Hydraulic Characteristics of Porous Clay Pipes for Subsurface Irrigation.

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ABSTRACT

The hydraulic characteristics of three types of locally made porous clay pipes for subsurface irrigation are presented in this report. The three clay pipes were made from pure clay (100% clay content), clay-sand mixture (95% clay + 5% fine sand), and clay-sand-sawdust mixture (90% clay + 5% fine sand + 5% sawdust), respectively. Each pipe was installed at 25 cm depth below the soil surface of a well prepared seedbed, and their seepage rate, hydraulic conductivity and rate of soil wetness were determined.

The results showed that the seepage rate and hydraulic conductivities of the pipes were significantly influenced by the materials used to make the clay pipes. The addition of 5% fine sand to clay mixture increased both the seepage rate and hydraulic conductivity of the pipes by about 35- 45%, while a further addition of 5% sawdust to the clay-sand mixture increased both the seepage rate and hydraulic conductivity by about 57-63%. The average rate of soil wetness of the pipe made from clay-sand-sawdust mixture was found to be 64% and 45% higher than those of pure clay and clay-sand mixture, respectively. The average rate of soil wetness of the clay-sand mixture pipe was also found to be 34% higher than the pure clay pipe. In order to increase the hydraulic properties of clay pipe, fine sand and sawdust may be mixed in the fractional proportion to clay when making the clay pipes.

(Keywords: porous clay pipe, subsurface irrigation, soil wetness, hydraulic conductivity, seepage rate)

INTRODUCTION

Subsurface irrigation involves the application of irrigation water beneath the soil surface. It is usually carried out by burying the medium used to convey the water at some depth below the soil surface. Some media used to convey water for subsurface irrigation include pots, pitchers, porous clay pipes, perforated pipes and plastic drip lines with emitters. As water moves in the buried medium, it leaks or permeates into the soil, thus wetting and raising the moisture content of the soil. Subsurface method of irrigation is becoming increasingly common especially in the developed nations as a way of watering and fertilizing greenhouse crops. It is known to be very effective in management of irrigation water because of high irrigation uniformity and water use efficiency in a number of different cropping systems by supplying a low volume of water to the root zones of crops (Bainbridge, 2001; Ashrafi et al., 2002). Power (1985), Sheikh and Shah (1983), Batchelor et al. (1996), Hagazi (1998) and Bainbridge (2001) have reported high water use efficiency (i.e., high crop production per amount of water applied) for subsurface irrigation method. Subsurface method of water application is increasingly being used for the irrigation of corn, fruits and vegetables (Camp, 1998; Singh et al., 2006).

One noted improvement on the traditional method of subsurface irrigation is the use of porous clay pipes (Siyal and Skaggs, 2009). The clay pipes consist of baked short length pipes (25 to 50 cm) made from clay which are joined together or lay end to end to form long tubes of desired length. The pipes are buried in the soil, and water is supplied continuously to these pipes from a point source. At one end, an elbow fitting is attached and an upright section of pipe installed. Water is poured into the porous pipe through the upright pipe. The water seeps into the root zones through the joints between the individual pipes, or through the pipe walls if the pipe surface is not glazed. As water seeps out of the porous wall of the pipe it creates a wetting front along the entire length of the lateral. In this system of irrigation, both conveyance and application of the water are done simultaneously by the same pipe. This method of irrigation has been used in some arid and semi-arid regions of the world with a significant success (Ashrafi et al., 2002; Qiasheng et al., 2007). It has been found suitable for crops grown in row such as vegetables and trees (Ashrafi et al., 2002).

Siyal (2008) computed the water used for the growing of turnip (an edible root vegetable) using clay pipes and compared with water needed by turnip when irrigated with flood irrigation method, and found out that the clay pipe method saved more water than the flood irrigation method for sandy-loam soil. The turnip production obtained was 11ton/ha for the clay pipe method which is about 20% more than that obtained with application of conventional flood irrigation. Siyal et al. (2011) also reported that with the clay pipe irrigation method, water saving up to 80 % were achieved compared to that of surface irrigation methods. Moreover, yield of vegetables (okra, eggplant and turnip) irrigated with the system were 5 to 16% more than the normal production obtained with surface irrigation methods. The ITDG (2002) technical briefing also reported that though clay pipes were laborious to fill by women who used them to raise vegetables, it was much more cost effective as the vegetables needed to be watered only a week instead of 3-4 times for surface watering, thus reducing watering by 50 %.

Clay pipe irrigation technology is yet to be fully explored in Nigeria. Moreover, the effect of particles of other materials on the hydraulic property of the clay pipe has not been widely reported. This study was an attempt to explore the use of clay pipes for subsurface irrigation of vegetables. The objective of the report presented herein was to evaluate the hydraulic characteristics of clay pipes made from pure clay and those mixed with a fraction of fine sand and saw dust. The aim was to study the permeability of the fabricated pipes, seepage rate and the rate at which the soil moisture content increases with time. This information, it is hope, will be a useful in clay pipe irrigation technology.

MATERIALS AND METHODS

Location of study

The study was carried out in the Department of Agricultural Engineering, Ahmadu Bello University Zaria. The University lies in Latitude $11^0$11' N and Longitude $7^0$35'E, at 686 m above sea level. The clay pipes were fabricated in the Hydraulic Laboratory and the field evaluation was carried out at the Irrigation demonstration garden of the Department.

Fabrication of the Clay Pipes

Three types of clay pipes were fabricated. Type A was made from 100% pure clay, Type B was 95% clay and 5% fine sand, and Type C was 90% clay, 5% fine sand and 5% sawdust. For each Type, three pipes and one elbow were fabricated. The length of each pipe was 50 cm long. The thickness of each pipe was 2.5 cm with regular inner and outer diameters of 7.5 cm and 10 cm, respectively.

At one end of each pipe, a coupling head was made. The inner and outer dimensions of the coupling head were 10 cm and 12.5 cm, respectively. This was made to allow for fitting of the other end of the pipe into the coupling head of the other pipe. The three pipes of each type gave a total length of 1.5 cm long when coupled together. The elbow of each Type was 33 cm long and 26.5 cm high with 10 cm radius. The elbow was also coupled to one end of the pipe length, and upon installation in the soil, the height of the elbow protrudes above the soil surface by 5 cm. Through the protruded opening, the pipes filled with water. Since the pipe fitted at the end of pipe length had a close end, the entire pipe length can hold water of about 5.5 liters at a time.

In order to make the pipes and elbows of regular shape and dimensions, linear and elbow molds were cast with corresponding dimensions using Plaster of Paris (POP). Each mold has two halves which are easily separated. The clay, fine sand and sawdust were weighed out at appropriate proportions. 10 kg of pure clay was used for each of the Type A pipes, while 9.5 kg of pure clay mixed with 5 kg of fine sand and 9.0 kg mixed with 5 kg each of fine sand and sawdust were used for each of the Type B and C pipes, respectively. Each mixture was thoroughly mixed into paste with 13.5 liters of water, and allowed to properly dissolve for five hours.

Deflocculant was added to the mixture which made the particles to be randomly suspended during casting. The paste (liquid prepared mixture) were then poured into the molds, and upon solidification, they were removed from the molds to air-dry for two weeks.

Table 1: Some soil physical properties of the experimental site

Soil Depth (cm)	Hyd. Cond. (cm/s)	Bulk Density (g/cc)	Particle Size Distribution			
			% Clay	% Silt	% Sand	Textural class
0- 25	0.07	1.46	14	40	46	Loam
25- 35	0.22	1.56	20	36	44	Loam
35 – 45	0.19	1.57	24	30	46	Loam
45 – 60	0.19	1.57	24	30	46	Loam

The pipes were thereafter put in a kiln and fired to a temperature of 1000^0C to bake. Plates 1 and 2 shows a typical pipe and elbow type, respectively, in which the first half of the mold has been removed to allow the pipe/elbow to air-dry

Plate1: Linear pipe in the mold (half of the mold removed to allow clay pipe to dry).

Plate 2: Elbow pipe in the mold (half of the mold removed to allow clay pipe to dry).

Field Evaluation of Seepage rate, Hydraulic Conductivity and Soil Wetness of the Pipes

Three seedbeds of 0.6 m x 2.0 m (1.2 m^2) each were tilled and excavated to a depth of 25 cm from the soil surface at the center along the bed length for the purpose of installing the fabricated clay pipes.

The beds were separated by a distance of 1.5 m apart. Each pipe Type were coupled together to form a pipe length of 1.72 m long (including the elbow pipe). The elbow pipe was joined to one end of the pipe, and upon installation (buried in the soil) the open end protrudes above the soil surface by about 5 cm.

The coupled points were sealed with Portland cement to prevent leakage at the joints, so that water only leaves the pipe by seeping through the body of the full pipe length. The section of the pipe fitted at the end of the full pipe length had a closed end, which enable the entire pipe length to hold water.

Each pipe was installed horizontally in the excavated seedbeds slightly tilted away from the elbow. The excavated soils were carefully replaced, thus burying the pipes. A thin layer of coarse sand was applied to each excavated pipeline before the pipe was buried to serve as envelope material for the pipes, to prevent soil from clogging and sealing of the pipe's pores.

Table 1 shows some physical properties of the soils of the experimental site. Plates 3 and 4 show the assembled pipes and the field installation of one of pipes, respectively.

Plate 3: The assembled clay pipes.

Plate 4: One of the assembled pipes lay in the excavated bed.

After installation, the pipes were filled with water through the open end of the elbow piece. In order to aid the settlement of the excavated line, the seedbeds were also watered with a watering can, and setup was left fallow for one week before data collection began.

The determination of the seepage rate, hydraulic conductivity and the rate of soil wetness of the installed pipes was carried out one week after the installation. Each setup was filled with water to the brim and seepage rate was observed for one hour. A near constant head (water level in the pipe) was maintained by continuously filling the pipes to the brim throughout the duration of the test. The volume of water replaced was noted.

The seepage rate was taken as the volume of water replaced over time, while the hydraulic conductivity was computed using Equation 1, where the volume was the amount of water replaced and the area was the surface area of the entire pipe length including the closed end.

$$K_s\,(cm/hr) = \frac{Volume\ (cm^3)}{Area\ (cm^2)\ x\ Time(hr)} \quad \textbf{(1)}$$

The rate at which the soil moisture content increases as a result of wetting from the installed pipes of each plot was monitored by sampling soils at different depths into moisture cans using an auger, and taken to the oven to dry at 105^0C for 24 hrs. in the Hydraulic Laboratory. Soils were sampled on both sides of the buried clay pipelines at 10, 20 and 30 cm away from the pipeline, and for each distance, soil samples were taken at 0-25 cm, 25- 35cm, 35-45 cm, and 45-60 cm profile depths. The first sets of sampling were done just before filling the pipes with water in order to establish the antecedent soil moisture content. Subsequent soil samplings were carried out at 30 min and one hour later. Since the pipe was at the center of each plot, the wetting pattern was assumed to be symmetrical; therefore, the moisture content computed for the corresponding depths of both sides were averaged and used to determining the rate of advancement of the wetting front.

RESULTS AND DISCUSSION

Hydraulic Conductivities of the Clay Pipes

Table 2 shows the seepage rate and hydraulic conductivity (Ks) of the different clay pipes. The seepage rate varied from 6103 to 14200 cm^3/hr while the hydraulic conductivity varied from 2.07 to 4.8 cm/hr. The clay pipe recorded the least seepage and hydraulic conductivity values while the clay-sand-sawdust pipe recorded the highest values in the range. Further analyses of the seepage rates and hydraulic conductivities of the different pipe types showed that the addition of fine sand and sawdust significantly increased the flow properties of the pipes. The addition of 5% fine sand to clay increased both the seepage rate and hydraulic conductivity of the pipes by about 35- 45%, while a further addition of 5% sawdust to the clay-sand mixture increased both the seepage rate and hydraulic conductivity by about 57-63%.

Table 2: Seepage Rate and Hydraulic Conductivity of the Pipes Installed in the Field.

Clay Pipe Type	Seepage Rate (cm^3/hr)	Hydraulic Conductivity Ks (cm/hr)
A (100 % Clay)	6130	2.07
B (95 % clay + 5 % fine sand)	9100	3.08
C (90 % clay + 5% fine sand + 5 % sawdust)	14200	4.80

Table 3: Moisture Content (% dry weight basis) of the Soil around the Clay Pipes at Various Soil Profile Depths.

Soil sampling depth (cm)	Moisture content at start of measurement	30 min of water application			60 min of water application		
		Pipe Type			Pipe Type		
		A	B	C	A	B	C
10 cm away from the pipe							
0-25	17	23	27	31	29	37	44
25-35	20	24	28	32	28	36	43
35-45	21	23	23	27	26	28	33
45-60	22	23	21	23	24	24	26
20 cm away from the pipe							
0-25	16	21	24	28	25	31	38
25-35	18	23	25	28	28	32	39
35-45	22	24	25	27	25	27	30
45-60	21	23	21	24	24	23	27
30 cm away from the pipe							
0-25	14	18	20	24	22	26	26
25-35	15	17	18	23	19	23	23
35-45	18	19	20	24	20	22	22
45-60	20	21	21	23	24	24	24

Soil Wetness

Table 3 shows the moisture content (% dry weight basis) of the soils where the different pipes were installed, obtained at 10, 20 and 30 cm distances away from the center line of the installed pipe after 30 and 60 min of water application. The moisture content in the soil profile before water application ranged from 17 to 22%, 16-22%, and 14-20% at 10, 20, and 30 cm distances away from the pipe, respectively.

After 30 minutes of water application, the moisture content of the soil around pipe Type A varied from 23-24%, 21-24% and 18-19% for 10, 20, and 30 cm distances from the center of the pipe line, respectively. The moisture content of the soil around pipe Type B varied from 21-27%, 21-25%, and 18-21% at 10, 20, and 30 cm distances away from the center of the pipe line, respectively, while that of Type C also varied from 23-32%, 27-28%, and 23-24% at 10, 20, and 30 cm distances away from the center of the pipe line, respectively.

Table 3 also shows that after 60 minutes of water application, the soil moisture content at 10, 20, and 30 cm distances from Pipe Type A ranged from 24-29%, 24-28%, and 19-24%, respectively. The moisture content at 10, 20, and 30 cm distances from pipe Type B was found to varied from 24-37%, 23-32% and 22-26%, respectively, while that of Type C also varied from 26-44%, 27-39%, and 22-26% for the 10, 20, and 30 cm distances from the center of the pipeline, respectively.

Figures 1 to 3 show the graphical representation of the soil wetting pattern at 10 cm, 20 cm and 30 cm away from the pipelines, respectively. The SMC is the trend of the soil moisture content before water application. The plotting points on the soil profile depth axis were the midpoint of the range of depths from which the soil samples were taken. It may be noticed from the graphs that there was appreciable increase in the moisture content of the soil profile both vertically (down the soil profile) and horizontally (distance away from the pipe). However, the increase was more in the horizontal than the vertical direction. This agreed with the findings of Siyal and Skaggs (2009) who reported that greater horizontal spreading occurred in fine texture soils. Additionally, there seems to be very minimal changes at the 45-60 cm depth for the three distances away from the pipeline. This implies that there were appreciable increases in soil moisture contents over the time of water application in that profile depth.

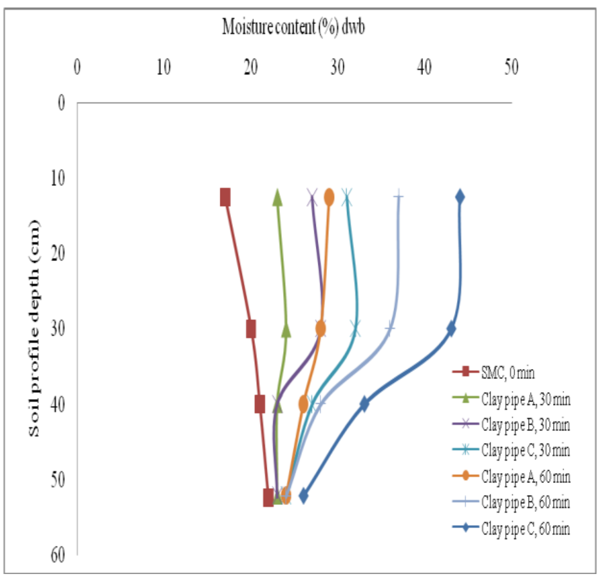

Figure1: Soil Wetting Pattern of the Clay Pipes at 10 cm away from the Pipeline.

Further analyses of the results showed that after 30 minutes of water application, the wetness of the soil at 10 cm distance around the Type A (100 % clay) pipe had increased by 35.3 %, 20.0 %, 9.5 % and 0.65 % for 0-25 cm, 25-35 cm, 35-45 cm and 45-60 cm soil profile depth, respectively. At 20 cm distance away from the installed pipe, the increase in soil wetness was by 31.3 %, 27.8 %, 9.1 % and 1.3% in the 0-25 cm, 25-35 cm 35-45 cm and 45-60 cm soil profile depths.

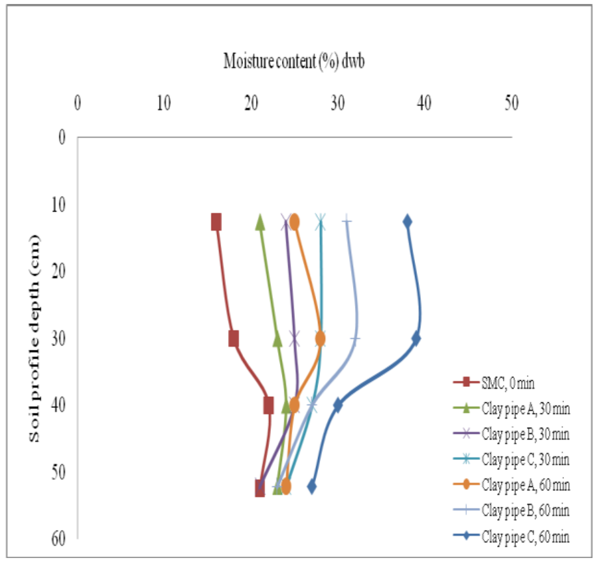

Figure 2: Soil Wetting Pattern of the Clay Pipes at 20 cm away from the Pipeline.

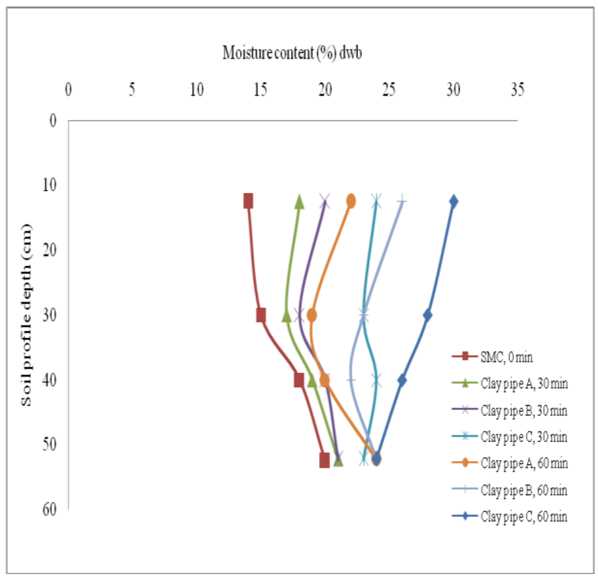

Figure 3: Soil Wetting Pattern of the Clay Pipes at 30 cm away from the Pipeline.

Furthermore, at 30 cm distance away from the pipe, soil wetness increased by 28.6%, 13.3%, 5.6% and 0.8% in the 0-25 cm, 25-35 cm, 35-45 cm, and 45-60 cm soil profile depths, respectively.

The soil wetness around the Type B pipe was found to have increased by 58.8%, 40.0%, 9.5%, and 1.2% for 0-25 cm, 25-35 cm 35-45 cm, and 45-60 cm soil profile depths, respectively at 10 cm distance from the pipe. At 20 cm distance away from the installed pipe, the percentage increase in soil wetness was 50.0%, 38.9%, 13.6%, and 6.5% in the 0-25, 25-35, 35-45 cm, and 45-60 cm soil profile depths. At 30 cm distance away from the pipe, soil wetness was noticed to have increased by 42.9%, 30.3%, 11.1%, and 1.2% in the 0-25 cm, 25-35 cm, 35-45 cm, and 45-60 cm soil profile depths, respectively.

The moisture of the soil around Type C pipe was found to have increased in wetness by 82.4%, 60.0%, 28.6%, and 12.3% for 0-25 cm, 25-35 cm, 35-45 cm, and 45-60 cm soil profile depths, respectively at 10 cm distance away from the pipe. At 20 cm distance away from the Type C pipe, the soil wetness increased by 75.0%, 55.6%, 22.7%, and 10.2% in the 0-25 cm, 25-35 cm, 35-45 cm, and 45-60 cm soil profile depths. At 30 cm distance away from the pipe, soil wetness increased by 71.4%, 53.3%, 23.3%, and 12.2% in the 0-25 cm, 25-35 cm, 35-45 cm, and 45-60 cm soil profile depths, respectively.

The results trend indicate the average soil wetness of the clay pipe C was, 64% and 45% higher than Type A (100% clay) and Type B (95% clay + 5% sand), respectively. The average rate of wetness of the Type B pipe was also found to be 34% higher than the Type A pipe. The rate of wetness was influenced by the clay pipe materials. Higher rate of wetness was recorded in Clay Pipe C because of higher surface porosity due to the mixture of clay, sand and sawdust.

The rate of soil wetness of the clay pipes after one hour of continuous water application had similar trend with what was observed after 30 min of water application. The percentage differences between the moisture content at the start of the experimentation and one hour later were found to be about twice (both vertically and horizontally) what they were after 30 min of water application. This implies that the rate of seepage was steady throughout the period of water application. This was not unexpected since the pipes were full of water throughout the period. It also suggests that if the pipes are filled with water throughout the period of application, the rate at which the soil around the pipe is wetted will steady increase. This however, may not be indefinite as upon equilibrium between the soil potential and the water in the pipe (when the soil approaches saturation), seepage through pipe surface will obviously reduce.

CONCLUSION

The seepage rate, hydraulic conductivity, and rate of soil wetness of three types of clay pipes made from 100% clay, 95% clay + 5% fine sand, and 90% clay + 5% fine sand and 5% sawdust, were determined and compared. The seepage rate and hydraulic conductivities of the pipes were significantly influenced by the materials used to make the clay pipes. The addition of 5% fine sand to clay mixture increased both the seepage rate and hydraulic conductivity of the pipes by about 35- 45%, while a further addition of 5% sawdust to the clay-sand mixture increased both the seepage rate and hydraulic conductivity by about 57-63%. The average rate of wetness of the pipe made from clay-sand-sawdust mixture was 64% and 45% higher than those of pure clay and clay-sand mixture, respectively. The average rate of soil wetness of the clay-sand mixture pipe was also found to be 34% higher than the pure clay pipe. In order to increase the hydraulic properties of clay pipe, fine sand and sawdust may be mixed in fractional proportion to clay when making the clay pipes.

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