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Subsurface Porous Pipe Irrigation with Vertical Option as a Suitable Irrigation Method for Light Soils

A.M. Akhoond-Ail and M. Golabi
Faculty of Water Science Engineering, University of Shahid Chamran, Ahwaz, Iran

Abstract: The main aims of current study are testing a new idea of vertical installation of porous pipe instead of horizontal installation, leading irrigated water down according to root depth, minimizing evaporation from soil surface and preventing deep percolation. This system was designed for three lengths of porous pipe (30, 45 and 60 cm) with three water heads of 2, 4 and 6 m and for a maximum irrigation duration of 300 min. The experimental results showed vertical expansion of soil moisture to the extent of 200% of porous pipe length in all treatments. However, acceptable horizontal expansion of soil moisture was recorded ouly for application of 6 m of water head. The produced soil moisture content by this system was shown in a range between 14.8 and 17.4% (w/w), which is around field capacity water content. Therefore, it can support plant growth in effective manner.

Key words: Sand dune, vertical option, porous pipe, moisture patterns, percolation

INTRODUCTION

About 0.35 million ha of sand dunes exist in Khuzestan Province at South West of Iran (Barootzadeh, 2000). These areas are associated with arid climatology and sand is eroded and blown away by wind. These areas are surrounded by Karkheh and Karoon Rivers and irrigation water can be applied for crop coverage development. However, irrigation water is easily lost by deep percolation because of high infiltration rate (Akhoond-Ali, 2004) and surface evaporation because of large scale of soil porosity. Therefore, a suitable irrigation method is needed to manage these light textured soils. A successful irrigation method will develop crop coverage, which may result in prevention of wind erosion, development of agricultural economy and improved health and social affairs. Application of a subsurface or buried irrigation method to these light soils may reduce both evaporation and deep percolation. In a review, Camp *et al*. (2000) showed that water requirements with subsurface irrigation methods are equal to or lower than other irrigation systems, including surface drip irrigation methods. There is increased interest in use of this technology for grasses, pasture and forage crops, especially for alfalfa (Hutmacher *et al*., 1992). One reason for this is that sub surface irrigation maintains a relatively dry soil surface, which reduces the need for the required drying period prior to harvest of these crops (Camp *et al*., 2000). The depth of installation of subsurface irrigation system is in a range of 0.02 to 0.7 m due to soil and crop type (Camp, 1998). Assessment of system application uniformity is more difficult for sub surface irrigation methods than for surface drip irrigation because most components are buried and not available for direct assessment. Indirect methods, including computer models, are available to assist in uniformity evaluations (Phene *et al*., 1992). Discussions of subsurface irrigation is included in several reviews such as Camp (1998) and Ayars *et al*. (1999).

Porous pipe irrigation system is very similar to drip irrigation because it is able to discharge water with low quantity. This system could be installed at soil surface or subsurface. Therefore, it is categorized not ouly as a micro scale irrigation (like drip system) but as a subsurface irrigation system. It seems that the porous pipe irrigation technique is one of the best methods applicable to sand dunes of studied area, because it discharges very low level of water allowing slow infiltration. Many researchers have evaluated different aspects of this irrigation method using the pipe with horizontal

Corresponding Author: A.M. Akhoond-Ali, Faculty of Water Science Engineering, University of Shahid Chamran, Ahwaz, Iran Tel: 0098 611 3364055/0098 9161184896 Fax: 0098 611 3365670

installation. Yoder and Mote (1995) evaluated discharge rate of unused porous pipes. In this study, discharges variation among 20, 0.3 m segments of 2 manufacturing lots (each 6 m pipe length) were measured and the mean flow rate decreased as much as 40% for the same pressure between lot 1 and lot 2. Teeluck and Sutton (1998) compared discharge uniformity for parts of 6 m long porous pipes, with 10 and 20 kPa water pressure by using filtered and non-filtered waters. Results of the filtered water showed that the discharge rate decreased with time but in non-filtered water the discharge remained constant. Manufacturing coefficient of variation with filtering water was in the range of 20% to 35% and these values increased with time. To observe and assess moisture movement from horizontal porous pipes in a light-textured soil, Akhoond-Ali (2004) used parts of porous pipes of 40 cm length, which were installed in three prospected boxes at a soil depth of 30 cm. Then, water pressure heads of 4, 6, 8 and 10 m were applied to them to irrigate for durations from 30 to 300 min. Results showed that upward vertical movement of water was to the extent of 10 cm. Therefore, the depth of setting was fixed at 10 cm. Khorramian and Mirlatifi (2000) tested a set of 6 m of this pipe under a range of water pressure from 20 to 100 kPa for evaluation of hydraulic characteristics. The emission rates were evaluated and compared three treatments viz unused dry porous pipes, unused soaked porous pipes and used porous pipes. Result showed that emission rate had linear function of pressure for dry porous pipe, however emission rate of unused soaked pipe was always lower than unused dry pipe. Emission rate for used porous pipe was very low. These works were carried out under horizontal setting of porous pipe. However, Akhoond-Ali (2003) studied moisture movement patterns from porous pipes that were vertically installed in glass boxes. Tests were done for three types of soils including light, medium and heavy textured. For this study, three lengths of pipe (30, 45 and 60 cm) of 13 mm diameter were used under 2 m of water pressure. Irrigation duration was 3 hr and results showed cylindrical wetting patterns for all types of soils following power functions of time for vertical and horizontal water movements. So considering the importance of irrigation water as well as soil types exist in these region the study was undertaken with an aims to assess vertical and horizontal expansion of soil moisture under vertical installation of porous pipe in light textured soil. Obtaining the aims, make sense the ability of managing irrigated water with an optimized low level of discharge, leading down according to root depth, minimizing evaporation from soil surface and preventing deep percolation.

MATERIALS AND METHODS

Experimental Site

Sand dunes in Khuzestan Province are spread between eastern longitude of 47° 40′ to 49° 20′ and northern latitude of 31° 5′ to 32° 20′ and these hills are extended from North West to South East. Total area is 0.35 million h, which represent 5.4% of total area of Khuzestan and 29.5% of agricultural lands. The field study was done in October 2003 at the Albaji Natural Resources Research Station (lat. 31° 20′ N and long. 48° 40′ E and 20 m asl). Average soil bulk density from 60 cm soil profile at the site is around 1.55 g cm^{-3}. Average initial water content of dry soil, average field capacity and average saturated condition from 90 cm soil profile at the site are around 1.5, 15 and 25% (w/w). Soil textures of the experimental site from depths of 0-30 and 30-60 cm are very similar. The average soil texture is categorized as sand and its particle size analysis is presented in Table 1.

System Structure and Installation

For this current study, porous pipe (type HD2216) with 22 mm external diameter was used. Three sets of porous pipe (each set included five the same sections) with three different lengths of 30, 45 and 60 cm were provided. To permit emitting of water only through the porous of pipe, end of the pipes were blocked by small caps. To consider uniformity of tests, each set included sections of unused and dry pipes. Then, each prepared set of porous pipes with the same length were connected to a polyethylene pipe of 32 mm diameter by fitted counectors considering 1.5 m distance between each pair of porous pipe sections to prevent interaction of soil moisture patterns resulting from porous

Table 1: The average soil texture of Albaji hills from a soil profile of 60 cm depth

Particle type	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Particle diameter(mm)	0.5-1	0.25-0.5	0.25-0.1	0.05-0.1	0.002-0.05	<0.002
Percent	0	28	65.5	1.5	2	2.5
Soil texture				Sand		

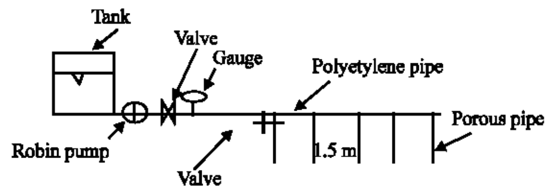

Fig. 1: Schematic structure of system installation

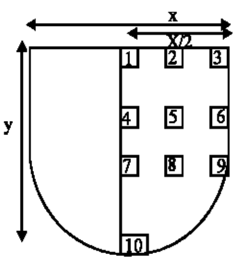

Fig. 2: Schematic observation of soil moisture pattern and sample points

pipe discharges. Immediately after each connector, a small control valve was installed on each porous pipe section because each section was considered to irrigate only each defined duration according to its order on polyethylene pipe. For example, the first section had to irrigate 10 min, the second 30 min and the fifth section (final one), 300 min. Therefore, five sections with the same length of porous pipes were ready to intake water from polyethylene pipe for delivering it inside soil as an emitter. One end of the polyethylene pipe was blocked and the other end linked to a Robin pump that pumped the required water from a tank to the system. A control value and a gauge regulated the required pressure head. Finally, all sections of each set of porous pipes were fitted in a set of prepared holes, which were dug out vertically. This system was made for mentioned three different lengths of porous pipes and repeated for application of 2, 4 and 6 m of water pressure heads (Fig. 1).

After preparation of system, tests were done over each set (including five sections of porous pipe with the same length) so that after 10 min of irrigation, the first valve on the first section was blocked and irrigation was terminated. Then by making a vertical cross section along the porous pipe, the produced symmetrical soil moisture pattern was observed (Fig. 2) and recorded. At the same time, 10 soil samples were collected from each cross section for laboratory measurement of soil moisture content. The locations of collected soil samples are shown in Fig. 2. This method of observation was repeated for other porous pipes after 30, 60, 180 and 300 min. By this methodology, it was possible to put all soil moisture patterns and lines over each other on one sheet specified for each applied water pressure head. Therefore, all soil moisture movement were observed with time for time periods from 10 to 300 min. Due to application of three lengths of porous pipes, three pressure heads and five irrigation durations, 45 soil moisture patterns were collected. From this large database, data of soil moisture patterns and lines resulting from 300 min of irrigation have sited in results section. To make these data simple to nnderstand, they are shown in the form of diagrams as well. To predict the value of vertical and horizontal soil moisture movements with time, some empirical fnnctions were fitted to the collected data.

RESULTS AND DISCUSSION

Vertical Soil Moisture Expansion

Results of soil moisture movement patterns for porous pipes of 30, 45 and 60 cm lengths are shown in Table 2 by y parameter and are plotted in Fig. 3-5, respectively. To predict the value of vertical soil moisture movement with time, some empirical functions were fitted to the collected data. These functions are shown in Table 3. Figure 3 shows that for porous pipe of 30 cm length with 300 min. irrigation duration with 2, 4 and 6 m of water pressure head, vertical expansions of soil moisture are 45, 50 and 60 cm, respectively. These expansions of soil moisture for porous pipe of 45 cm length (Fig. 4) are 60, 65 and 85 cm when the same irrigation duration and water pressure head were maintained. In case of 60 cm length of porous pipe under same irrigation duration and water pressure head, vertical expansion of soil moisture was, 78, 85 and 110 cm, respectively (Fig. 5). However, for all three porous pipes with different lengths, maximum vertical expansion of soil moisture occurred when, maximum water pressure head of 6 m was applied. Application of this highest water pressure head, resulted in to maximum vertical expansion of soil moisture, which was approximately equal to the length of porous pipe. In other words, at 6 m water pressure head, total vertical expansion of soil moisture was approximately equal to double the pipe's length. For simplifying these results to users, empirical equations were extracted from the data of soil moisture movements with time (Table 3). As past to produce Y. Value of constant parameter shows pipe's length for all equations. As shown, all equations are simple and linear with Y (cm), defined as vertical soil moisture from the soil surface to the end of moisture pattern and t (min), as time. Coefficients of determination, R^2 for all fitted equations is around 0.9. Therefore, these equations have been well fitted to the data and vertical soil moisture patterns should be well predicted by these equations. Because of these, user could be able to lead irrigation water down conformed to root zoon, or lead root system downward following produced moisture pattern. Therefore, one of the aims of current study might be achieved. This is an advantage over other irrigation systems for sand soils, because of reducing

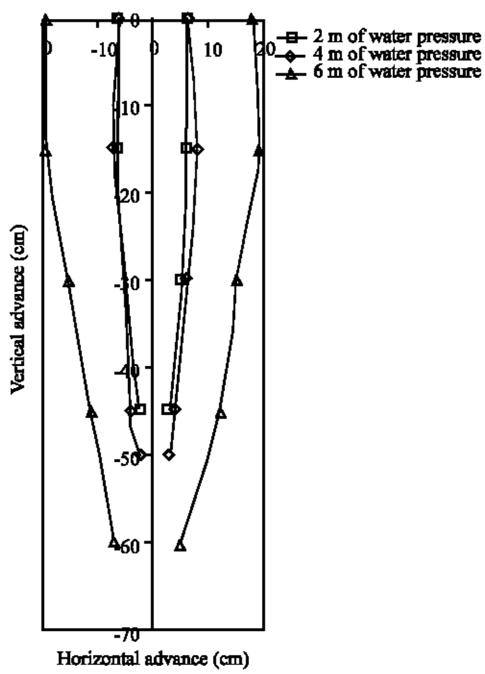

Fig. 3: Soil moisture patterns for porous pipe of 30 cm

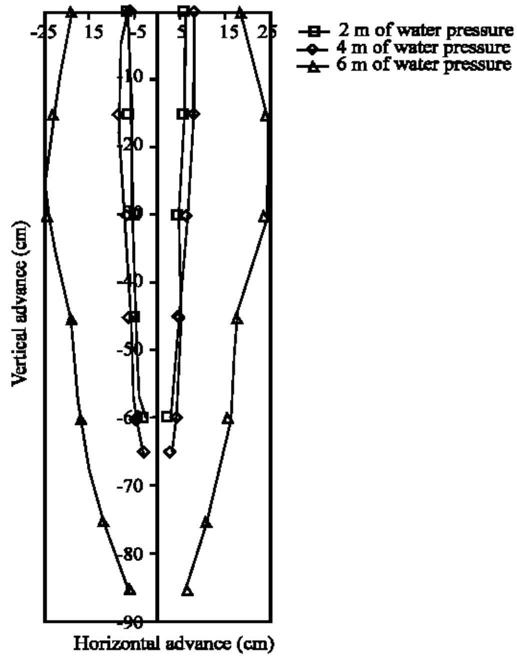

Fig. 4: Soil moisture patterns for porous pipe of 45 cm

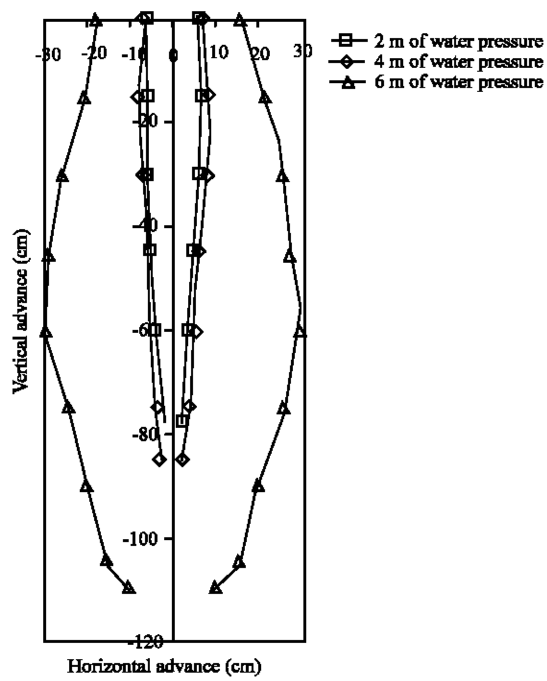

Fig. 5: Soil moisture patterns for porous pipe of 60 cm

evaporation from soil surface and preventing deep percolation and also preserving tree failure against wind by leading root system enough down. These results are significant and unique findings of the current research.

Horizontal Soil Moisture Expansion

Horizontal expansion of soil moisture patterns for porous pipes of 30, 45 and 60 cm lengths under 2, 4 and 6 m of water pressure head and irrigation duration of 300 min are shown in Fig. 3-5, respectively. Also, for predicting value of horizontal expansion of soil moisture with time, some empirical functions were fitted to the recorded data. These functions with best fitness to logarithm of observed data are linear as controlled by coefficient of determination R^2 and are shown in Table 4-6. These functions were extracted from data of horizons of 0, 15 and 30 cm for porous pipe of 30 cm, from horizons of 0, 30 and 45 cm for porous pipe of 45 cm and from horizons of 0, 30 and 60 cm for porous pipe of 60 cm. Shapes of all the remainder patterns under porous pipe ends are approximately conical. Therefore, these patterns are predictable by using last function for knowing radius of X at each horizon of porous pipe end and vertical soil moisture Y for the same time period of irrigation used for calculation of X. As shown in Fig. 3, for porous pipes of 30 cm length with 2 m of water pressure head, horizontal expansion of soil moisture varies between 5 to 12 cm; with 4 m of water pressure, it ranged between 5 to 15 cm and with 6 m of water pressure, it was 12 to 38 cm. For porous pipes of 45 cm length (Fig. 4) with 2 m of water pressure head, horizontal expansions was found between 6 to 12 cm; with 4 m of pressure head, it was between 6 to 16 cm and with 6 m of water pressure head, it was between 13 to 48 cm. For porous pipes of 60 cm length (Fig. 5), with 2 m of water pressure head, horizontal expansion was between 4 to 13 cm; with 4 m water pressure head it was between 5 to 16 cm and with 6 m of water pressure head it was between 20 to 60 cm. These data show that horizontal expansion of soil moisture varied a little by changing the length of the pipe. However, variations were much more when water pressure head changed from 2 and 4 to 6 m. Therefore, this system can be designed for porous pipe of 30, 45 and 60 cm lengths with at least 6 m of water pressure head because of not making a proper horizontal soil moisture pattern when 2 and 4 m of water pressure head of irrigation water was applied. The reason of limitation for horizontal expansion of soil moisture was due to soil texture, which was sand and irrigated water was more affected by gravity force than

Table 2: Vertical (y) and horizontal (x_1 and x_2) expansion of soil moisture movements (cm) around porous pipes after 300 min of irrigation

Length of pipe (cm)																										
									Pressure (meter of water)																	
30									45									60								
2			4			6			2			4			6			2			4			6		
x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2	x_1	y	x_2
6	0	6	6	0	6	19	0	18	6	0	6	7	0	8	19	0	19	6	0	6	7	0	7	18	0	16
6	15	6	7	15	8	19	15	19	6	15	6	8	15	8	23	15	24	6	15	7	8	15	8	21	15	22
5	30	5	5	30	6	15	30	15	5	30	5	7	30	6	24	30	24	6	30	6	7	30	8	26	30	26
2	45	3	4	45	4	11	45	12	5	45	5	6	45	5	19	45	18	5	45	5	6	45	6	29	45	28
			2	50	3	7	60	5	3	60	3	5	60	4	17	60	16	4	60	4	5	60	5	30	60	30
												3	65	3	12	75	11	2	78	2	4	75	4	25	75	26
															6	85	7				3	85	2	20	90	20
																								15	105	16
																								10	110	10

Table 3: Empirical equations fitted to vertical soil moisture movements as functions of time (Y in cm and t in min)

	Water head pressure (m)		
Pipe's length (cm)	2	4	6
30	Y = 0.494t+30	Y = 0.059t+30	Y = 0.0861t+30
	R^2 = 0.98	R^2 = 0.89	R^2 = 0.88
45	Y = 0.0469t+45	Y = 0.0611t+45	Y = 0.1216t+45
	R^2 = 0.97	R^2 = 0.89	R^2 = 0.95
60	Y = 0.572t+60	Y = 0.0784t+60	Y = 0.1553t+60
	R^2 = 0.98	R^2 = 0.97	R^2 = 0.96

Table 4: Empirical equations fitted to horizontal soil moisture movements as functions of time (X in cm and t in min) -porous pipe of 30 cm

	Horizon under soil surface (cm)		
Water head (m)	30	15	0
2	X = 1.1492 Ln(t) -0.7	X = 0.94 Ln(t)+0.9	X =0.9278 Ln(t)-0.5
	R^2 = 0.99	R^2 = 0.97	R^2 = 0.94
4	X = 1.0628 Ln(t)+0.3	X = 1.1492 Ln(t)+0.7	X = 0.94 Ln(t)+0.4
	R^2 = 0.9	R^2 = 0.9	R^2 = 0.85
6	X = 4.2148 Ln(t)-4.7	X = 3.625 Ln(t)-1.2	X =1.9718 Ln(t)+2
	R^2 = 0.98	R^2 = 0.98	R^2 = 0.56

Table 5: Empirical equations fitted to horizontal soil moisture movements as functions of time (X in cm and t in min) -porous pipe of 45 cm

	Horizon under soil surface (cm)		
Water head (m)	30	15	0
2	X = 1.1492 Ln(t)-0.7	X = 0.6239 Ln(t)+1.3	X=0.9037 Ln(t)-0.5
	R^2 = 0.9877	R^2 = 0.9098	R^2 = 0.8981
4	X = 1.1896 Ln(t)+0.8	X = 0.8635 Ln(t)+2	X = 0.9923 Ln(t)
	R^2 = 0.69	R^2 = 0.77	R^2 = 0.95
6	X = 3.7112 Ln(t)-3	X = 4.6967 Ln(t)-2	X = 3.7478 Ln(t)-2
	R^2 = 0.94	R^2 = 0.95	R^2 = 0.98

Table 6: Empirical equations fitted to horizontal soil moisture movements as functions of time (X in cm and t in min) -porous pipe of 60 cm

	Horizon under soil surface (cm)		
Water head (m)	60	30	0
2	X = 1.1492 Ln(t)-0.7	X = 0.8354 Ln(t)+2	X = 0.5193 Ln(t)+1
	R^2 = 0.98	R^2 = 0.77	R^2 = 0.72
	X = 1.0286 Ln(t)+2	X = 0.6974 Ln(t)+3.5	X = 0.6974 Ln(t)+1
4	R^2 = 0.77	R^2 = 0.98	R^2 = 0.98
	X = 3.3089 Ln(t)-1.8	X = 4.7701 Ln(t)-0.5	X = 7.0573 Ln(t)-12
6	R^2 = 0.99	R^2 = 0.98	R^2 = 0.97

Table 7: Moisture content (W/W) at 10 points in the wetted profile around porous pipe after 300 min of irrigation

	Length of pipe (cm)								
	30			45			60		
No. of point pressure (meter of water)	2	4	6	2	4	6	2	4	6
1	14.7	14.9	16.3	15.2	15.8	17.1	15.4	16.0	17.5
2	14.5	14.6	15.0	15.0	15.5	16.8	15.2	15.8	17.0
3	14.1	14.2	14.8	14.9	15.3	16.5	15.0	15.5	16.7
4	14.9	15.1	16.5	15.4	16.0	17.4	15.6	16.2	17.7
5	14.8	14.8	15.4	15.1	15.6	17.1	15.3	16.0	17.4
6	14.4	14.5	15.0	15.0	15.5	16.9	15.2	15.6	17.0
7	15.0	15.3	16.7	15.6	16.2	17.7	15.7	16.4	17.9
8	15.1	15.0	15.5	15.4	15.9	17.3	15.4	16.1	17.7
9	14.7	14.7	15.2	15.3	15.7	17.0	15.2	15.8	17.3
10	15.5	15.5	15.6	15.5	16.0	17.6	15.5	15.9	17.8

the matrix force. However, using 2 or more porous pipes together, might make the system able for applying 2 and 4 m of water pressure head because diameter of horizontal pattern of soil moisture will extend much more.

Actual Soil Moisture Content

Figure 6-14 depicted actual soil moisture content lines (w/w %) for porous pipes of 30, 45 and 60 cm lengths, in which irrigation was applied continuously for 300 min at 2, 4 and 6 m of water

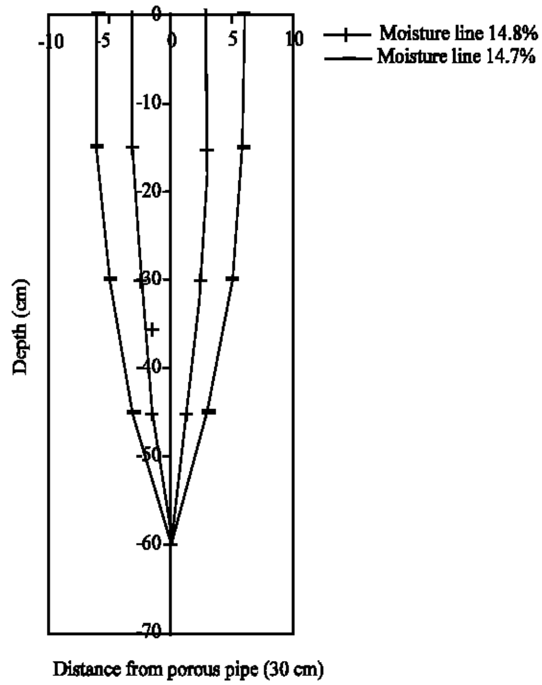

Fig. 6: Soil moisture line during application of 2 m water head

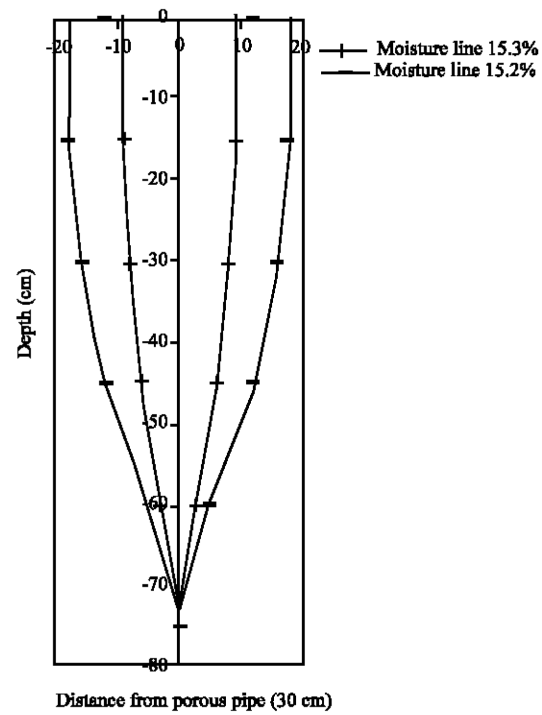

Fig. 7: Soil moisture line during application of 4 m water head

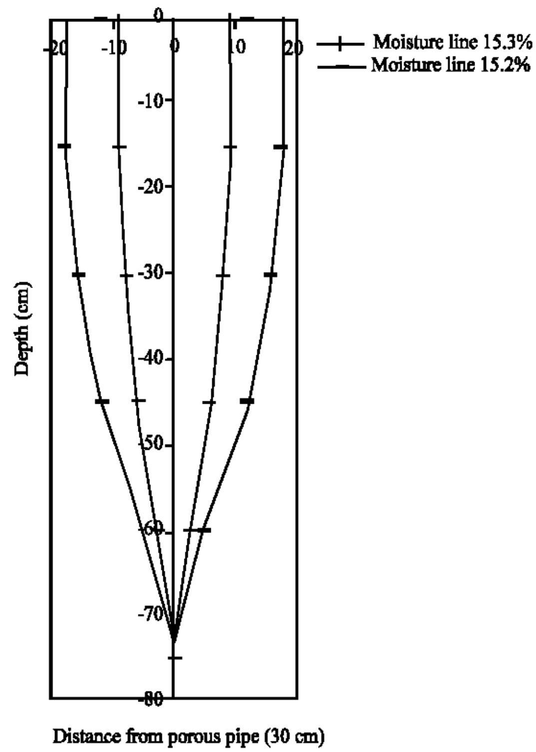

Fig. 8: Soil moisture line during application of 6 m water head

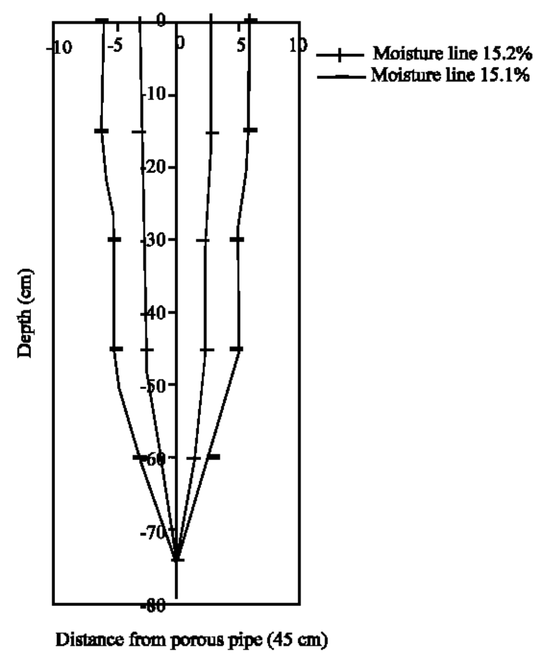

Fig. 9: Soil moisture line during application of 2 m water head

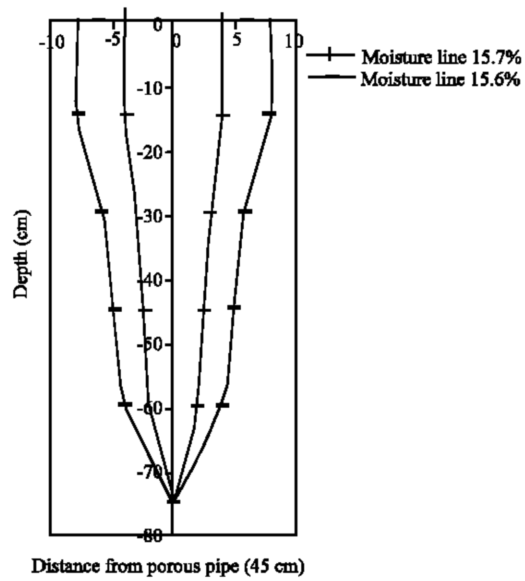

Fig. 10: Soil moisture line during application of 4 m water head

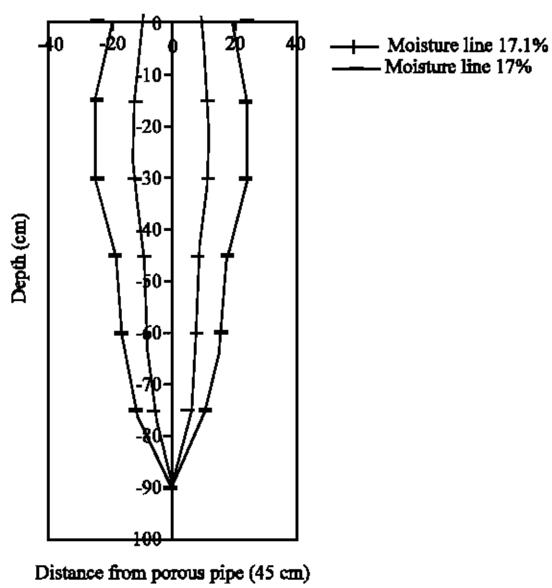

Fig. 11: Soil moisture line during application of 6 m water head

pressure heads. The value of soil moisture decreased a little, when the distance of wetting front pattern increased from porous pipe location. This was because of decreasing matrix potential gradient from pipe location to wetting front. In addition, increasing pressure head from 2 to 4 and 6 m, showed a little increase in soil moisture content. However, minimum moisture content of 14.8% (w/w) for porous pipe of 30 cm length at 2 m of water pressure head and 17.4% (w/w) for porous pipe of 60 cm length at 6 m of water pressure head was recorded (Table 7). Porous pipe with 2 and 4 m of water pressure

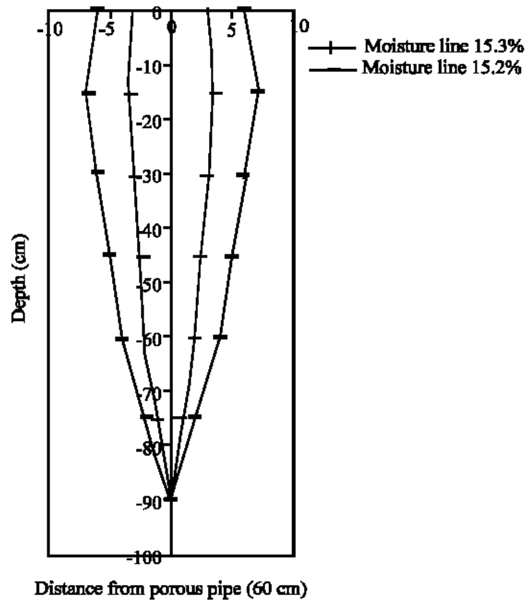

Fig. 12: Soil moisture line during application of 2 m water head

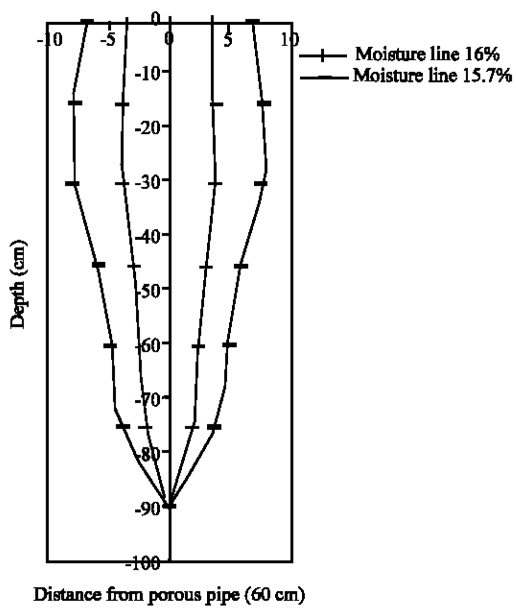

Fig. 13: Soil moisture line during application of 4 m water head

does not make a proper horizontal moisture pattern as explained in previous section. However, these soil moistures are around average field capacity moisture content 15% (w/w) which was obtained from the experimental site and are conformed to results of Akhoond-Ali (2003) for the same soil and are proper moistures for plant to use. Therefore, from this point of view the objective of this study is satisfied because with field capacity condition, the lost water from deep percolation can be preserved.

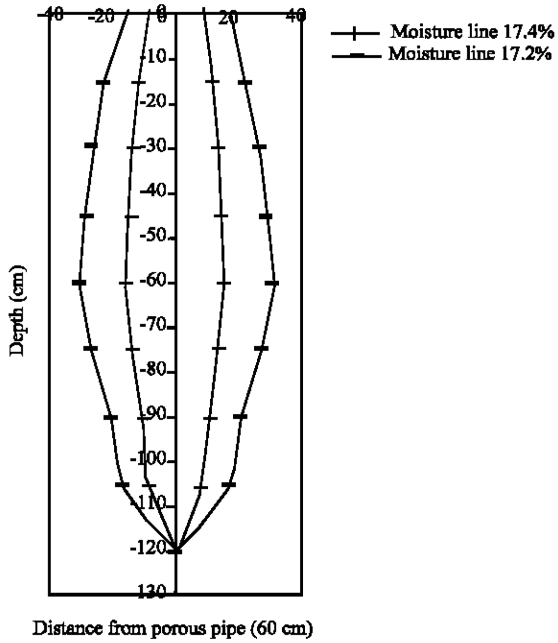

Fig. 14: Soil moisture line during application of 6 m water head

Attention to increasing soil moisture in a few percents with increasing water pressure, leads to this point that if the pressure head increases for levels more than 6 m, the produced soil moisture might increase toward higher levels up to saturated condition. Therefore, some tests for higher pressure heads are needed to generate a general empirical equation, related produced soil moisture to pressure head.

CONCLUSIONS

An initial test on a new idea of using porous pipe vertically was presented. This system was designed for three lengths of porous pipe (30, 45 and 60 cm) with three water heads of 2, 4 and 6 m and for a maximum irrigation duration of 300 min. The experimental results showed vertical expansion of soil moisture to the extent of 200% of porous pipe length in all treatments. However, acceptable horizontal expansion of soil moisture was recorded only for application of 6 m of water head. The produced soil moisture content by this system was shown in a range between 14.8 and 17.4% (w/w), which is around field capacity water content. Therefore, it can support plant growth in effective manner.

This system might have two advantages over horizontal installation of porous pipe. First, it might be able to lead root system down enough following length of porous pipe and downward emitted water to preserve tree failure against wind. The second advantage is involved in pipe obstruction by root system. In terms of horizontal installation of porous pipe, obstruction will interrupt all the line. However, obstruction in vertical installation will change the pattern of soil moisture only for the obstructed part, which is an off-line branch from lateral line and works locally like a dripper.

REFERENCES

Akhoond-Ali, A.M., 2003. Evaluation of applying porous pipe with vertical option of installation (Persian). Research Report No. 406, Shahid Chamran University, Ahwaz, Iran.

Akhoond-Ali, A.M., 2004. Determining moisture patterns for Khuzestan soils using subsurface porous pipe irrigation (Persian). Research Report No. 486, Shahid Chamran University, Ahwaz, Iran.

Ayars, J.E., C.J. Phene, R.B. Hutmacher, K.R. Davis, R.A. Schoneman, S.S. Vail and R.M. Mead, 1999. Subsurface drip irrigation of row crops: A review of 15 years of Research at the Water Management Research Laboratory. J. Agric. Water Mgt., 42: 1-27.

Barootzadeh, M., 2000. An investigation on growing potato in sand dune using drip and spray-jet emitters (Persian). M.Sc. Thesis, Submitted at College of Agriculture, Shahid Chamran University, Ahwaz, Iran.

Camp, C.R., 1998. Subsurface Drip Irrigation: A Review. Transaction of the ASAE., 5: 1353-1367.

Camp, C.R., F.R. Lamm, R.G. Evans and C.J. Phene, 2000. Subsurface drip irrigation-past, present and future. In: Proceedings of the 4th Decennial National Irrigation Symposium, 14-16 November, Phoenix AZ, pp: 363-373.

Hutmacher, R.B., C.J. Phene, R.M. Mead, D. Clark, P. Shouse, S.S. Vail, R. Swain, M. Van Genuchten, T. Donovan and J. Jobes, 1992. Subsurface drip irrigation of alfalfa in the Imperial Valley. In: Proceedings of the 22nd California/Arizona Alfalfa Symposium, 9-10 December, 1996, University of California and University of Arizona Cooperative Extension, Holtville, CA, pp: 20-32.

Khorramian, M. and S.M. Mirlatifi, 2000. Hydraulics of porous pipe evaluation. J. Soil Water Sci., 2: 187-188 (Persian).

Phene, C.J., R. Yue, I-Pai Wu, J.E. Ayars, R.A. Schoneman and B. Meso, 1992. Distribution uniformity of subsurface drip irrigation systems. J. ASAE, 92: 2569-2583.

Teeluck, M. and B.G. Sutton, 1998. Discharge characteristics of porous pipe micro irrigation lateral. J. Agric. Water Manage., 2: 123-134.

Yoder, R.E. and C.R. Mote, 1995. Porous pipe discharge uniformity. In: Proceedings of the 5th International Micro Irrigation Congress, 2-6 April, Orlando, Florida, pp: 750-755.