). Emitter capability in distributing water in horizontal direction will determine the distance amongst emitters along drip line, number of emitter required, initial investment cost and maintenance cost of constructed irrigation system. Average horizontal wetting width for treatments and replications obtained from irrigation prediction results for 60 minutes duration (Figure 2).

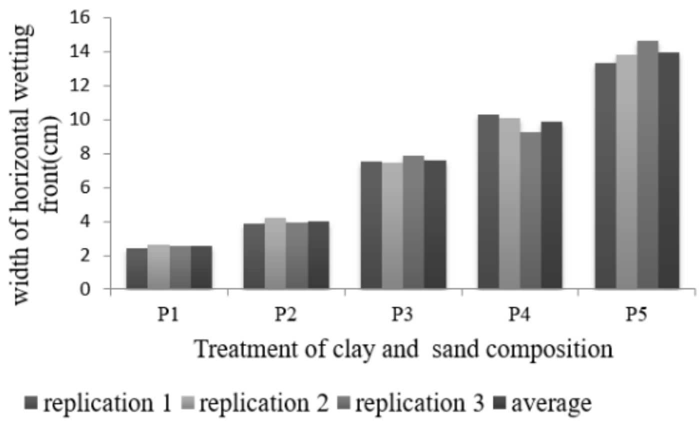

Figure 2: Wet surface width in horizontal direction for each treatment of clay and sand composition

Irrigation applied below soil surface cause water potential increase in surrounding of drip line. Driving force in this condition has role for water distribution into all directions and getting further from emitter. P_5 treatment showed significant increase of wetting width up to 13.95 cm from emitter position (Table 1). The higher the initial water content, the higher wetting pattern size into all directions (Skaggs *et al*., 2004; El-Nesr *et al*., 2010; Liu *et al*., 2011; Rasheed, 2023). For emitter with higher discharge, soil moisture increase faster, faster water distribution and wider wetting front. However, some aspects should taken into account such as the effect of soil physical property and gravitational effect on wetting ratio below drip line and root zone that will be irrigated. Distribution in horizontal direction can increased by decreasing emitter discharge and increasing application time (Cai et al., 2022). Capability of emitter in distributing water at horizontal direction will determine distance amongst emitters along drip line and subsequently can affect the use of initial cost and maintenance cost.

Water spreading in soil also occurs at vertical direction. Vertical wetting above drip line (V_a) is affected by capillary force which related to adhesion and cohesion forces. Vertical spreading above drip line is significantly increase when maximum clay composition is 50% or 1:1 (P_3). Water spreading in vertical direction above drip line is continuously increase significantly and the highest is 10.52 cm which produced by P_5 treatment having clay and sand composition of

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1:1.5 (Table 1). The farther from emitter position, the smaller the effect of capillary force so that wetting perimeter above drip line resemble semicircle form (hyperbole).

Table 1: LSD test results for response of wetting distance in horizontal direction

Wetting distance (cm)	LSD 0,05	Clay and sand composition treatment				
		P_1	P_2	P_3	P_4	P_5
Average horizontal*)	1.28	2.54^a	3.99^b	7.61^c	9.88^d	13.95^e
Vertical above *drip line**)	2.04	2.15^a	3.25^{ab}	6.02^b	9.13^c	10.52^d
Vertical below *drip line**)	3.69	1.94^a	3.19^a	6.91^b	8.02^b	13.21^c

*) Obtained from average simulation result for each treatment and replication up to 60 minutes irrigation time.

For vertical wetting distance below *drip line* (V_b), P_5 treatment also showed the deepest wetting with magnitude of 13.95 cm (Figure 2). Increase in emitter discharge cause faster increase of water mass and gravitational force effect is more dominant than water spreading into soil surface due to capillary force action or capillarity so that wetting ratio below drip line (H/V_b) become smaller (Table 1). If soil receive continuous irrigation, accumulation of infiltration can results in soil water logging. Percolation in this research controlled by matching irrigation operation time with emitter discharge. Proper system design can decrease evaporation at soil surface and percolation in order to prevent unnecessary water loss and increasing water use efficiency (Lamm *et al*., 2006). In optimizing technological potential of subsurface drip irrigation system, study of some operational parameters are required such as frequency and time duration of irrigation, discharge and distance amongst emitters and placement of *drip line* (Skaggs *et al*., 2004).

In addition to emitter flow discharge, water movement into soil is also affect by soil texture and structure (Warrick, 1974; Bresler, 1978; Kumar *et al*., 2021). In soil that contain more sand particle, irrigation water is easily move into deeper soil layer. Some studies showed that soil texture is important factor to determine irrigation design parameter because it has high effect on infiltration. Therefore, design for subsurface drip irrigation system should considered soil texture (Skaggs *et al*., 2010; Nagliˇc *et al*., 2014; Patel *et al*., 2009; Khoshravesh *et al* 2015). Vertical water migration below root zone area can solved by discharge matching (Patel *et al.,* 2007).

3.2. Ratio of Horizontal and Vertical Wetting Distance

Ratio of horizontal wetting distance (H) to vertical wetting distance (V) is one of important parameter in operation of subsurface drip irrigation system. Water spreading considered excellent if it has ratio $H/V \approx 1$ or $H/V \geq 1$.

Ratio of horizontal wetting distance to vertical wetting distance above drip line (H/V_a) is increase if sand composition in emitter increased with average ratio value of 1.19 for P_1 treatment up to 1.34 for P_5 treatment. This fact showed that water spreading is more dominant toward horizontal direction. Emitter discharge for P_1, P_2, P_3, P_4 and P_5 treatments are 1.3 ml/min, 2.1 ml/min, 2.5 ml/min, 5.0 ml/min and 10.0 ml /min respectively. The drip irrigation study by Sharu&Razak (2020) in Malaysia showed that the best emitter discharge is 0.03 l/h.

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The increase of soil moisture surroundin 1 drive capillarity force above *drip line* and driving force. Initial soil water content determine soil water potential at initial stage of infiltration. The higher the initial soil water content, the higher the wetting pattern size into all directions and more uniform (Skaggs *et al*., 2010; El-Nesr *et al*., 2014; Liu *et al*., 2011; Cai *et al*., 2018). The different condition shown by H/V_b ratio, i.e. the higher the sand composition, the lower H/V_b ratio (Table 2).

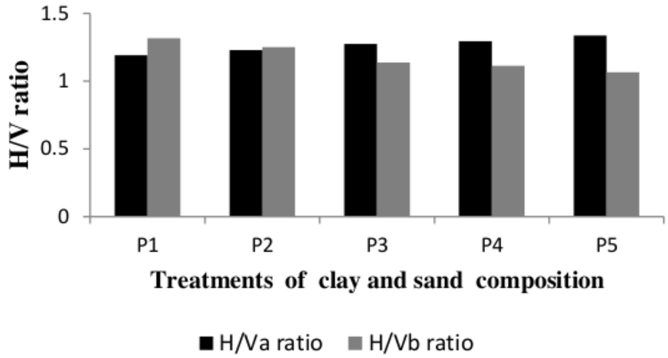

Figure 3: Ratio H/V_a and H/V_b for porous ceramic emitter for each treatment of clay and sand composition

Results of variance analysis (Table 2) showed that different in sand and clay composition has no effect on increase of H/V_a ratio. This is cause by wetting width increase as results of increase of emitter discharge follow by increase of capillary water.

For wetting below the drip line, emitter discharge increase as results of higher sand composition has negative effect on H/V_b ratio (Table 3). High emitter discharge cause faster water mass increase so that gravitational effect is more dominant than driving force effect and capillary force.

Table 2: Analysis of variance result for ratio of horizontal wetting distance to vertical wetting distance below *drip line* (H/V_b)

Source of Variation	Degree of Freedom	Sum of Square	Mean Square	$F_{calculated}$	F_{table}
					5%
Block	2	0.01	0.005	0.40	4.46
Treatment	4	0.04	0.010	0.75	3.84
Error	8	0.10	0.013		
Total	14	0.15			

Water movement through soil particles in vertical direction to deeper soil layer below drip line is infiltration phenomenon that can measured by several methods such as Horton method (Wilson, 1970) and Phillips method. Rasio H/V_b ratio is significantly decrease when clay and sand composition is 1:1.5 which shown by P_5 treatment.

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Table 3: Ratio of horizontal wetting distance to vertical wetting distance below *drip line* (H/V_b)

Clay and sand composition treatment	Ratio H/VB	LSD 5% = 0.24
P1	1.32	a
P2	1.25	ab
P3	1.14	ab
P4	1.11	ab
P5	1.06	b

4. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

Clay and sand composition in porous ceramic emitter making has effect on horizontal wetting (H), vertical wetting (V_a and V_b) and wetting ratio below drip line (H/V_b).

Emitter having the highest sand composition (P_5) showed the highest values of horizontal wetting distance, wetting above drip line and wetting below drip line with respective magnitude of 13.95 cm, 10.52 cm and 13.21 cm.

However, it has the lowest value for ratio of horizontal wetting distance to wetting distance below drip line (H/V_b) with average value of 1.06. Increase of sand compostion only has effect on wetting ratio below *drip line* (H/V_b).

Result of simulation also showed that all treatments have horizontal wetting to vertical wetting ratio higher than 1.0 as one criteria to express relatively good wetting pattern. In term of horizontal wetting width, the best treatment (P_5) with 1.0 part of clay and 1.5 part of sand composition.

4.2. Recommendation

Porous ceramic with composition 1.5 part of sand and 1 part of clay has the lowest pressure strength or easily brittle. Therefore, additional material must considered in order to increase porous ceramic strength. For field application of porous ceramic, water loss due to evaporation and percolation should minimized by matching emitter discharge, irrigation time period and drip line depth with soil texture and irrigation water requirement. After irrigation, drip line should still contains water in order to prevent hardening of fine soil particles in surrounding emitter.

Evaluation toward horizontal wetting of all emitters is appropriate to be used for SDI. The higher the sand fraction content, the farther the horizontal wetting. However, emitter strength become lower due to increase of sand material.

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