Optimizing the Hydraulic Properties of Porous Clay Capsules for Providing Soil Moisture in Subsurface Irrigation System

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Research Article

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Abstract

Clay capsule is one of the porous pipes in sub irrigation system that can release water in near root zone. This paper has attempted to improve the physical and hydraulic properties of clay capsules based on organic matter percent changes in the raw materials. Raw material used for making clay capsules is obtained from calcareous soil of Nasr Abad village of Gorgan, Iran. The ratio of rice bran to calcareous soil as improving hydraulic properties was 1:2, 1:5, 1: 10, 1:15 and 1:20 (kg of rice bran to kg of air-dried soil). The produced clay capsules were named G2, G5, G10, G15 and G20 respectively. The water discharge and soil water distribution of clay capsules were measured at 10, 25, 50, 80, 100 kPa of hydrostatic pressures by discharge-pressure automation instrument. The results showed that a significant relationship between discharges of porous clay capsules and organic matter mixed in raw material. Also, the results show that with increasing organic matter percentage in clay capsule component, the discharge of clay capsules increased. The relationship between discharges of G20 with hydrostatic pressure is linear and in G2, G5, G10, and G15, this relationship becomes non-linear. Meanwhile, soil wetting shape followed a spherical trend due to the slow seepage of clay capsules. But the soil wetting shapes in G15 and G20 was completely spherical, and in G10, G5 and G2 trend to ellipsoid vertically. Finally this is of significance for irrigating plants in arid and semi-arid regions.

Highlights

-Introduction of sub-irrigation method that apply for irrigating plants in arid and semi-arid regions.

-Introduction of buried porous clay capsule that can release water in near root zone.

- Introduction of a solution to reduce water losses for many orchards at arid and semi-arid regions

-Introduction of the soil wetness by clay capsule types for installing into the soil.

1. Introduction

Creating uniform and adequate soil moisture is one of the most challenging issues in irrigated lands. The use of irrigation systems with high water efficiency, such as a sub-irrigation system that provides the optimum water content of the soil, is recommended as a solution to reduce water losses (Adu et al., 2019;Cai et al., 2021) for many orchards at arid and semi-arid regions (Tesfay 2011; Bhople et al. 2014; Al-Mayahi et al. 2020). Also, information on soil moisture variation is an important factor for managing a sub-irrigation system design (Bhayo et al. 2018; Saefuddin et al. 2019). On the other hand, knowing that more than 90% of plants need moisture at the level of soil field capacity for optimal growth. Therefore, using new technology for controlling and monitoring of soil water content at about field capacity range plays a key role in developing soil and water management programs under unsaturated conditions (Ashrafi et al. 2002; Vasudevan et al, 2011; Ghorbani Vaghei et al., 2015; Gebru et al. 2018; Saefuddin et al. 2019).

Clay capsule nozzle is one of the new technologies in irrigation tools which is able slowly to seepage water into soil in the range of field capacity (Bainbridge 2001; Bainbridge 2002; Abu-Zreig et al. 2006; Siyal et al. 2009; Bahrami et al., 2010; Vasudevan et al., 2011; Ghorbani Vaghei et al. 2015; Abu-Zreig et al., 2018). Clay capsule is one of the porous pipes in the sub-irrigation system that can release water in the near root zone. Buried clay capsule irrigation system is known to be very effective in the management of water by supplying a low volume of water to the near root zone, based on the water requirement of crops. As well, it is one of the most important efficient traditional methods for small farms in many arid and semi-arid regions. This system has been used for sub-irrigation of fruits and vegetables during the last 1000 years in many small-scale drylands of the world (Bainbridge, 2001; Siyal et al. 2009; Bahrami et al., 2010; Ghorbani Vaghei et al., 2015) and also this method of irrigation is becoming increasingly common especially in the developed nations as a way of watering and fertilizing greenhouse crops (Das Gupta et al., 2009). Buried clay pot irrigation is still used limitedly in drylands of India, Iran, Pakistan, the Middle East, and Latin America and where the rainfall is less than 500 mm per year (Bainbridge, 2001; Ashrafi et al., 2002; Qiasheng et al., 2007: Bahrami et al. 2010; Siyal et al., 2011; Araya et al., 2014; Bhpole et al., 2014; Ghorbani Vaghei et al. 2015).

The water flow rate of buried clay capsules is an important factor for the designation, operation, and management of irrigation system (Jiusheng et al. 2004; Qiasheng et al. 2007; Bahrami et al. 2010; Ghorbani Vaghei et al. 2016; Bhayo et al. 2018; Saefuddin et al. 2019). However, the pattern of soil water distribution is affected by the physical and hydraulic properties of clay pots as well as the physical properties of soil (Qiasheng et al. 2007; Naik et al. 2008; Siyal and Sakaggs, 2009; Ghorbani vaghei et al., 2016). Once the water is released into the soil, its movement will be depended on the physical characteristics of the soil which with during time, its wetting pattern is completed.

The key parameters such as porosity and pore size distribution of clay capsules are used to predict the water flow rate of buried clay capsules (Cultrune et al. 2004; Naik et al. 2008; Freyburg and Schwarz, 2007; Bahrami et al. 2010). Also, the water flow rate of clay capsule is affected by some factors including the hydrostatic pressure, the saturated hydraulic conductivity of the clay capsule material, wall thickness, surface area, soil type, type of crop, and the rate of evapotranspiration (Abu-Zreig et al. 2006; Bahrami et al., 2010; Vasudevan et al., 2011). However, the hydraulic conductivity of clay capsules is one of the most important factors affecting outflow rate to provide enough water in the root zone (Bainbridge, 2001; Abu-Zreig et al. 2006; Siyal and Sakaggs, 2009; Ghorbani Vaghei et al. 2016). The scientific results showed that the relationship between the discharge of clay capsule and hydrostatic pressure is non-linear (Abu-Zreig et al. 2006; Qiasheng et al., 2007; Haijun et al. 2009; Das Gupta et al., 2009; Bahrami et al. 2010). Siyal and Skaggs (2009) reported that in sub-surface irrigation with porous clay pipe, the radius of wetted zone increased as a result of increased system water pressure (Siyal and Sakaggs, 2009). Also, Bahrami et al. (2010) which developed a fuzzy model to determine the soil wetted radius and depth based on using porous clay capsule irrigation method, reported that the wetted radius and vertical depth values at 25 kPa of hydrostatic pressure with the low discharge of clay capsules were about 13.5 and 22 centimeters, respectively. While, these parameters in clay capsules with high discharge rates were 14 and

45 centimeters, respectively. It means that increasing discharge rate increased the soil wetted depth that is a lot more than the changes of soil wetted radius (Bahrami et al. 2010).

For providing a good irrigation system, engineers must have a good understanding of the discharge ability of clay capsule types. Clay capsules irrigation technology is yet to be fully explored in Iran. Moreover, the effect of organic matter percent on the hydraulic properties of clay capsules has not been widely studied and reported. This material is also important to fabricate clay capsules with low weight and porous media with a good water discharge rate. Up to now, low research has been carried out on improving the discharge of clay capsules with added cheap organic matter in raw materials for seepage ability. Therefore, this research is aiming to develop and upgrade the seepage ability of clay capsules for providing soil moisture in the root zone by changing the material phase. As mentioned earlier, the achievements of this study will be useful for developing the use of buried clay capsule irrigation technology on small-scale land in Iran and also arid and semi-arid regions of the world.

2. Materials And Methods

2.1. Experimental procedures

The raw material used for the fabrication of porous clay capsules was obtained from NasrAbad village of Gorgan, Iran. The mineralogy of the raw material and the baked materials (soil of NasrAbad village of Gorgan), as well as its corresponding < 2 mm fraction, were determined by X-ray diffraction (XRD), and X-ray fluorescence (XRF) analysis. The PSD of raw material was realized by sedimentation procedure, based on the Stocks' law and dry sieve (Gee and Bauder, 1986).

2.2. Fabrication of clay capsules

In this research, the raw material used for making clay capsules is obtained from the calcareous soil of Nasr Abad village of Gorgan, Iran. The ratio of rice bran to calcareous soil as improving hydraulic properties was 1:2, 1:5, 1: 10, 1:15, and 1:20 (kg of rice bran to kg of air-dried soil). The produced clay capsules were named G2, G5, G10, G15, and G20 respectively. This study was carried out in the Soil Science Department of Tarbiat Modares University and the clay capsules were fabricated in clay capsule cells manufactured by T.M.U. Porous clay capsules with cylindrical shapes were fabricated by an automation machine of clay capsules (Fig. 1). This machine delivers 20 raw clay capsules at every time mud injection. After producing the raw clay capsules, they were released for 48 hrs under atmospheric conditions (air-dried) and were then put in an electrical dryer at 60 ^{0}C for 24 hrs. The clay capsules were thereafter transferred to the kiln and fired to the temperature of 980 ^{0}C to bake with a rate of 3 ^{0}C. min for 8 hrs (Fig. 2). The real picture of the porous clay capsule is shown in figure 3. The length of the clay capsule was 20 cm and its thickness was 10 mm with regular inner and outer diameters of 1.5 cm and 3.5 cm, respectively (Fig. 3). The wall thickness and outer diameter of clay capsules were checked by a Vernier Caliper and found to be achieved 1.5 ± 0.11 cm and 3.5 ± 0.20 cm, respectively.

At one end open of each clay capsule, a female plastic coupling head was made. One end coupling head is installed to the irrigation tube and the other head is made to allow for fitting clay capsule.

2.3. Measurement of clay capsule discharge in laboratory

The discharge of clay capsules was measured by Discharge-Pressure Automation Device (DPDA). It has double cylindrical structures that provide a test for a long time (Fig. 4). DPAD measures the discharge of capsules automatically. Also, it can accurately measure the discharge of the clay capsule in the range of 45 to 2000 ml per hr with about 5 ml errors per hour.

In the field experiment, the average discharge of clay capsules has an important role in providing water in the root zone (Bahrami et al., 2010). To determine the average discharge of porous clay capsules (Qcc), they were immersed to their necks in a volumetric flux. For each clay capsule type, this experiment was repeated 35 times. The saturated hydraulic conductivity ( ) of the porous clay capsules (PPC) was also measured based on the steady head method described by Abu-Zreig and Atoum (2004):

$$Q_{CC} = K_{S_{PCC}} \times A \times \Delta H / \Delta L \qquad (1)$$

Qcc is the average discharge of clay capsule, is saturated hydraulic conductivity of clay capsule, and are hydrostatic pressure head, wall thickness, and surface area of clay capsule, respectively. The wall thicknesses of clay capsules were measured by a Vernier Caliper. The clay capsules surface area was calculated by using the following equation;

$$A = (\pi D h + \pi D^2 / 4) \qquad (2)$$

A is the surface area of clay capsules. D and h are the outer diameter and length of the clay capsule, respectively.

2.4. Distribution pattern of soil moisture due to the seepage of porous clay capsule

The spatial pattern of soil moisture dynamics is an important factor for the designation, operation, and management of the buried clay capsule irrigation system. Therefore, the main purpose of this work is to recognize the ability of clay capsules to achieve the various dimensions of soil moisture pattern in the irrigation time. This part of the laboratory experiment was carried out using a container (60 cm in diameter and 100 cm height) filled with air-dried soil. The results of this part help to select the suitable depth of inserting the porous clay capsule into the soil which is also able to minimize the water evaporation from the soil surface.

In this way, at the first step, each clay capsule was installed vertically at depth of 20 cm from the soil surface with clay loam texture and their wetness shape were recorded after 24 hrs and 48 hrs. The clay capsule should be covered by a 50 mm thick layer of fine sand (particle size less than 0.1 mm) before being buried. At the second step, moisture wetted radius (r) and wetted depth (d) were determined in the soil for each of the 5 types of porous clay capsules at 25, 50, 80, and 100 (kpa) hydrostatic pressures. Wetted radius means the horizontal distance from the linear center of the clay capsule to the wetted zone of soil, and wetted depth is the vertical distance from the linear center of the clay capsule to the wetting front of soil.

3. Results And Discussion

3.1. Mineralogy of clay capsules before and after firing

Table 1 shows the chemical analysis of raw material by XRF that was used to fabricate the clay capsule. Earth-alkaline oxides (CaO and MgO) and iron oxides have an important role in changing soil physical and chemical properties. Cultrune et al. (2004) reported that these materials affect the porosity of bricks. Earth-alkaline elements lead to higher porosity and iron oxides lead to lower porosity (Monterio and Vieira, 2004). Also, earth-alkaline oxides (CaO and MgO) and TiO_2 confer the typical buff color to the ceramic products. However, high Fe_2O_3 content makes the product's typical reddish color (Monterio and Vieira, 2004). According to Table 1, the earth-alkaline oxides (CaO and MgO) are significant in raw materials. This chemical combination produces a buff light color in baked porous clay capsules (Fig. 5). While the Fe_2O_3 content is low in raw materials and cannot create the dominant red color to products porous clay capsules.

Table 1
Chemical analysis of clay capsule before and after baking by XRF

Component (%)	raw	Baked at 980^0C
L.O.I	14.07	0.8
MgO	2.78	3.14
Al_2O_3	12.44	14.39
SiO_2	51.88	58.44
CaO	11.24	12.42
Fe_2O_3	4.79	4.82
TiO_2	0.58	0.67
K_2O	2.37	2.76
Na_2O	1.41	1.55

The scientific results showed that increasing kiln temperature significantly caused changes in the structure of phyllosilicates (Newman, 1987). In the baking clay capsule at high temperature (near 1000^0C) the chemical structure of clay converted to a new composition. XRD analysis also showed that Chlorite in the raw clay capsule converted to Microcline in baked clay capsule at 980^0C (Table 2). The Microcline is joined together and creates a new particle with big size such as sand during the bake. This phenomenon helps to produce a clay capsule with more porosity.

Table 2
XRD analysis of G0 before and after baking

Component (%)	Muscovite	Quartz	Dolomite	Calcite	Clay	Hematite	Albite
G_0 (Raw)	+	+	+	+	Chlorite	+	+
G_0 -8-980	-	+	-	-	Microcline	+	-

Table 3
The physical characteristics of porous clay capsules

	G_2	G_5	G_{10}	G_{15}	G_{20}
Bulk density ($kg.m^{-3}$) in raw clay capsules	1.65	1.67	1.70	1.71	1.71
Bulk density ($kg.m^{-3}$) in clay capsule after baking at 980^0 C	1.23	1.29	1.36	1.44	1.49
Total porosity (%) in clay capsule after baking at 980^0 C	25.5	22.7	20	15.6	13
Soil texture in raw clay capsules	Si.Cl.L.[1]	Si.Cl.L.	Si.Cl.L.	Si.Cl.L.	Si.Cl.L.
Soil texture after firing at 600 and 980^0 C	L.Sa[2]	L.Sa	L.Sa	L.Sa	L.Sa
[1] and [2] are Silty Clay Loam and Loamy Sand.					

3.2. Physical and hydraulic properties of porous clay capsules

3.2.1. Physical properties of porous clay capsules

The soil texture of the raw material in G2, G5, G10, G15, and G20, was silty clay Loam. This soil texture converted to loamy sand after baking at 980^0C temperature. Sintering has happened to this phenomenon.

Sintering caused to joint some particles together. Therefore, new soil particles play the role of sand in stocks law. The results showed that by increasing the baking temperature, the size distribution of soil particles have shifted from 2 to 2 mm at 980^0C.

The physical characteristics of porous clay capsules used in this study are summarized in Table (3). According to the results of table (3), the baking temperature in the kiln had a significant effect on the bulk density of the clay capsule. The results showed that the Bulk density of baked clay capsules was less than the bulk density of raw clay capsules. The presence of carbonate in the raw material is an important factor to decrease the bulk density of baked clay capsules. Table 2 shows that a Dolomite and Calcite component is in the chemical structure of soil (raw material is called G0), but after baking CO_2 was removed from G0, and Ca+Mg was involved to create in the creating a new chemical structure such as Microcline. These components are caused by a low weight and high micropores in baked clay capsules Also, the addition of rice bran to raw material increased the porosity of clay capsules baked at 980^0C. At high baking temperatures, the organic matter in the clay capsule is burned and removed from the solid structure of the clay capsule. This phenomenon helps to create more porosity in the clay capsules. The porosity is also affected by seepage and saturated hydraulic conductivity of the clay capsules (Abu-Zreig et al. 2006). So that, more porosity will be associated with more hydraulic conductivity in clay capsules. Therefore, it is expected that the seepage of the clay capsule in G20 will be less than that of G2. Generally, the most and the least porosity of baked clay capsules were observed in G2, and G20, respectively. The percentage of total porosity of baked porous clay capsules (G2, G5, G10, G15, and G20) was 25.5, 22.7, 20, 15.6, and 13 respectively.

3.2.2. Hydraulic properties of porous clay capsules

The saturated hydraulic conductivity of clay capsules is influenced by the total porosity percentage and the seepage of clay capsules as well as the saturated hydraulic conductivity of clay capsules. Table 4 shows the seepage and saturated hydraulic conductivity of clay capsule types (G0, G2, G5, G10, G15, and G20) with a no-significant difference in size and wall thickness, but there is a significant difference in wall porosity. The wall porosity of G15, and G20 is low and it affects the saturated hydraulic conductivity of G15, and G20. While, the total porosity of G2 and G5 is high and it affects the saturated hydraulic conductivity of G2, and G5 (see Table 4).

Table 4 The effects of hydrostatic pressure (Δh) on discharge and saturated hydraulic conductivity of clay capsules, baked at 980°C

Clay Capsule type	Measured Statistics	Hydrostatic pressure (kPa)			
		25	50	80	100
G2	$K_{S_{PCC}}$ [a]	0.351	0.282	0.23	0.231
	Q_{cc} ($l.hr^{-1}$)	20.5	32.2	42.1	52.9
	sd of Q_{cc} [b]	4.6	7.5	6.3	7.5
	C.V. of Q_{cc} [c]	12.7	13.4	14.9	14.2
G5	$K_{S_{PCC}}$	0.244	0.207	0.151	0.164
	Q_{cc}($l.hr^{-1}$)	13.7	23.7	27.7	37.5
	sd of Q_{cc}	4.6	6.6	6.5	7.5
	C.V. of Q_{cc}.	14.3	18.1	13.52	10.1
G10	$K_{S_{PCC}}$	0.068	0.059	0.065	0.066
	Q_{cc}($l.hr^{-1}$)	3.9	6.8	12.0	15.1
	sd of Q_{cc}	1.1	2.1	3.1	3.4
	C.V. of Q_{cc}.	18.5	19.7	16.1	12.5
G15	$K_{S_{PCC}}$	0.014	0.011	0.014	0.015
	Q_{cc}($l.hr^{-1}$)	0.8	1.3	2.5	3.5
	sd of Q_{cc}	0.24	0.26	0.69	0.69
	C.V. of Q_{cc}	10.1	10.6	17.9	9.9
G20	$K_{S_{PCC}}$	0.010	0.011	0.011	0.017
	Q_{cc}($l.hr^{-1}$)	0.6	1.3	2.1	3.1
	sd of Q_{cc}	0.17	0.29	0.40	0.53
	C.V. of Q_{cc}.	17.1	12.6	8.6	7.1
G0 (Raw material)	$K_{S_{PCC}}$	31×10^{-4}	33×10^{-4}	36×10^{-4}	37×10^{-4}
	Q_{cc}($l.hr^{-1}$)	0.06	0.12	0.22	0.28

[a] is saturated hydraulic conductivity of clay capsule ($cm.hr^{-1}$)

[b] *is standard deviation of the average discharge of clay capsule*

[c] *is coefficient of variation of the average discharge of clay capsule*

The results showed that the saturated hydraulic conductivity of clay capsules was constant with increasing pressure head. The saturated hydraulic conductivity of G20 increased from 10×10^{-3} to about 17×10^{-3} ($cm.h^{-1}$) with increasing pressure head. This increment is however ignorable. This phenomenon has been also observed for G15, G10, G5, and G2. It means that the saturated hydraulic conductivity is a constant physical property for a special type of clay capsule. But, the results showed that at a constant hydrostatic head pressure, the saturated hydraulic conductivity of clay capsules increased from G20 to G2. This phenomenon is related to the addition of rice bran in the soil material for making clay capsule. The pressure head and the saturated hydraulic conductivity accordingly affected the discharge of clay capsules. The seepage of G15 and G20 is low and varied from 600 to 3500 $cm3hr^{-1}$ (Fig. 6) while it was from 3900 to 15100, 13700 to 37500, and 20500 to 52900 $cm^3.hr^{-1}$ for G10, G5, and G2, respectively. Further analyses showed that the addition of rice bran significantly increased the flow properties of the clay capsules. The addition of 5 to 6.6 percent rice bran into the soil (G0) increased both the seepage and hydraulic conductivity of G15 and G20 by about 10 times, while further addition of 20% rice bran into the soil (G0) caused both the seepage and hydraulic conductivity of G5 by about 228 times. Therefore it can be concluded that the rice bran has a good effect on clay capsules' porosity and it is a good method for fabricating different porous clay capsules with various seepage rates.

In the buried clay capsule irrigation system, the water seepage of clay capsule nozzles must also be released slowly into the soil until it can create soil water content in the range of field capacity. It is an important factor to select a good nozzle for a sub-irrigation system and its recommended that discharges of clay capsules should be less than 2000 ($cm^3.hr^{-1}$). According to table (4), the discharges of G5 and G2 nozzles are not recommended to use in sub-irrigation systems. But the G5 and G2 nozzles are as good choices for installing the surface irrigation system. It should be noted that the relationship between the discharge of G2, G5, G10, G15, and G20 with hydrostatic pressures is already linear (Fig. 5). According to Fig. 5, a strong positive linear relationship was observed between G10, G15, and G20 at low hydrostatic pressure conditions from 25 to 50 kPa. On other hand, most farmers can supply water pressure of up to 50 kPa on the farm. Therefore, G10, G15, and G20 can be good choices for installing in arid and semi-arid fields.

3.3. Soil wetness by clay capsules

The rate of wetness and the size of soil wetting shapes were influenced by the hydraulic properties of clay capsules and soil. Each of the engineers must have informed the soil wetness by clay capsules to provide and install a good irrigation system into the soil. Hydraulic properties of six clay capsule types (G0, G2, G5, G10, G15, and G20) with the non-significant difference in size and wall thickness, but significantly different in the wall properties were studied in the present paper. Table 5 shows the soil wetness by these clay capsules that were installed vertically at 20 cm depth below the soil surface into the clay loam soil texture. The water distribution of clay capsules was tested to evaluate the influence of pressure on variations of their wetted radius and depth with time. The results showed that the soil wetting shape followed a spherical trend, which is due to the low discharge of clay capsules, in G10, G15, and G20 at 24 hours irrigation times. While the spherical wetness shape in G5 and G2 was observed at 4 hours irrigation times and over-irrigation time, the pattern of soil moisture distribution changed from spherical to elliptical. But, the spherical soil moisture distribution shape was constant for G10, G15, and G20 during the irrigation time up to 48 hours.

It may be noticed from Table 5 that there was an appreciable increase in the moisture content of the soil profile both vertically (down the soil profile) and horizontally (distance away from the clay capsule). However, this increase was in the vertical direction same as the horizontal direction at the low hydrostatic pressure conditions (10-50 kPa). But, this increase was more in the vertical than the horizontal direction at the high-pressure head (80 – 100 kPa). This agreed with the finding of scientific researches in clay capsule irrigation systems (Siyal and Skaggs, 2009: Ghorbani et al., 2010).

The wetted radius and depth of G5 and G2 imply that there were considerable increases in soil moisture contents over the time of water application. These results indicate that G5 and G2 have no auto-regulative seepage ability over the time of irrigation. Therefore, the suitable irrigation time of G5 and G2 is less than 8 and 4 hrs, respectively. While elapsed irrigation times, were 24, 48, and 48 hours for G10, G15, and G20, respectively. Wetted radius and depth of G10 were more than G15, and G20 at the same irrigation time. Wetted radius and depth of G10 in the low-pressure head (25 kPa) for 24 hrs irrigation time was 42 cm and 49 cm, and in the high-pressure head (100 kPa), it was 100 cm and 109 cm, respectively (Table 5).

Table5 The effect of hydrostatic pressure on wetted radius and depth in types of the porous clay capsules

Type of porous clay capsule	Pressure (kPa)	Wetted radius (cm)	Wetted depth (cm)	Irrigation time (hour)	Water volume (litter)
G2	25	68	77	4	36
	50	87	100	4	58
	80	88	105	2	45
	100	96	112	2	59
G5	25	42	48	8	15
	50	67	70	8	29
	80	68	74	8	38
	100	83	100	8	54
G10	25	42	49	24	19.5
	50	68	70	24	31
	80	90	97	24	44
	100	100	109	24	59
G15	25	30	46	24	14
	50	34	52	24	23
	80	46	59	24	32.5
	100	50	73	24	42.5
G20	25	35	36	24	11
	50	45	40	24	19
	80	53	50	24	28
	100	68	62	24	36

In the buried clay capsule irrigation system, the water seepage of clay capsule nozzles must be released slowly into the soil until be able to create a soil water content in the range of field capacity. The results of wetted radius and depth of clay capsules showed that G10, and G15 can play a good role in plants' water requirements. It should be mentioned that the wetted pattern was already constant during the 48 hrs period indicating that discharge of clay capsules reduced with an elapsed time (when the moisture of the soil around the clay capsule approaches saturated condition).

4. Conclusion

The discharge, saturated hydraulic conductivity, and soil wetness shape of clay capsules made from calcareous soil were determined and compared. The discharge and saturated hydraulic conductivity of clay capsules were significantly influenced by the ratio of very fine rice bran used to make the clay capsules. The addition of very fine rice bran to the calcareous clay mixture increased both the saturated hydraulic conductivity and discharge of the clay capsules. The saturated hydraulic conductivity of each of clay capsule types with increasing water pressure head from 25 kPa to 100 kPa was constant, while the discharge of clay capsules had been increased by about 63-80% at this condition. The higher discharge was observed in G2, G5, G10, G15, and G20 respectively. Also, the rate of soil wetness was influenced by the clay capsule type. Therefore, a higher rate of wetness was recorded in G2, because of higher porosity due to the mixture of very fine rice bran to calcareous clay soil. But it is not recommended that G2 and G5 be used in buried clay capsule irrigation systems because of the high water volume released into the soil. The wetted radius and depth of G5 and G2 imply that there were appreciable increases in soil moisture contents over the time of water application. These results indicate that G5 and G2 have no auto-regulative seepage ability over the time of irrigation. Generally, in the buried clay capsule irrigation system, the water seepage of clay capsule nozzles must be released slowly into the soil until be able to create a soil water content in the range of field capacity. At these conditions, soil wetting shape is already constant using clay capsules at the time over 48 hrs. The results of wetted radius and depth of clay capsules showed that G10, and G15 can play a good role in providing plants water requirements in buried clay capsule irrigation systems. To increase the hydraulic properties of clay capsules, it is recommended that very fine rice bran must be mixed in the fractional proportion to calcareous clay soil when making the clay capsule. Also, The study results are useful in designing the lateral spacing and installation depth of the porous clay capsule nozzle, irrigation run time and length, and the hydrostatic head required for proper operation of porous clay capsule-based subsurface irrigation systems. The final convenience for the widespread adoption of a porous clay capsule irrigation system will depend on water availability and prices.

Declarations

Ethics Approval

All authors kept the ‘Ethical Responsibilities of Authors’.

Consent to Participate

All authors gave explicit consent to participate in this work.

Consent to Publish

All authors gave explicit consent to publish this manuscript.

Authors Contributions

All authors contributed to the study conception and design. Data collection, material preparation, and analysis were performed by Hojjat Ghorbani vaghei, Hosein Ali Bahrami*, and* Farzin Nasiri Saleh, respectively*. The first draft of the manuscript was written by* Hojjat Ghorbani vaghei *and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.*

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Competing Interests

The authors declare that they have no conflict of interest and there is *no relevant financial or non-financial interest to disclose.*

Availability of data and materials

Not applicable.

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Figures

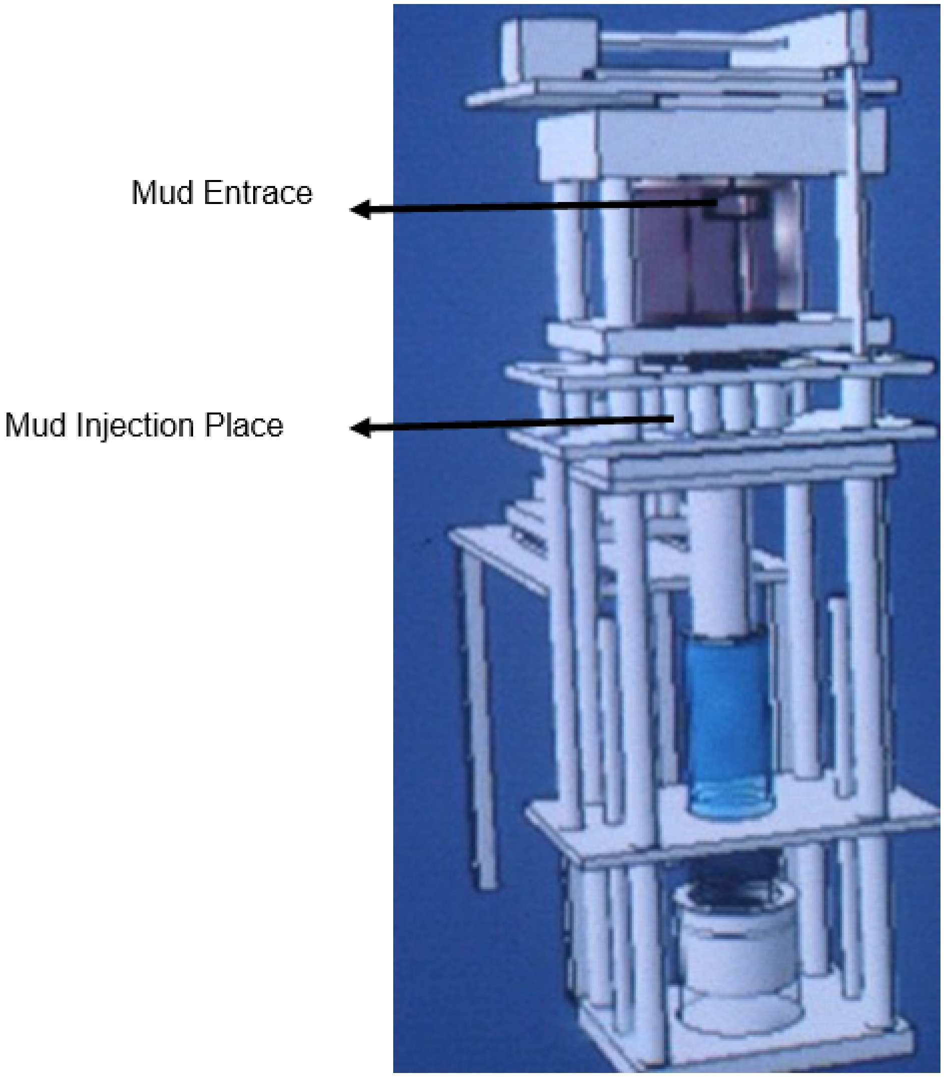

Figure 1

Automation Machine of Clay Capsule (Designed in ANDISHAB Company)

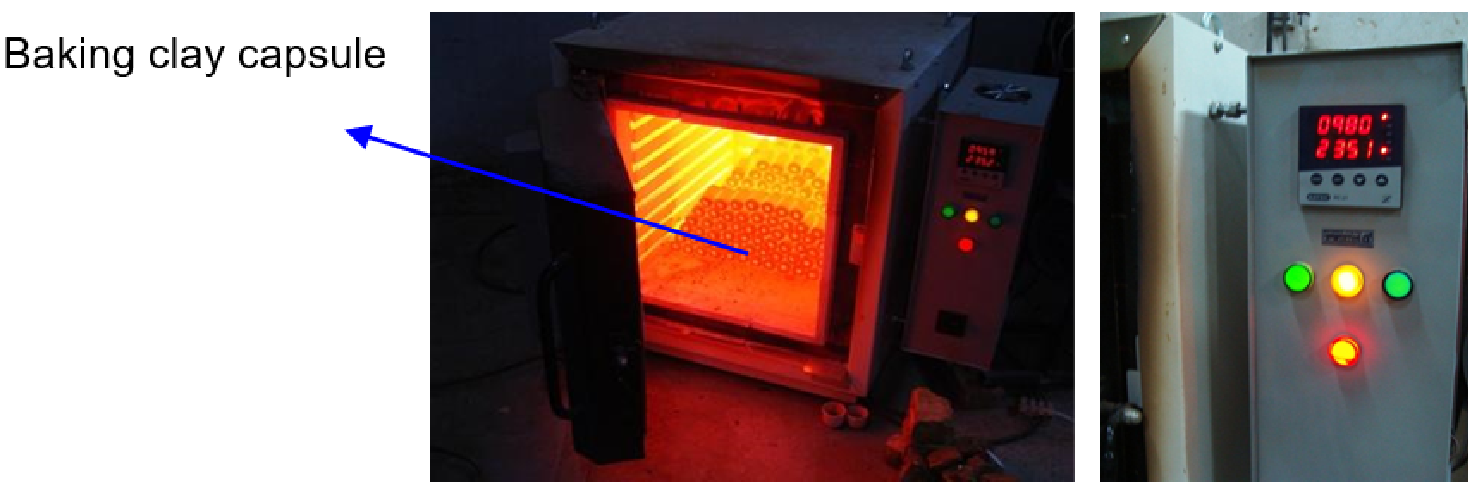

Figure 2

Electric kiln in range of 0-1200^{0}C

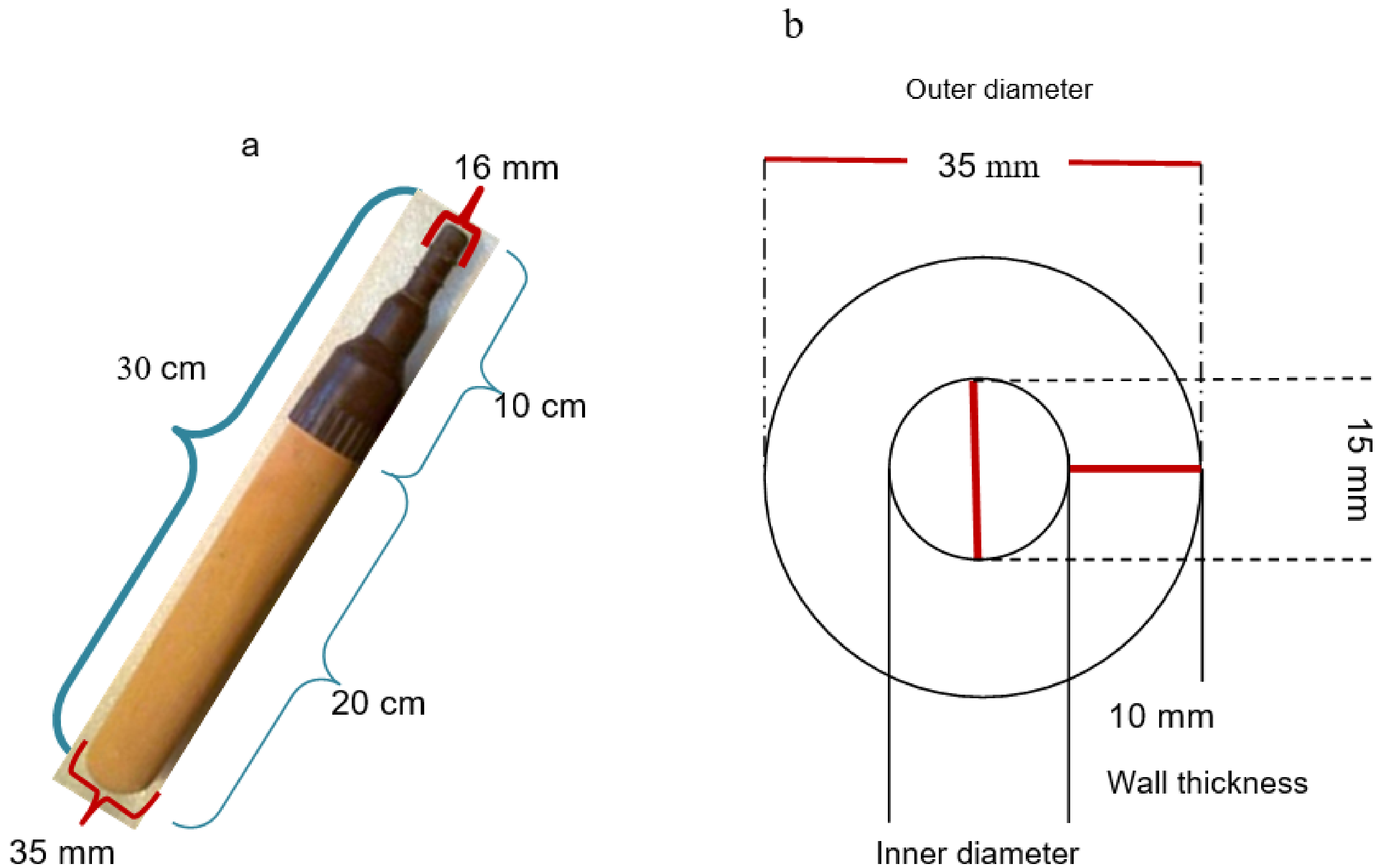

Figure 3

Surface morphology of clay capsule (a) and schematic inner and outer diameter of clay capsule pipe (b)

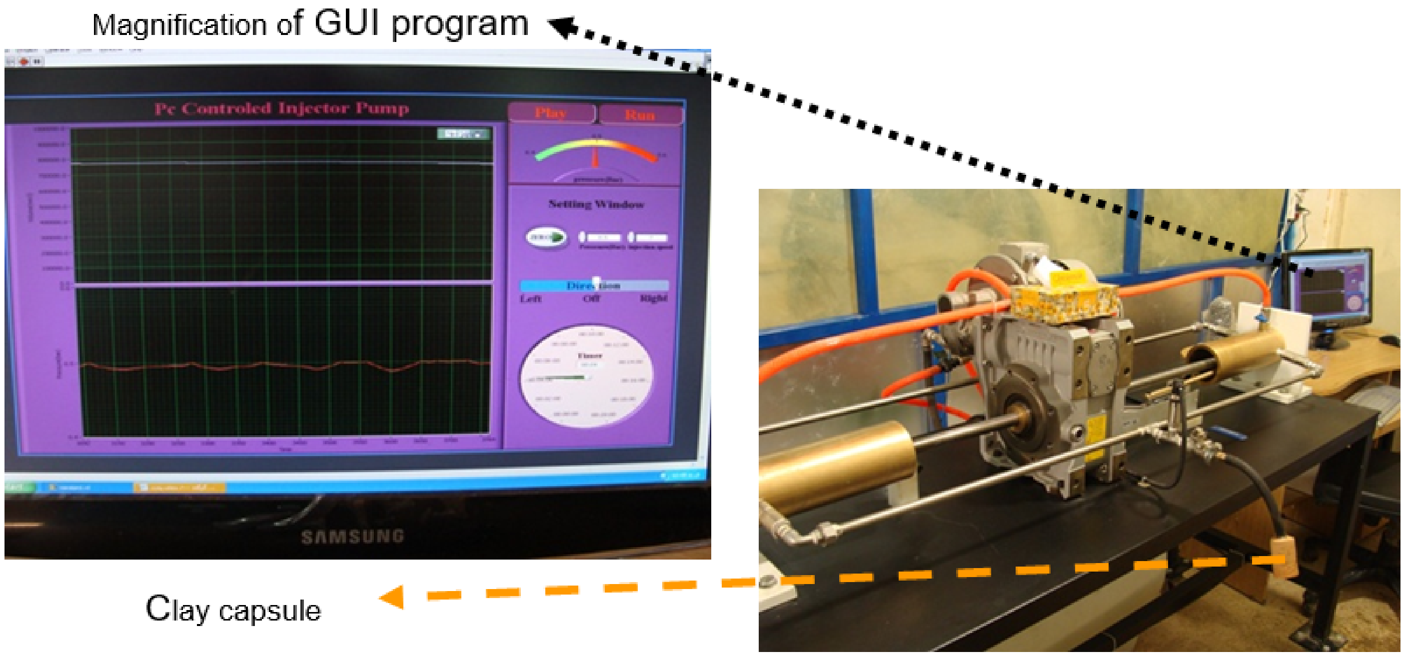

Figure 4

Discharge -Pressure Automation Device (Designed and produced in ANDISHAB Company)

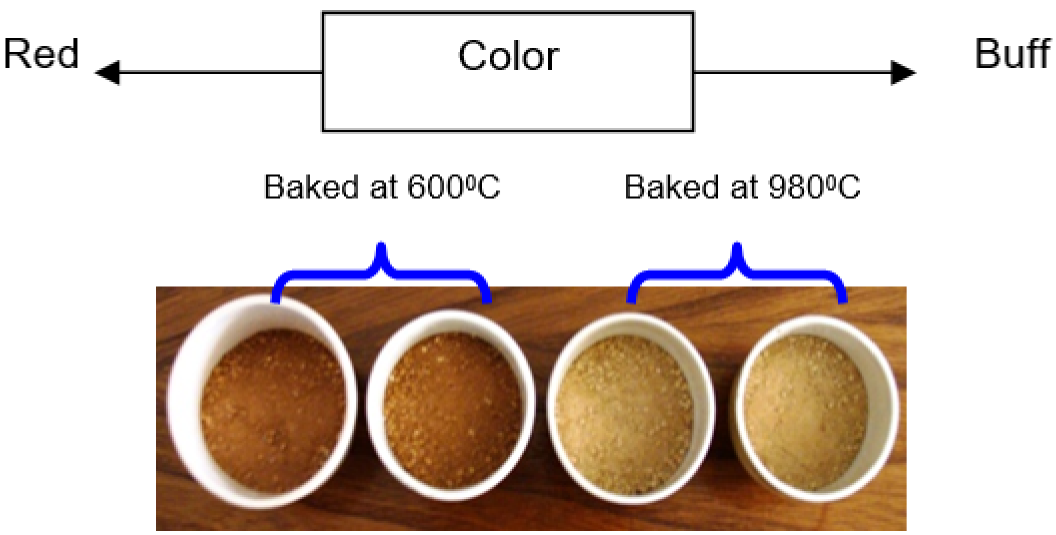

Figure 5

Color of baked porous clay capsule in 600 ^{0}C and 980 ^{0}C.

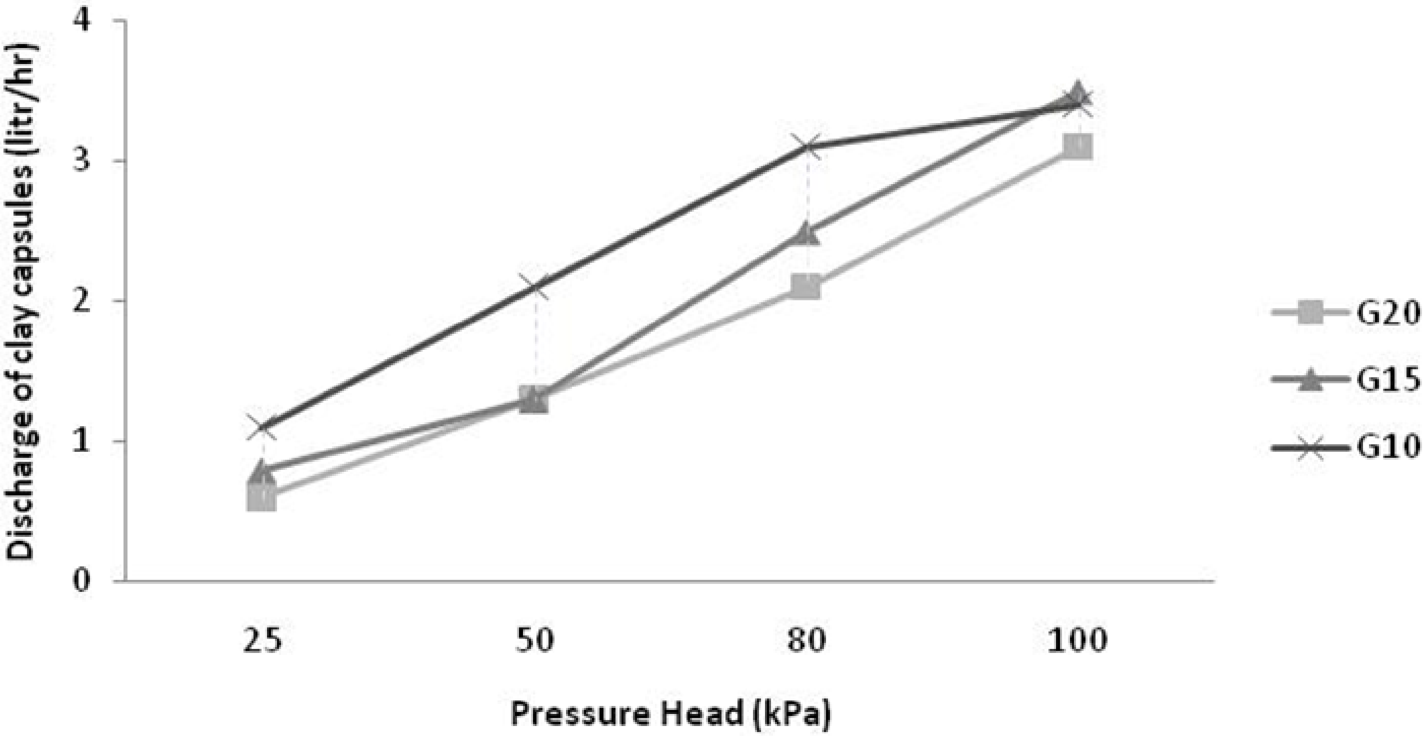

Figure 6

The relationship between hydrostatic pressure head and discharge of clay capsules