THE EFFECT OF POT VOLUME ON THE PERFORMANCE OF POT IRRIGATION SYSTEM [+]

تاثير حجم الاوعية على اداء نظام الري بالاوعية الفخارية

Fadhil Mohammed Al- Mohammed [*]

Abstract:

Clay pot method is one of the most efficient traditional systems of irrigation known and is well suited for small farmers in many areas of the world. Pot irrigation system consists of unglazed clay pots; each has many micropores in its wall. The microporous wall guides water seepage from it in the direction where suction pressure develops. When the clay pot buried in the soil, filled with water and crops planted adjacent to it, the pot effects sub-surface irrigation as water seeps out of it due to suction force which attracts water molecules to the plant roots. Field experiments were conducted to quantify the effect of pot volume on water use efficiency and surface wetting edge by comparing the performance of large pots to that of smaller ones. Two types of pot irrigation systems, the first type consists of pots with large volume "PIS_1" and the second type consists of pots with small volume "PIS_2", were prepared in a clay loam soil by using three crops, namely, tomato, beans, and cucumber. Results showed that water use efficiency when applying "PIS_1" was greater than that of "PIS_2" for all crops used in the experiments. The crop yield under "PIS_1" is higher than that of "PIS_2" but it requires much more water for all crops. "PIS_2" is a water saving system compared to "PIS_1". A positives and significant correlations were found between surface wetting edge and time of seepage opportunity with R^2 of 0.96 and 0.93 for large and small clay pots respectively. Results indicate that it is possible to use clay pots with various volumes to consist pot irrigation systems, considering that using pots with small volume leads to decrease water use efficiency and surface wetting edge.

Keywords: Pot irrigation; Water use efficiency; Surface wetting edge; Water saving

المستخلص:

ان طريقة الري بالاوعية الفخارية هي من اكثر انظمة الري المعروفة كفاءة وهي ملائمة بالنسبة للمزارع الصغيرة في مناطق متعددة في العالم. يتكون نظام الري بالاوعية الفخارية من مجموعة من الاوعية الفخارية ذات الاسطح غير الصقيلة والتي تحتوي جدرانها على عدد كبير من المسامات الدقيقة. ان الجدران المسامية للاوعية الفخارية تتحكم في كمية الماء المتسربة من خلالها الى التربة المجاورة لها اعتمادا على قيمة ضغط الامتصاص في التربة.تم اجراء التجارب الحقلية لتقييم تاثير حجم الوعاء الفخاري على كفاءة استخدام الماء وحافة الرطوبة

[+] Received on ٢٠ /6/2011 , Accepted on 26/12/2011 .

[*] Lecturer / Technical Institute/Karbala

السطحية وذلك باستخدام الاوعية الفخارية باحجام مختلفة. تم تحضير ونصب نظامين للري بالاوعية الفخارية،احدهما باستخدام الاوعية الكبيرة والاخر باستخدام الاوعية الصغيرة في تربة مزيجية طينية بزراعة ثلاثة محاصيل هي الطماطة واللوبيا والخيار.اظهرت النتائج بان قيم كفاءة استخدام الماء لنظام الاوعية الكبيرة اكبر منها لنظام الاوعية الصغيرة لكافة المحاصيل.كما بينت النتائج بان كمية الانتاج للمحاصيل المزروعة بنظام الاوعية الكبيرة اكبر منها لنظام الاوعية الصغيرة ولكنها تحتاج كميات مياه ري اكبر.كما تم التوصل الى وجود ترابط موجب ومعنوي بين حافة الرطوبة السطحية والزمن منذ بداية تشغيل نظام الري بالاوعية الفخارية وبمعامل ارتباط ٠,٩٦ و ٠,٩٣ لنظامي الري المكون من اوعية كبيرة وصغيرة على التوالي.

ان النتائج التي خلص اليها البحث تدل على انه يمكن استخدام الاوعية باحجام مختلفة لتكوين نظام الري بالاوعية الفخارية مع الاخذ بنظر الاعتبار ان استخدام الاوعية الفخارية الصغيرة الحجم يؤدي الى تقليل قيم كفاءة استخدام الماء وحافة الرطوبة السطحية.

Introduction:

Water scarcity in arid and semi arid countries is the main constraint in agricultural production. Therefore, agricultural practices should be directed to systems where high saving potential for water is possible. Improving water use efficiency is very important in many parts of the world that have limited water resources. Subsurface irrigation, in which water is applied below the soil surface, can help conserve water by reducing evaporative water losses in irrigation systems. Sub-surface irrigation has been practiced in various forms since ancient times, including pitcher or pot irrigation [1] and porous clay pipe irrigation [2, 3].

Clay pot irrigation consists, in its simplest form, of unglazed clay pots filled with water to provide a steady supply of moisture to plants growing nearby [4]. Water gradually seeps out through the porous wall of the pots into the root zone due to hydraulic and soil matric potential. Abu-Zreig, et. al. [5] found that most types of clay pots can be suitable for irrigation under arid climates having high potential evaporation. Daka [6] showed that a 50% to 70% saving on irrigation water can be achieved by clay pot irrigation of vegetables, compared with conventional small-farmer irrigation systems. Altaf A. Siyal, et. al. [7] found that a small clay pot half the size of larger one, but with double the hydraulic conductivity, will produce approximately the same wetting front as the larger pitcher.

Thus far, little research has been carried out on the performance of pot irrigation systems (PIS), including the various factors affecting water seepage out of the pots. The rate of water flow seeping out of a pot and thus the number of plants that can potentially be irrigated by the pot are affected by, among other things, the saturated hydraulic conductivity of the pot wall, pot wall thickness, pot surface area, soil type, crop type, and the rate of evapotranspiration.

In Iraq and other places, large pots cost more than small pots, and thus, the volume of a pot affects start-up and installation costs. To minimize costs, it would thus be beneficial to use small pots for irrigation. The question then arises whether small pots are capable of producing water use efficiency and surface wetting edge that are comparable to those produced by larger pots.

The objective of this research is to investigate the effect of pot volume on water use efficiency and surface wetting edge by comparing the performance of large pots to that of smaller ones by using three different crops, namely, tomato, beans, and cucumber.

Materials and methods:

This research was conducted in a greenhouse of 10x25 *m* within technical institute of Karbala (TIK) during the period from 12-1-2010 to 30-6-2010. TIK is located in the central zone of Iraq 32˚ 34' 35" North 44˚10' 24" East, with an altitude of 28.5 *m*. The soil in the experimental site is classified as clay loam CL. The soil texture, determine by hydrometer method, was 40.3% sand, 27% silt, and 32.7% clay. The following soil properties were measured in the lab: soil pH was 7.8 at 30°*C*, extract electrical conductivity (EC) = 2.4 *dS/cm*, and soil bulk density (ρ) = 1.34 gm/cm^3.

Clay pots:

Thirty six clay pots were produced in right circular conical shape as shown in Fig. (1). Table (1) shows the average chemical compositions of clay material were used for product the clay pots.

The pots were categorized as large "L" and small "S" depending on their dimensions and volumes. The average physical characteristics of the experimental pots are shown in Table (2). The thickness of the pot was estimated by breaking up several pots and measuring the thickness of the fractured pieces with a vernier caliper. An average wall thickness of 8.6 *mm* was found for all pots.

Fig. (1). Right circular conical clay pots of varying volume.

Table (1). Result of X-Ray analysis of the used clay.

Clay components as a percentage of the total weight								
SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	L.O.I	Total
42.92	8.23	6.94	18.78	0.31	5.63	0.36	16.5	99.67

Table (2). Clay pots dimensions and water volume.

Clay pot class	Upper end diameter *Cm*	Lower end diameter *cm*	Height *cm*	Surface area cm^2	Volume *mL*
L	26	14	29.7	1894	7841
S	17.2	11.1	17.2	779	2023

Pot irrigation system:

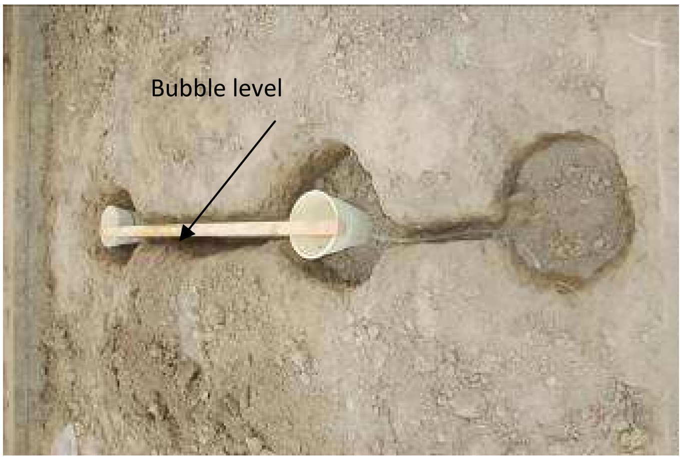
Pot irrigation systems were applied to irrigate three different crops, namely, tomato, bean and cucumber.

Each PIS consists of two clay pots with same class, L or S. Two water tanks were installed to supply water to the clay pots that were used in the experiments, the first is to supply water and provided with a plastic tube at its side to measure the vertical distance of water fall down. The second tank was installed to maintain the water in clay pots at a constant level. The comparison between the PIS, consisting of large pots "PIS_1"and with the other PIS, consisting of small pots "PIS_2" was based on the crops yield, seasonal consumptive use, water use efficiency, and surface wetting edge. In the present research the water was continuously supplied to the clay pots.

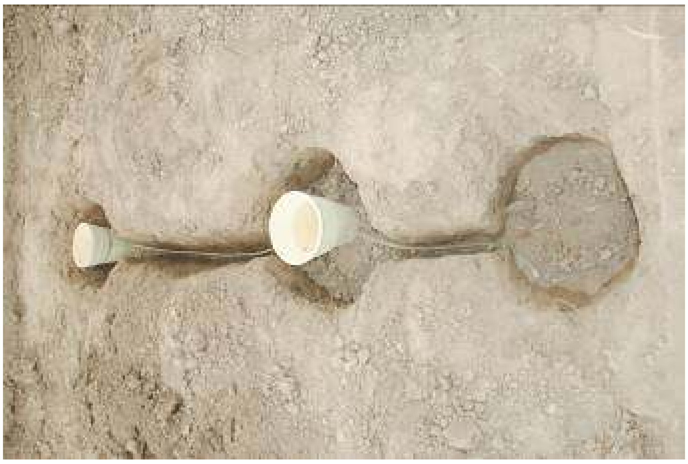
PIS_1 and PIS_2 were prepared and installed for each experiment as shown in Fig. (2) according to the following steps:

1. Examining the external surface of the clay pots to be sure that there are no cracks.
2. For each experiment, two planting holes about three times as the upper end diameter wide and two times as deep as the clay pot was adopted.
3. Digging trenches, one trench for each experiment, by using hand shovel with length equal to distance between the two planting holes.
4. Filling the planting holes with soil partially and then placing the pots in the planting holes at the same level by using wooden board and bubble level such that the vertical distance between the rim of each pot and soil surface level is approximately 2 *cm*.
5. Fixing the water supply for each pot tightly. For each experiment, the two pots were connecting by using plastic pipe 1 cm in diameter.
6. Filling the planting holes and trench with soil and leveling the experimental area.
7. Connecting the PIS net to water supply tank and constant level tank by using a plastic tube of *1 cm* diameter. Covering each clay pot with a galvanized lid.
8. Carrying out seeding in the wetted area (in four situations) surrounding the pots, three days after filling up the clay pots by operating PIS.
9. Observing water volumes consumed for each experiment by measuring the drawdown of water level in a plastic pipe with a 1 *cm* diameter which was fixed beside the supply tank.
10. Surface wetting edge that surrounding each clay pot was measured in six constant radial lines by using graded ruler, the average value was adopted.

a- Preparing planting holes.

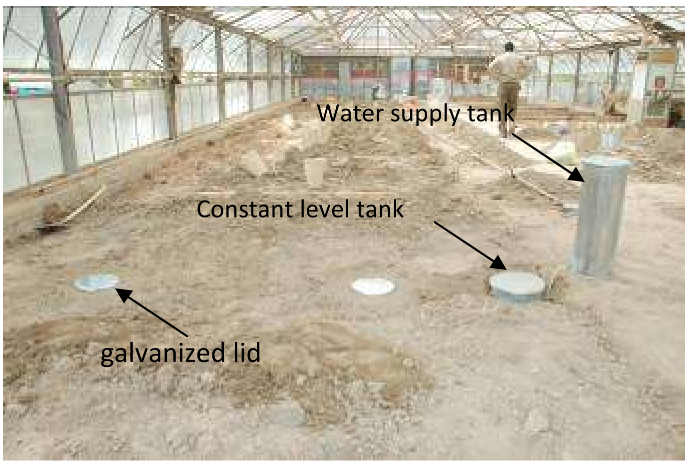


b- Digging trench and filling the planting holes with soil partially.

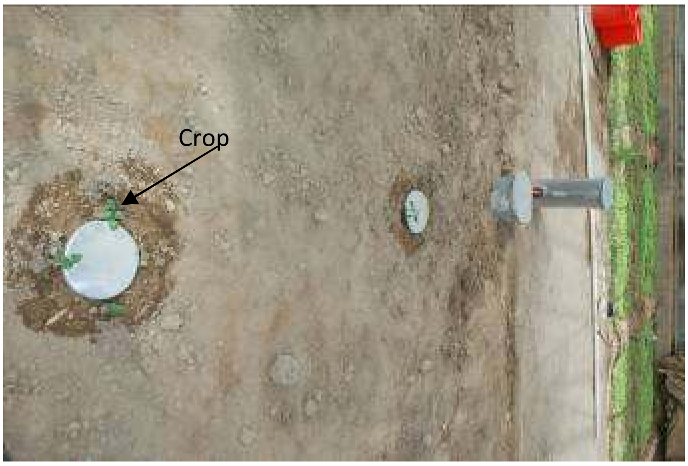


c- Fixing the water supply pipe tightly.

d- Filling the planting holes and trench with soil.



e- Connecting the PIS net to water supply tank.



f- Carrying out seeding in the wetted area.

Fig. (2). Steps of preparing and installing pot irrigation system.

Fig. (3) shows a layout of a greenhouse that was used to carry out the experiments to compare cultivation of crops under the PIS_1 and PIS_2.
Eighteen situations were prepared to be planted with three crops, six for each crop. Half of these situations were irrigated by using PIS_1 and the others by PIS_2. Two factors were considered, irrigation system type PIS_1 and PIS_2 and crop categories, tomato, beans, and cucumber. Experiments were replicated three times for each of the two factors.

Fig. (3). Layout of the experimental greenhouse.

Results and Discussion:

This research was performed to obtain the yield, seasonal crop water requirements (CWR), water saving (WS), water use efficiency (WUE), and surface wetting edge (SWE), when applying PIS_1 and to be compared to that when applying PIS_2 by using three crops, tomato, beans, and cucumber. Table (3) shows yield, CWR, and WUE for all replications. A statistical computer package called EXCEL was used to analyze the statistical significance in crop yield and crop water requirements differences.

Yield responses:

Yield data of tomato, beans, and cucumber irrigated under PIS_1 and PIS_2 are presented in Table (4). There is a difference in crop yield; PIS_1 gives greater yield than that with PIS_2 for all crops used in the experiments. Tomato, beans, and cucumber yield under PIS_2 is 46.35%, 37.75%, and 56.54% lower than that under the PIS_1, respectively.

In the present research statistically significantly higher yields with PIS_1 than with PIS_2 were obtained for the three crops as shown in Table (4). For all crops, the analysis of least significant difference, LSD, [8] showed there is a significant difference between the yields under the two irrigation systems. In any district small-farmers are able to grow excellent vegetables with very simple techniques. This is well illustrated by the photographs from this research presented here in Fig. (4).

Table (3). Yield data, seasonal crop water requirements, and water use efficiency for various crops under PIS_1 and PIS_2.

Crop	PIS type	REP. No.	Yield *Kg*	CWR *liter*	WUE *kg/m³*
Tomato	PIS_1	1	13.438	1307.8	10.275
		2	12.237	1442.6	8.483
		3	9.296	1362.3	6.824
	PIS_2	1	5.988	927.2	6.458
		2	6.633	797.9	8.313
		3	6.142	689.4	8.909
Beans	PIS_1	1	2.341	996.7	2.35
		2	1.956	1134.96	1.72
		3	2.268	1193.2	1.90
	PIS_2	1	1.327	798.59	1.66
		2	1.508	893.6	1.69
		3	1.253	726.4	1.72
Cucumber	PIS_1	1	3.520	1113.5	3.16
		2	2.714	1168.2	2.32
		3	3.286	1116.8	2.94
	PIS_2	1	1.229	851.3	1.44
		2	1.762	788.1	2.24
		3	1.148	1000.4	1.15

REP. No. =Replication number

Table (4). Average yields for various crops under PIS_1 and PIS_2.

Crop	Yield *kg*		Decrease %	LSD (5%)	SIGNF
	PIS_1	PIS_2			
Tomato	11.657	6.254	46.35	3.46	SNF
Beans	2.188	1.362	37.75	0.39	SNF
Cucumber	3.173	1.379	56.54	0.85	SNF

SIGNF=Significance; SNF= Significant; LSD=Least Significant Difference

Fig. (4).Tomato, beans, and cucumber grown by using PIS techniques.

Crop water requirements

CWR and WS by applying PIS_1 as compared to PIS_2 are presented in Table (5). CWR, of crops is the water consumption during the period from planting to harvest. WS of an irrigation system compared to other irrigation system may be expressed as below [9]:

$$WS\% = 100 - (\frac{CWR2}{CWR1} * 100)$$

in which

CWR1=crop water requirement under the irrigation system, (L^3), and

CWR2= crop water requirement under the other irrigation system, (L^3).

From the results presented in Table (5) , it is observed that water savings between 22.3% and 41.3% are achievable with PIS_2 as compared with PIS_1 where the pots used in PIS_2 are small, that minimizing of seepage to soil.

In this research statistically significantly higher CWR with PIS_1 than with PIS_2 were obtained for all crops as shown in Table (5).

Table (5). Average CWR for various crops under PIS_1 and PIS_2 and WS under PIS_2 instead of the PIS_1.

Crop	Crop water requirements *Liter/season*		LSD (5%)	SIGNF	Water saving %
	PIS_1	PIS_2			
Tomato	1370.9	804.8	219.59	SNF	41.3
Beans	1108.3	806.19	210.30	SNF	27.3
Cucumber	1132.8	879.9	181.49	SNF	22.3

Water use efficiency:

Water use efficiency in irrigation has various definitions. Whereas physical efficiency compares the volumes of water delivered and consumed, economic efficiency relates the value of output and opportunity costs of water used in agricultural production to the value of water applied [10]. WUE can be calculated as the ratio between crop production and water use during the period from planting to harvest [6]. The WUE of PIS1 and PIS_2 are presented in Table (6). For the three crops, WUE of the PIS_1 is higher than that of the PIS_2. Tomato, beans, and cucumber WUE under PIS_2 is 7.4%, 15.1%, and 42.7% lower than that under the PIS_1, respectively. This means that these crops irrigated by the PIS_1 require less water to produce a higher yield per unit applied water. As the surface area of class S pot is smaller than for class L, that will minimize seepage rate. Therefore yield values for PIS_1 are grater than that for PIS_2.

Table (6) . Average water use efficiencies for various crops under PIS_1 and PIS_2.

Crop	Water use efficiency *Kg/m^3*		Decrease %
	PIS_1	PIS_2	
Tomato	8.527	7.893	7.4
Beans	1.991	1.691	15.1
Cucumber	2.809	1.609	42.7

Surface Wetting Edge;

Surface wetting edge can be defined as the horizontal distance between the pot and the end of wetting area that surrounded the pot as shown in Figure (5). SWE around clay pot mainly depends on its geometry, soil texture, and seepage volume through its wall.

Fig. (5). Surface wetting edge of the clay pot.

Observation shown that for both pots class L and S, the SWE still continue and reach maximum values after approximately 7.5 *days* as shown in Fig.(6). Fig. (6) shows that rate of SWE has high values at the beginning of the experiment. As the water continually seeps through the pots wall, rate of SWE decreases until it reaches an approximately constant value. This result agrees with the results of previous studies [11, 12]. The results presented in Fig. (6) observed that the relationship between SWE and time of seepage opportunity described as a logarithmic formula with high R^2. The results showed that the average values of SWE after 7.5 *days* are 22 *cm* and 19.5 *cm* for the pots under PIS_1 and PIS_2 respectively.

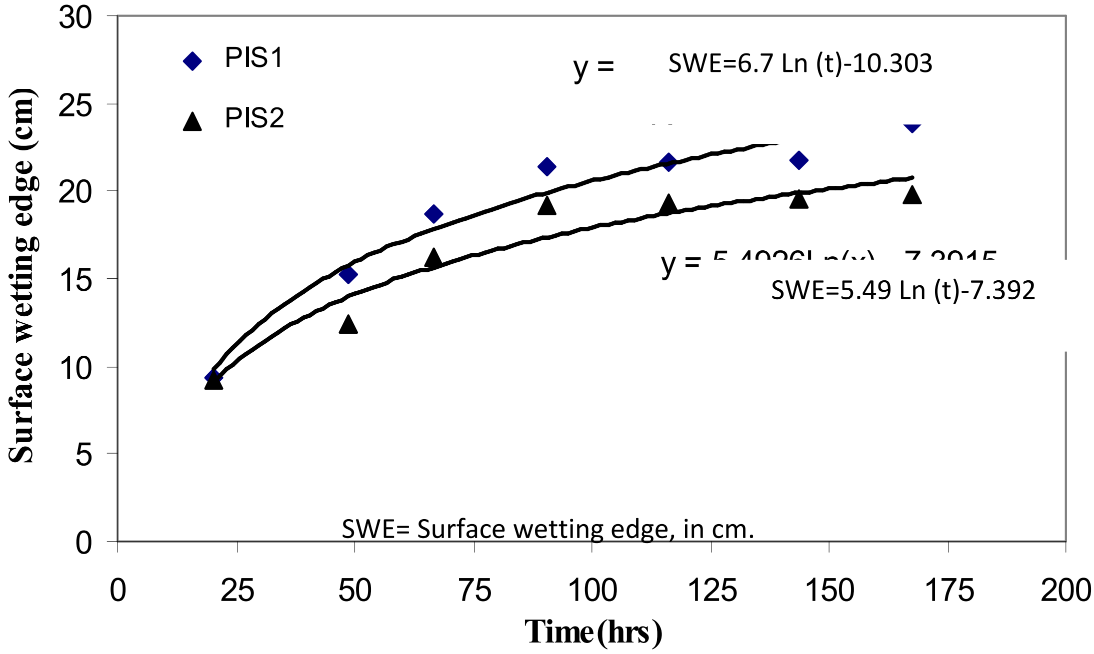


Fig. (6). Surface wetting edge of the clay pots under PIS_1 and PIS_2.

Conclusions:

Field experiments were carried out to investigate the effect of pot volume on water use efficiency and surface wetting edge for pots in right circular conical shape. A comparison between crop yield, water requirements, water use efficiency, water savings, and surface wetting edge under PIS_1 and PIS_2 were carried out by using three crops, tomato, beans, and cucumber. According to the results of this research, the following conclusions were found:

1. Yield under PIS_1 is higher than under PIS_2 for the three crops, tomato, beans, and cucumber.
2. The difference in crops yield under PIS_1 and PIS_2 is significant for the three crops; higher yield is achieved under PIS_1.
3. The difference in crop water requirement under PIS_1 and PIS_2 is significant, higher crop water requirement is obtained under PIS_1.
4. PIS_2 is a conservation irrigation system, which saves between 22% and 41% water when compared to PIS_1.
5. Water use efficiency under PIS_1 is higher than that under the PIS_2 for all crops. Tomato, beans, and cucumber WUE under PIS_2 is 7.4%, 15.1%, and 42.7% lower than that under the PIS_1, respectively.
6. The surface wetting edge still continues for small and large pots and reaches maximum values after approximately 7.5 *days*.

7. The coefficient of determination (R^2) between surface wetting edge and time of seepage opportunity were 0.96 and 0.93 respectively.
8. It is possible to use clay pots with various volumes to consist pot irrigation systems, considering that using pots with small volume leads to decrease water use efficiency and surface wetting edge.

References:

1- Bainbridge, D.A. "Buried clay pot irrigation: a little known but very efficient traditional method of irritation" *Agric. Water Manage.* , Vol.48, No.2, pp.79-88, 2001.

2-Ashrafi, S., Gupta, A., Singh, M.B., Izumi, N., Loof, R. "Simulation of infiltration from porous clay pipe in subsurface irrigation" *Hydrol. Sci. J.*, Vol.47, No.2, pp. 253–268, 2002

3- Qiaosheng, S., Zuoxin, L., Zhenying, W., Haijun, L. "Simulation of the soil wetting shape under porous pipe sub-irrigation using dimensional analysis" *Irrig. Drain,* Vol. 56, pp. 389–398, 2007

4-Bainbridge, D. A. "Alternative Irrigation Systems for Arid Land Restoration" *Ecological Restoratio*, Vol. 20, and No.1, pp.23-30, 2002.

5-Abu-Zreig, M. M., Abe, Y. and Isoda, H. "The Auto-Regulative Capability of Pitcher Irrigation System" *Agricultural Water Management*, Vol.85, No.3, pp.272-278, 2006.

6- Daka, A. E., *Clay pot Sub-Surface Irrigation as Water Saving Technology for Small–Farmer Irrigation, Chapter 7 in: Development of A Technological Package for Sustainable Use of Dambos by Small-Scale Farmers*, Ph.D. Thesis, University of Pretoria, South Africa,2001.

7- Altaf A. Siyal, Martinus Th. van Genuchten,and Todd H. Skaggs " Performance of Pitcher Irrigation System" *Soil Science* , Vol. 174, No. 6, pp.312-320 , 2009

8- Montgomery, D. C., *Design and Analysis of Experiments*, John Wiley and Sons, Inc., USA, 2001.

9- Saleh M. Ismail. "Influence of Deficit Irrigation on Water Use Efficiency and Bird Pepper Production (Capsicum annuum L.)" *Met., Env. & Arid Land Agric. Sci.*, Vol. 21, No. 2, pp. 29-43, 2010.

10- S. Shajari, M. Bakhshoodeh and G. R. Soltani "Enhancing irrigation water use efficiency under production risk: Evidence from wheat farms in Iran" *American-Eurasian J.Agric.&Environ*. Sci, 2(supple 1), pp.36-41, 2008.

11-Edward Saleh, Budi I. Setiawan "Numerical modeling of soil moisture profiles under pitcher irrigation application", *Agric Eng Int:CIGR Journal*, Vol. 12, No.2. Pp.14-20, 2010.

12-Dahir, F.M., *Hydraulic Characteristics and Viability of Applying Clay-Vessel Irrigation in High Permeable Soil*, Ph.D. Thesis, College of Engineering, University of Baghdad, Iraq,2009.