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# Effect of Porous Pipe Characteristics on Soil Wetting Pattern in a Negative Pressure Difference Irrigation System

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***ABSTRACT:*** *Sub-surface irrigation has been widely used to reduce conveyance, evaporation and percolation losses. This system involves the application of water directly into the root zone of crops. Negative Pressure Difference Irrigation (NPDI) is one kind of subsurface irrigation which is effective in management of irrigation water. The efficiency of this system is dependent on the soil wetting pattern as well as the characteristics of porous pipe. To examine the effect of characteristics of six different porous pipes on soil wetting pattern using NPDI system, experiments were done in laboratory at a negative pressure ($P_n$) of -3 cm. That $P_n$ was generated by placing water reservoir in a lower level than porous pipe, which was installed vertically at the center of soil column. The water was supplied for four hours and after removing dry soil from the column wetted soil was observed. The experimental results show that the soil wetting pattern varies for each type of porous pipe. The study reveals that the shape of the wetted soil is roughly truncated sphere. The maximum vertical expansion and maximum radial expansion vary with the change in diameter and length of porous pipes. With the change in diameter of 128.6%, the maximum radial expansion differs from 24.1% and 34.48% for X and Y axis respectively. Since the water use efficiency is in the range of 0.94 to 0.97, this advanced method can be used as alternative of other traditional methods.*

***Keywords*** **–** *Negative Pressure Difference Irrigation, Porous Pipe, Soil Wetting Pattern, Wetting Front*

## I. INTRODUCTION

Water is the most important factor that affects the agricultural production.When there is a lack of water, farmers always make an effort to irrigate their field to obtain high crop production. Vast majority of people is generally used conventional methods such as surface, furrow, sprinkler, basin irrigation etc.It is estimated that out of total 80% water losses, about 20% are farm water losses because of deep percolation and surface evaporation due to practice of traditional surface irrigation methods (Siyal2008[1]).In a sprinkler irrigation system, spray losses can become as high as 45% under extreme weather conditions such as bright sunlight, high temperature and low humidity (Frost and Schwalen 1955[2]). Moreover, owing to high water losses and installation cost, Furrow and Basin irrigation are rarely used in remote regions.

Consequently, there is a call for new irrigation method which will supply uniform soil moisture in the root zone e.g. high water use efficiency. Subsurface irrigation is one of the most well suited methods because precise amount of water is directly applied to the root zone and thus reduce water losses due to conveyance, evaporation and deep percolation. Negative Pressure Difference Irrigation (NPDI) is an improved version of subsurface irrigation whose water use efficiency is much higher than other traditional irrigation methods that are mentioned in this article and has no conveyance loss. NPDI system is an attractive mode of irrigation system in which water is supplied to the soil by means of porous pipe from the water reservoir using a negative pressure. The water wasted in the NPDI is less than that of the drip irrigation (Yabe et al. 1986[3]). The configuration of wetting front, porous pipe compositions are helpful for optimizing the performance of the NPDI system.

In past studies, most of the investigations on NPDI system were conducted with horizontal installation of porous pipe(For example, Kato et al. 1982[4], Tanigawa et al. 1988[5], Ashrafi et al. 2002[6], Siyal et al. 2009[7]). The infiltration rate and soil wetting pattern in vertically installed porous pipe has been rarely experimented except two groups of researcher (Peifu et al. 2004 [8] and Akhoond et al. 2008[9]). It can be easily predicted that the soil wetting pattern for vertically installed porous pipe will be different from horizontally installed porous pipe. Hence, it is necessary to know the variation in soil wetting pattern when porous pipe installed vertically.

The main objective of the study is to visualize and measure the soil wetting front. Another is to observe the effect of characteristics of six different porous pipes such as lengths, diameters on wetted soil volume at a negative pressure. The remaining objective is to detect the water use efficiency of different porous pipes.

## II. MECHANISM OF NPDI SYSTEM

In the NPDI system, water moves in a water supply conduit that links a water reservoir and a porous pipe which is installed vertically at the center of soil as shown in Figure 1.When the soil water matric potential (referred as matric potential, $\psi$) is smaller than the negative pressure in the porous pipe, $P_n$, water moves up from the reservoir to the porous pipe and then infiltrates through the porous pipe into the surrounding soil.

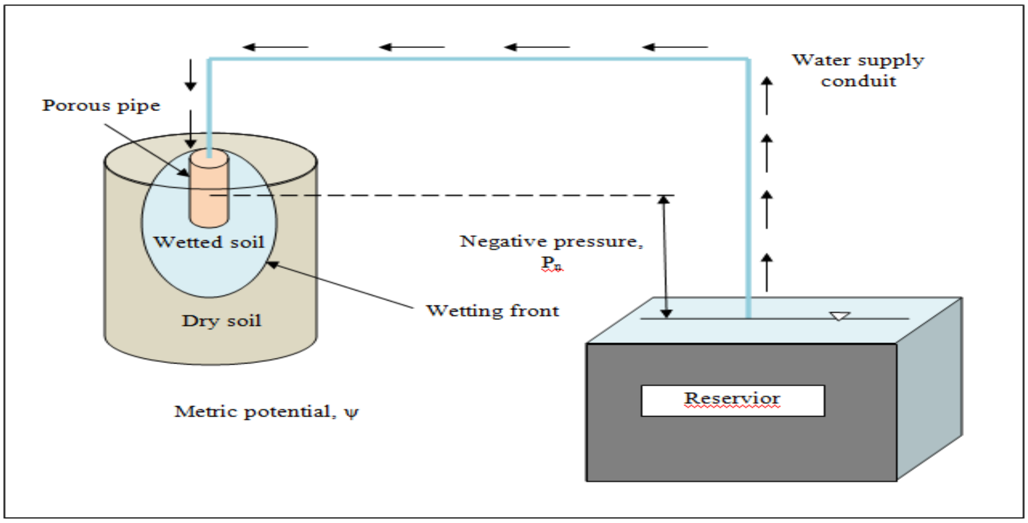


Fig. 1 Mechanism of a negative pressure difference irrigation system

On the other hand, when $\psi$ is equal or larger than $P_n$, the seepage stops automatically without any artificial work. The supplied water per unit time (Supplied water rate) is in proportion to the negative pressure difference (NPD), $|\psi - P_n|$ (Moniruzzaman et al. 2011[10]).

## III. MATERIALS AND METHODS

### 3.1 Location of the Study

The full research was conducted within the Department of Civil Engineering, Khulna University of Engineering and Technology.The preparation of porous pipes was completedin the geotechnical laboratory and the experimental set up and its related works were done in the environmental laboratory.

### 3.2 Fabrication of Porous Pipe

For the manufacture of porous pipe, locally available silty clay and rice husk were the main components. The percentages of them were 80% and 20% respectively. Rice husk is a good combustible material which can be used to produce porous pipe because their complete combustion could create pores within the bulk of a sand composite material.

For the necessity of the study, six different dimensions of porous pipe were selected. In Table 1, both dimensions and specifications are given.

Table 1 Dimensions and Specifications of porous pipe

| Sample No | Material Type | Shape of Porous Pipe | Length (cm) | Outer Diameter (cm) | Thickness (cm) |
|---|---|---|---|---|---|
| P1 | Silty Clay and Rice Husk | Cylindrical (One side closed) | 11 | 4.2 | 1 |
| P2 | | | 10.5 | 7 | |
| P3 | | | 12 | 8 | |
| P4 | | | 8 | 5.5 | |
| P5 | | | 8 | 3.5 | |
| P6 | | | 10.5 | 4.5 | |

To execute the making process, silty clay and rice husk were collected from local field and rice-mill respectively. The ingredients were sieved by # 40 and # 30 respectively. Using 4:1 ratio, the ingredients were mixed homogeneously with sufficient amount of water. In order to reduce the manufacturing cost and since the porous pipe was locally made, tap water was used instead of de-ionized water.

To make the preferred shape of porous pipe, different types of wooden mold was prepared and PVC pipe was cut into pieces to fulfill the dimension requirement. The entire mold was covered by polythene and enclosed it by the pipe. This produced structure was filled with mixture. A knife was used to remove the excess portion of mixture and for leveling the upper portion. Then the pipe and mold were removed respectively.

The rest of the porous pipes were prepared in the same process. Then, all of them were brought outside to dry primarily in sunlight for a period of half hour. Eventually, the porous pipes were kept in oven at 105$^{o}$C for 24 hours and desired one side open, hollow cylindrical shape porous pipes were obtained. In Figure 2, the complete manufacturing process is shown.

Fig. 2 Complete manufacturing process in form of pictures

### 3.3 Experimental Set Up

For the necessity of the arrangement, first of all, two electric balances with a minimum reading of 0.1 gm and a bottle which would be used as reservoir were collected. A soil column was made by using seven rings which was sliced from PVC pipe and each ring was of 3 cm, 20 cm and 0.5 cm in height, outer diameter and thickness respectively and attached to each other with binding tape to give a form of soil column. One end of the soil column was joined with a piece of glass by Silicon gum. The local sand wasused to fill the soil column and the bottle was loaded with water. Since the main theme of Negative Pressure Difference Irrigation (NPDI) system is negative pressure, for that reason, soil column was placed in higher elevation than the reservoir to produce a negative pressure of 3 cm. One of two electric balances was placed below the soil column to measure the amount of water stored in the soil, $M_{soil}$and the remaining one was under the reservoirto measure the supplied water from reservoir, $M_{sup}$. A pump was used to maintain the continuous flow with a pumping rate of 0.02292 gm/sec. Figure 3 shows the experimental arrangement.

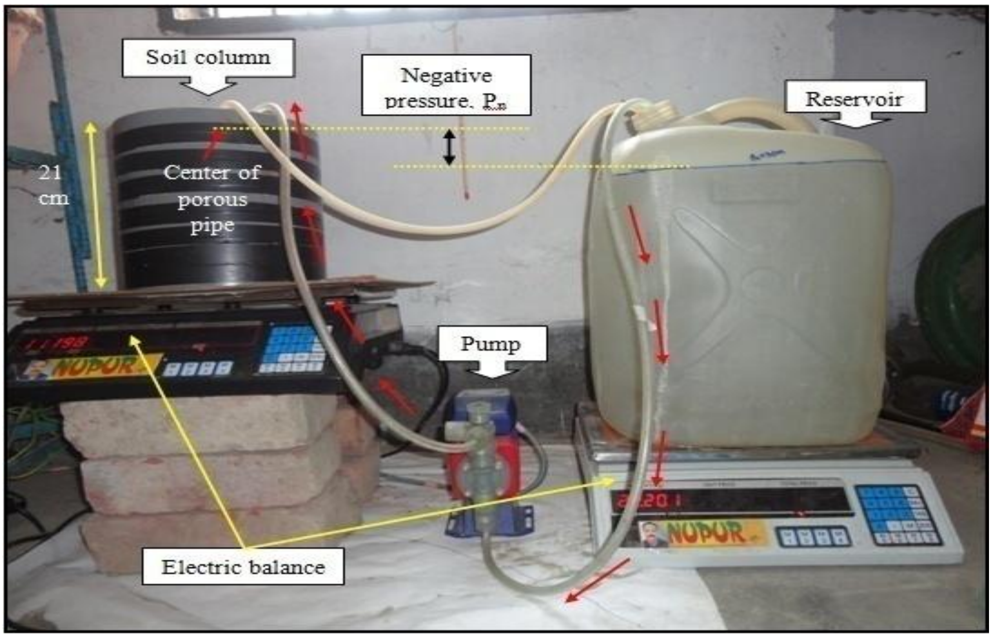


Fig. 3Overall experimental arrangements

All the data were collected at 40 minute intervals of total 4 hours. After recording data, evaporation from the soil surface, $M_{eva}$was calculated using following formula

$$M_{eva} = M_{sup} - M_{soil} \quad (1)$$

After water supply four hours, the measurements of soil wetting pattern were taken layer by layer after removing the dry soil from the column. Each layer was of 3 cm in depth. The measurements were taken both in X axis and Y axis of wetted soil surface.

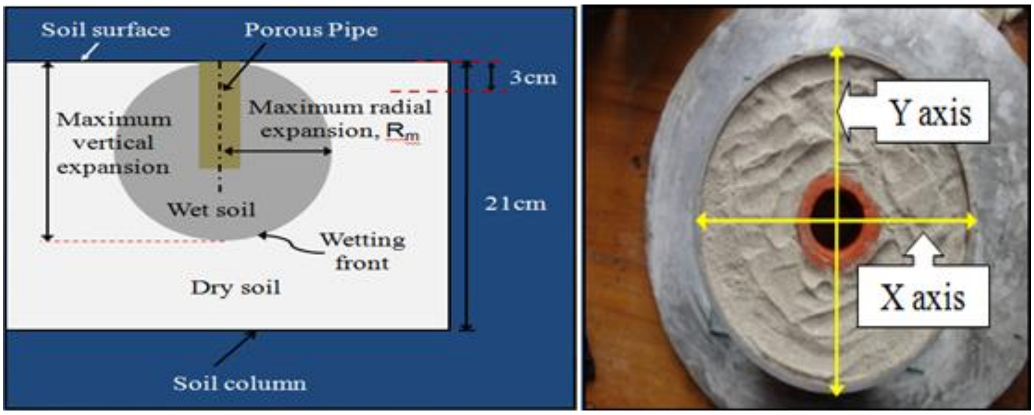


Fig. 4From left - Schematic diagram of soil wetting pattern measurement and picture showing axis

# IV. RESULTS AND DISCUSSIONS

## 4.1 Soil Wetting Pattern

The experimental results of soil wetting pattern for different porous pipes P1, P2, P3, P4….are shown in Table 2, Table 3, …… respectively.

Table 2Experimental Results for Porous Pipe $P_1$

| Mass Balance | | | |
|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) |
| 40 | 0.053 | 0.052 | 0.001 |
| 80 | 0.053 | 0.051 | 0.002 |
| 120 | 0.056 | 0.054 | 0.002 |
| 160 | 0.055 | 0.053 | 0.002 |
| 200 | 0.056 | 0.054 | 0.002 |
| 240 | 0.057 | 0.055 | 0.002 |

| Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|
| | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| 0 | 2.4 | 2.4 | 2.4 | 2.4 |
| 3 | 2.7 | 2.7 | 2.7 | 2.7 |
| 6 | 7 | 6.5 | 7 | 7 |
| 9 | 7 | 7 | 7 | 7 |
| 12 | 7.5 | 7.5 | 7.5 | 7.5 |
| 15 | 6.5 | 6 | 6.5 | 6.5 |
| 18 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 |

Table 3Experimental Results for Porous Pipe $P_2$

| Mass Balance | | | |
|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) |
| 40 | 0.053 | 0.052 | 0.001 |
| 80 | 0.057 | 0.054 | 0.003 |
| 120 | 0.055 | 0.052 | 0.003 |
| 160 | 0.054 | 0.050 | 0.004 |
| 200 | 0.055 | 0.052 | 0.003 |
| 240 | 0.055 | 0.052 | 0.003 |

| Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|
| | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| 0 | 3.6 | 3.6 | 3.6 | 3.6 |
| 3 | 3.8 | 3.8 | 3.8 | 3.8 |
| 6 | 6 | 6 | 7 | 6.5 |
| 9 | 8 | 8 | 8.5 | 8.5 |
| 12 | 8.5 | 9.5 | 8.5 | 8.5 |
| 15 | 6 | 6 | 6 | 6.5 |
| 18 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 |

Table 4 Experimental Results for Porous Pipe $P_3$

| Mass Balance | | | |
|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) |
| 40 | 0.052 | 0.050 | 0.002 |
| 80 | 0.055 | 0.052 | 0.003 |
| 120 | 0.053 | 0.050 | 0.003 |
| 160 | 0.052 | 0.049 | 0.003 |
| 200 | 0.053 | 0.049 | 0.004 |
| 240 | 0.056 | 0.052 | 0.004 |

| Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|
| | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| 0 | 4.25 | 4.25 | 4.25 | 4.25 |
| 3 | 4.5 | 4.5 | 4.5 | 4.5 |
| 6 | 6 | 6 | 7 | 6 |
| 9 | 7 | 7 | 8.5 | 8 |
| 12 | 9 | 9 | 10 | 9.5 |
| 15 | 6 | 6 | 6 | 6 |
| 18 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 |

Table 5 Experimental Results for Porous Pipe $P_4$

| Mass Balance | | | | Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) | | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| | | | | 0 | 3 | 3 | 3 | 3 |
| | | | | 3 | 3.5 | 3.5 | 3.5 | 3.5 |
| 40 | 0.054 | 0.053 | 0.001 | 6 | 7 | 6 | 7 | 6 |
| 80 | 0.053 | 0.051 | 0.002 | 9 | 8 | 8 | 9 | 8 |
| 120 | 0.055 | 0.053 | 0.002 | 12 | 7 | 6.5 | 7 | 6.5 |
| 160 | 0.055 | 0.052 | 0.003 | 15 | 0 | 0 | 0 | 0 |
| 200 | 0.053 | 0.050 | 0.003 | 18 | 0 | 0 | 0 | 0 |
| 240 | 0.055 | 0.052 | 0.003 | 21 | 0 | 0 | 0 | 0 |

Table 6 Experimental Results for Porous Pipe $P_5$

| Mass Balance | | | | Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) | | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| | | | | 0 | 2 | 2 | 2 | 2 |
| | | | | 3 | 2.5 | 2.5 | 2.5 | 2.5 |
| 40 | 0.055 | 0.054 | 0.001 | 6 | 6 | 6 | 6 | 6 |
| 80 | 0.053 | 0.052 | 0.001 | 9 | 7 | 7.5 | 7 | 7.5 |
| 120 | 0.057 | 0.055 | 0.002 | 12 | 5.5 | 6 | 5.5 | 6 |
| 160 | 0.055 | 0.053 | 0.002 | 15 | 0 | 0 | 0 | 0 |
| 200 | 0.056 | 0.054 | 0.002 | 18 | 0 | 0 | 0 | 0 |
| 240 | 0.054 | 0.052 | 0.002 | 21 | 0 | 0 | 0 | 0 |

Table 7Experimental Results for Porous Pipe $P_6$

| Mass Balance | | | | Depth from soil surface, Z (cm) | Expansion of wetted soil in X axis and Y axis | | | |
|---|---|---|---|---|---|---|---|---|
| Time (min) | $M_{sup}$ (kg) | $M_{soil}$ (kg) | $M_{eva}$ (kg) | | +X (cm) | -X (cm) | + Y (cm) | -Y (cm) |
| | | | | 0 | 2.8 | 2.8 | 2.8 | 2.8 |
| | | | | 3 | 3 | 3 | 3 | 3 |
| 40 | 0.052 | 0.051 | 0.001 | 6 | 6 | 6 | 6.5 | 7 |
| 80 | 0.054 | 0.052 | 0.002 | 9 | 8 | 8 | 8 | 7 |
| 120 | 0.056 | 0.054 | 0.002 | 12 | 8 | 8 | 8 | 7.5 |
| 160 | 0.055 | 0.053 | 0.002 | 15 | 6 | 6 | 6 | 6 |
| 200 | 0.054 | 0.051 | 0.003 | 18 | 0 | 0 | 0 | 0 |
| 240 | 0.054 | 0.052 | 0.002 | 21 | 0 | 0 | 0 | 0 |

From those data which was obtained for the expansion of wetted soil, it can say that the soil wetting pattern is almost circular in horizontal plane. The following figures show the soil wetting pattern for six porous pipes. It is seen from each of the graph that the cross section of wetting pattern at both X axis and Y axis of the soil column are almost overlaps each other.The shape of the wetted soil is roughly truncated sphere for all the graphs.

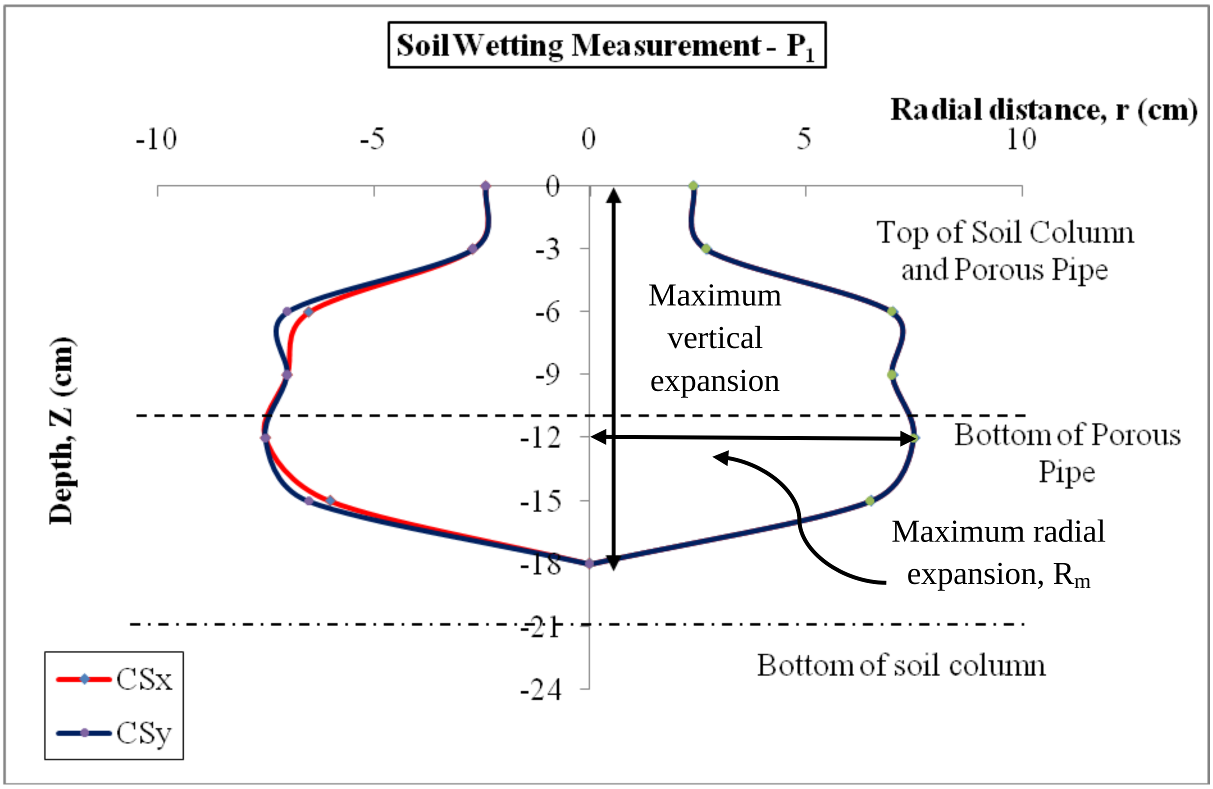


Fig. 5Wetting pattern for porous pipe ($P_1$). CSx and CSy represent the cross section of wetting at X and Y axis

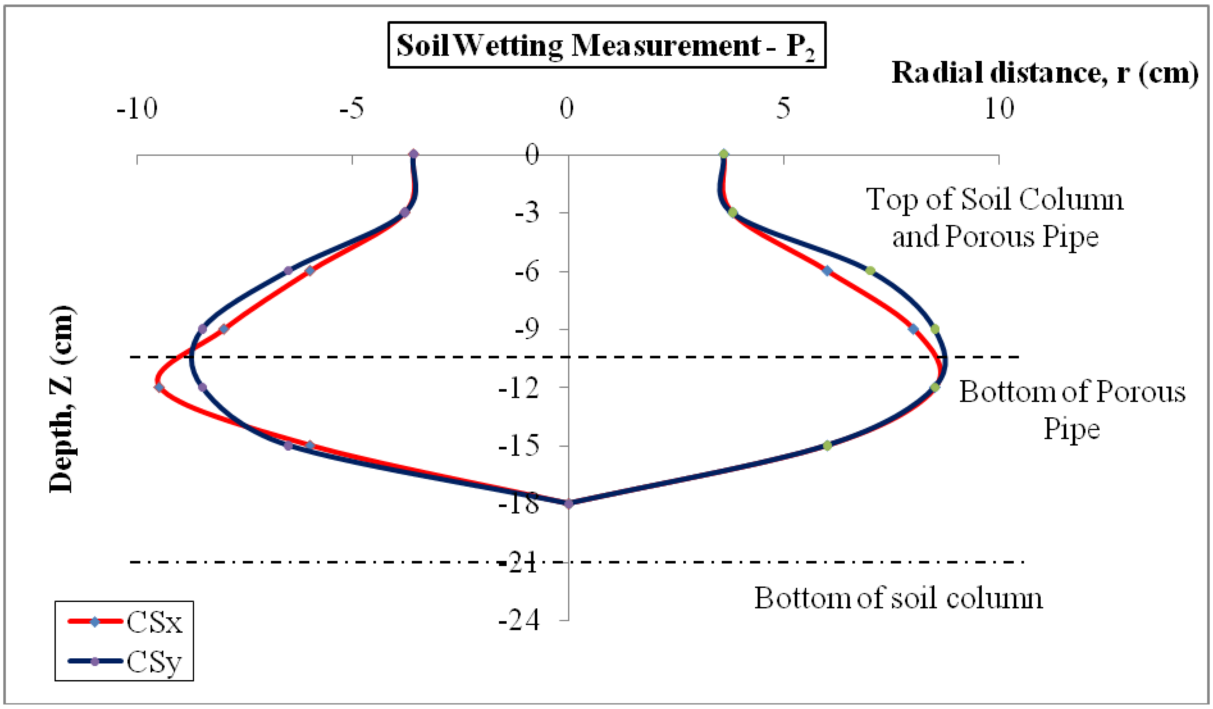


Fig. 6Wetting pattern for porous pipe ($P_2$)

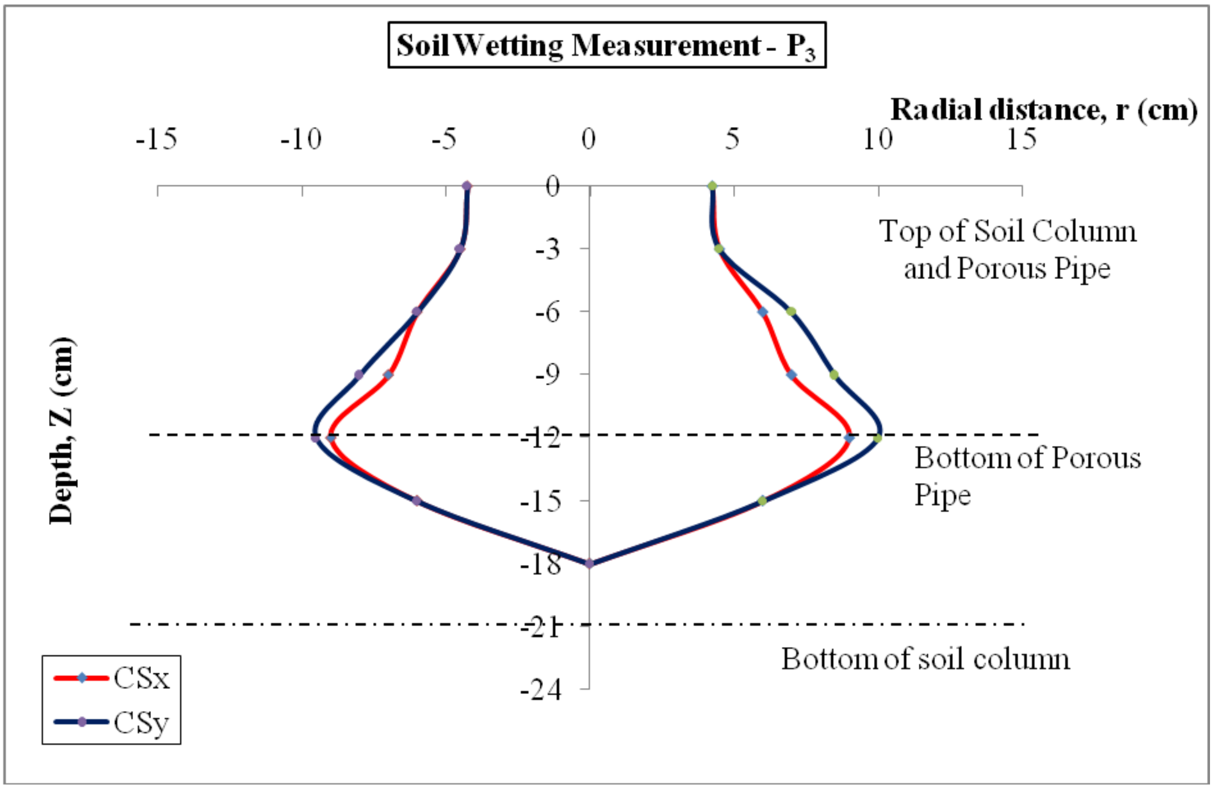


Fig. 7Wetting pattern for porous pipe ($P_3$)

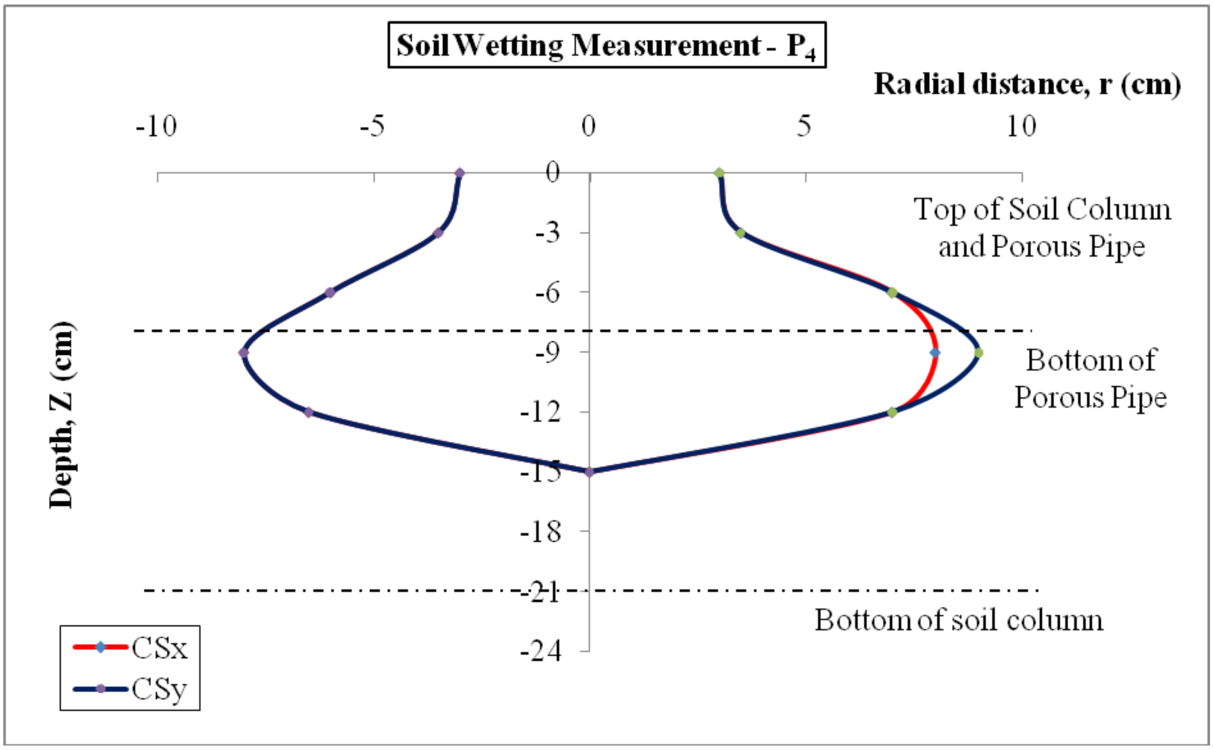


Fig. 8Wetting pattern for porous pipe ($P_4$)

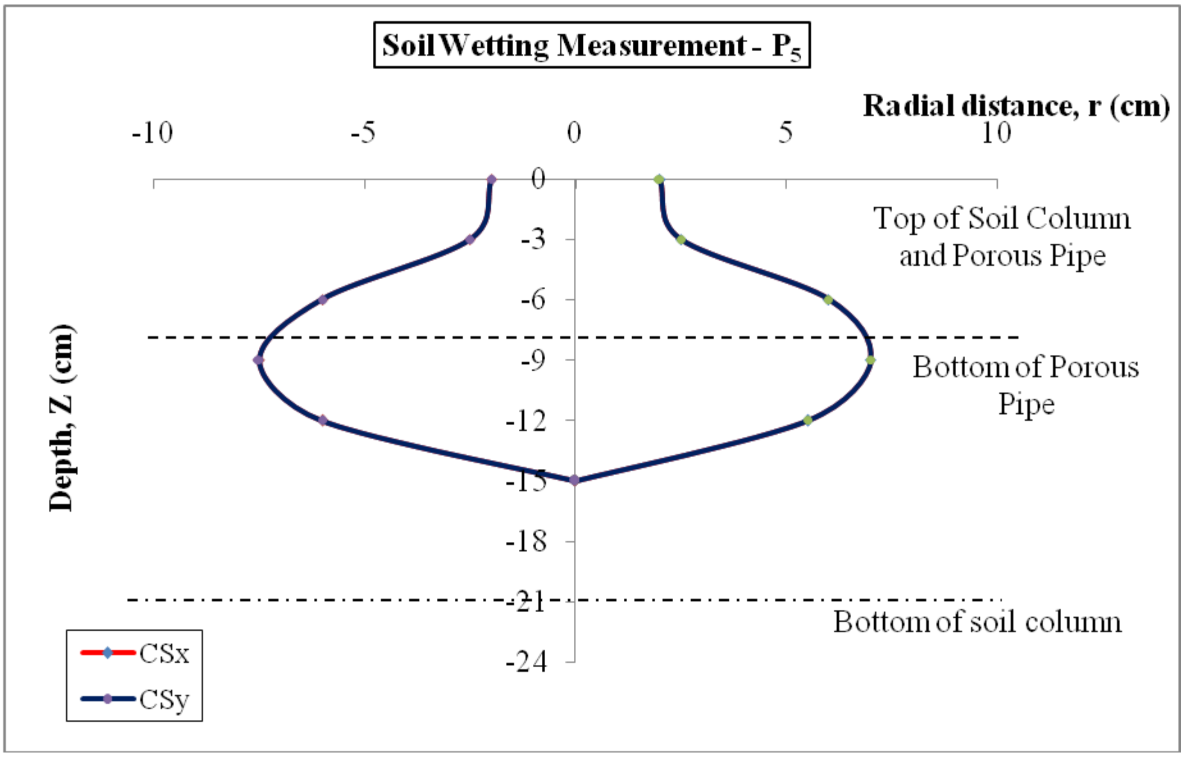


Fig. 9Wetting pattern for porous pipe ($P_5$)

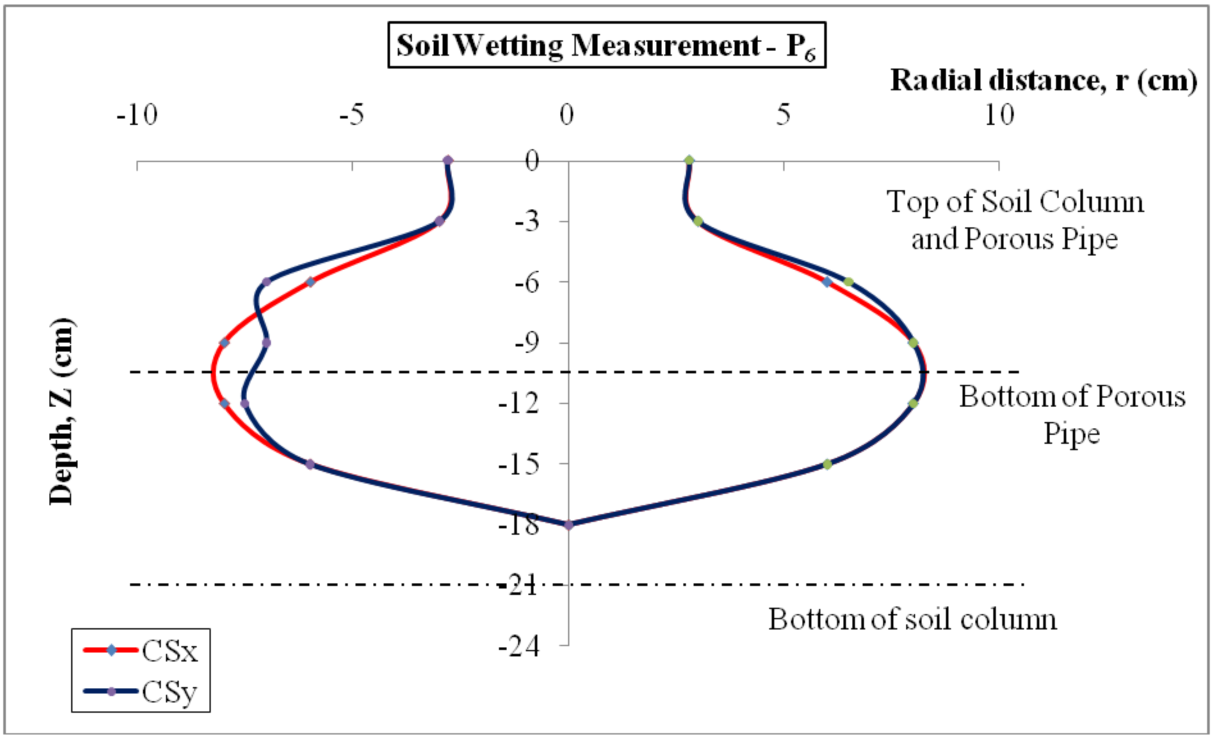


Fig. 10Wetting pattern for porous pipe ($P_6$)

After observing all the graphs, it can say that the wetted soil volume varies with the dimensions of porous pipe. Since the pipe length of $P_1$, $P_2$, $P_3$ and $P_6$ are higher than $P_4$ and $P_5$, the value of maximum vertical expansion of wetted soil is 18 cm whereas 15 cm for $P_4$ and $P_5$.

From the graphs, it can also say that the maximum radial expansion of wetted soil, $R_m$varies with both pipe length and outer diameter of porous pipe. It can be stated that when porous pipes having largerlength than 8cm, the maximum radial expansion, $R_m$ is seen in depth of 12cm. At the same time, the pipes having length equal to 8cm, the $R_m$ is in depth of 9cm.

In addition, it is observed that among the porous pipes whose outer diameter is maximum ($P_3$ = 8 cm), for that the value of maximum radial expansion, $R_m$ is also maximum and that is 9cm in X axis and 9.75 cm in Y axis. Besides, the pipe of smaller diameter ($P_5$) has maximum radial expansion of 7.25 cm in both axes.

It can be concluded that for the change in diameter of 128.6%, the Rm varies in percentage of 24.1 and 34.48 for X axis and Y axis respectively.

### 4.2 Evaporation

There are many factors that affect the evaporation such as temperature, surface area, humidity, wind speed etc. Since the evaporation only takes place at the exposed surface area, so it can say that the increase in diameter increases the evaporation rate. From the Figure11 and Table 8, the same thing is observed. The maximum value of evaporation is 19 gm.

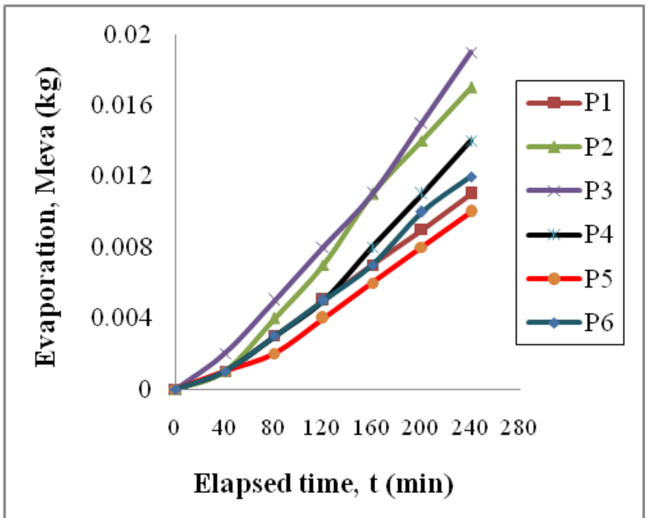


Fig. 11 Evaporation for different porous pipe

Table 8 Values of total evaporation for different porous pipe

| Porous Pipe | Outer Diameter (cm) | Total Evaporation, Meva (gm) |
|---|---|---|
| $P_1$ | 4.2 | 11 |
| $P_2$ | 7 | 17 |
| $P_3$ | 8 | 19 |
| $P_4$ | 5.5 | 14 |
| $P_5$ | 3.5 | 10 |
| $P_6$ | 4.5 | 12 |

### 4.3 Water Use Efficiency

The water use efficiency, $E_f$ may be defined as the ratio of $M_{soil}$ to $M_{sup}$ i.e. $M_{soil}$ / $M_{sup}$. The following figures representthe variations of the water use efficiency for different porous pipe.

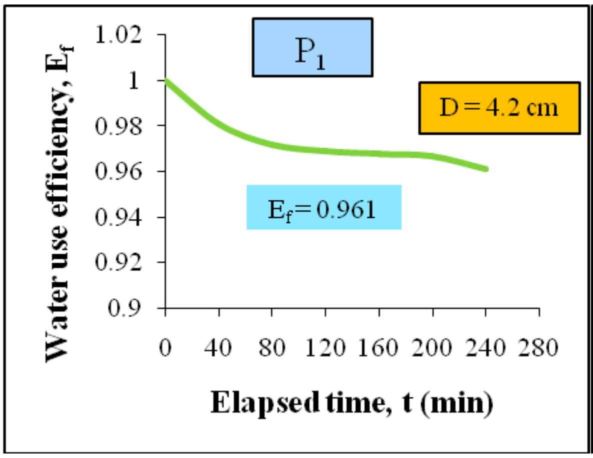


Fig. 12Water use efficiency for $P_1$

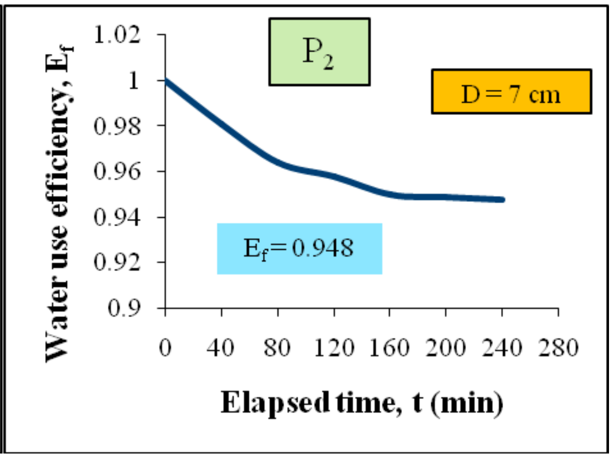


Fig. 13Water use efficiency for $P_2$

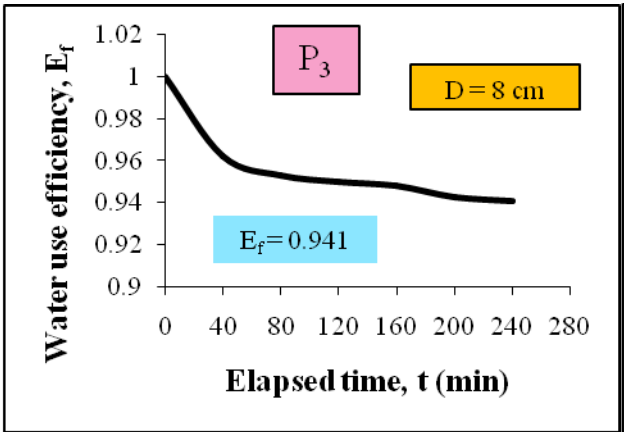


Fig. 14Water use efficiency for $P_3$

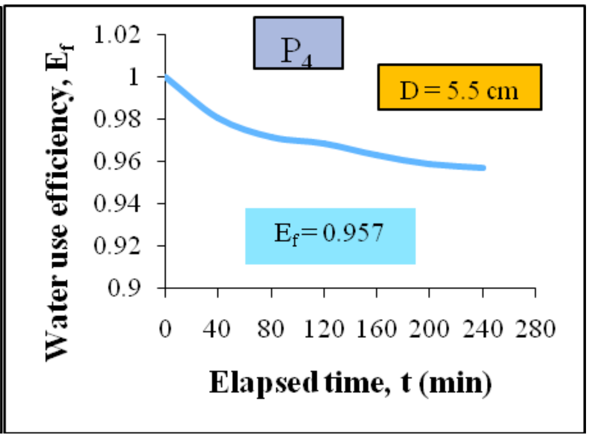


Fig. 15Water use efficiency for $P_4$

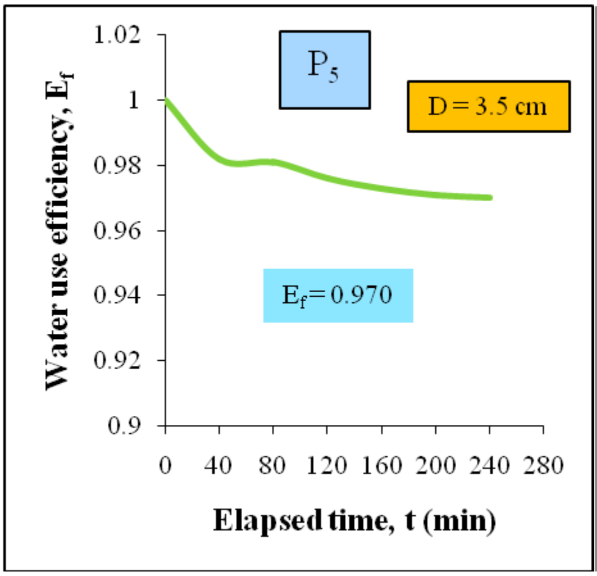


Fig. 16 Water use efficiency for $P_5$

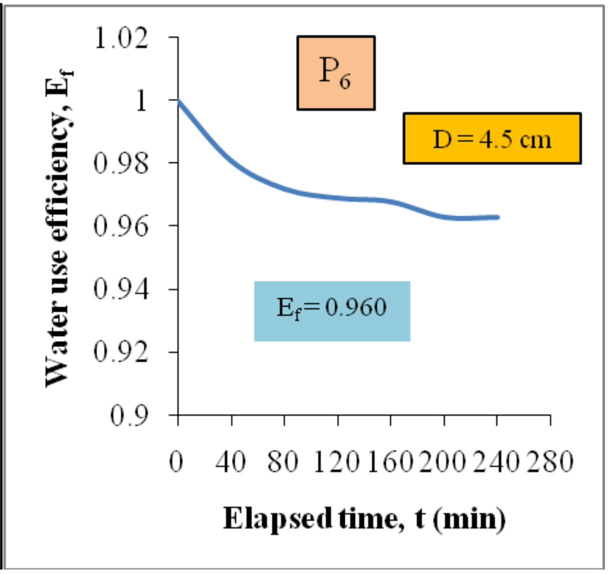


Fig. 17 Water use efficiency for $P_6$

After observing all the graphs, it can be stated that $E_f$decreases remarkably with time at the commencement of evaporation and then decreases gradually. In addition, it can say that $E_f$increases with a decrease of porous pipe diameter and ranges from 0.94 to 0.97.

## V. CONCLUSIONS

Soil wetting pattern is helpful for the management of negative pressure difference irrigation (NPDI) system. To know the effect of porous pipe characteristics on soil wetting pattern, laboratory experiments werecarried out using soil column, local sand, porous pipe, reservoir, pump and two electric balances. For the performance of the study, six different dimensioned porous pipes were used. The supplied water, soil water storage, evaporation and expansion of wetted soil for different porous pipe were measured at a negative pressure of 3 cm.

The main conclusions drawn from the study are as follows

1. Wetting pattern of local sand can be considered as a roughly truncated sphere.
2. The maximum vertical expansion and maximum radial expansion vary with the change in diameter and length of porous pipe.
3. With the change in diameter of 128.6%, the maximum radial expansion differs from 24.1% and 34.48% for X and Y axis respectively.
4. Evaporation increases with the increase in diameter of Porous Pipe.
5. Water use efficiency is very high and it ranges from 0.94 to 0.97.

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