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Performance evaluation of drip, surface and pitcher irrigation systems: A case study of prevalent urban landscape plant species

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ABSTRACT: Urban landscape water use is undoubtedly one of the main water consumptions in arid and semi-arid regions. In this study, performance of surface, drip and pitcher irrigation systems on Ligustrum vulgare, Berberis thunbergii, Pyracantha and Rosa hybrid, which are locally known as prevalent urban landscape plant species, is evaluated in a semi-arid region. Twelve treatments were arranged in completely randomized design with three replications. Growth parameters such as the height of plants, number of leaves and qualitative plant appearance score (QPAS) were determined biweekly. Volume of water applied was also recorded weekly. Root, stem, leaf and total water content of plants were calculated by measuring their total fresh and dry weights. Leaf area was determined at the end of the experiment. Results indicated that plants were appropriately grown under pitcher irrigation. Performance of pitcher irrigation resulted in growth of more leaves, more increase in height of plants and superior QPASs within the experiment. Even if there were some preferences in plants under drip and surface irrigations, the difference was negligible in almost all items. It was also found out that pitcher irrigation could save up to 60% and 30% of water compared to surface and drip irrigations, and it facilitates water absorption due to its continuous and auto-regulative seepage.

***Keywords*:** *Berberis thunbergii, Ligustrum vulgare, Pyracantha, Rosa hybrid,* Semi-arid, Water-saving

***Abbreviation*:**

QPAS qualitative plant appearance factor

INTRODUCTION

Urban landscapes are certainly one of the most important parts of communities, which need high amounts of water especially in arid and semi-arid regions of the world. High-technology irrigation systems have been increasingly applied in recent years in order to reduce water consumptions (Abu-Zreig *et al.* 2006). Although modern irrigation methods such as subsurface drip systems may save up to about half of the water presently used for irrigation, some technical, economical and sociocultural factors hinder the adoption of these technologies (Abu-Zreig *et al.* 2006, Siyal *et al.* 2009). With respect to such considerations, it is vitally important to develop adopting traditional irrigation systems which can simply reduce soil evaporation with less cost (Batchelor *et al.* 1996).This is a fact that has been ignored by most international developmental programs (Bainbridge 2001).

Pitcher irrigation is one of the water-saving, low cost and simple methods whose effectiveness has been proven many times by researches in arid and semi-arid zones such as Iran, India and African countries (Mondal 1974, Setiawan *et al.* 1998, Stein 1998, Bainbridge 2001, Siyal and Skaggs 2009, Siyal *et al.* 2009, Tesfaye *et al.* 2012, Siyal *et al.* 2013, Vasudevan *et al.* 2014).

Water gradually seeps out into the root zone in the soil through porous walls of pitchers. At low evaporation rate, the positive pressure head inside the pitcher and the saturated hydraulic conductivity control the seepage rate; whereas, at high evaporation rate, the negative pressure head at outer surface of the pitcher is relatively considerable (Abu-Zreig *et al.* 2006).

Although pitchers are well-suited for number of fruit trees and berry plants (Balakumaran *et al.* 1982, Mondal 1983, Okalebo *et al.* 1995, Bainbridge 2001, Tesfaye *et al.* 2012, Mari-Gowda 1974, Sheikh and Shah 1983, Singh *et al.* 2011), vegetables (Batchelor *et al.* 1996) or even have been used to establish desert's shrubs (Bainbridge 2012), few studies have been carried out on its performance in landscape development.

This paper presents a basic study on performance of three common landscape irrigation systems on four prevalent landscape species under field conditions. The advantages and disadvantages of the irrigation systems are quantitatively described and more preferable systems are proposed.

MATERIALS AND METHODS

Experimental site description

Field trials were carried out on experimental field of Mellat Park in Mashhad, Iran, with an area of 84m^2. The site is located between latitudes of 36° 12 0" N and longitudes of 59° 24 0" E with the elevation of 999.2m above mean sea level. The area is influenced by local steppe climate. Based on The Köppen-Geiger climate classification, the area is placed in BSk category. The annual average precipitation is 251 mm. The mean annual temperature in Mashhad is 13.5°C. The warmest month of the year is July with an average temperature of 25°C. In January, the average temperature is 0.5°C, which is the lowest average temperature of the whole year. The difference in precipitation between the driest and the wettest months is 54mm. The experiment was conducted from June 2011 to October 2011. No considerable rainfall was observed during the experimental season.

Four soil samples were taken on each experimental plot at depths of 0-30 and 30-60cm. Subsequently, hydrometer method was used to determine the soil texture. The soil texture of the experimental site was recognized to be sand at 0-30cm and loamy sand at 30-60cm of depth. Table 1 summarizes some physical properties of soil in the experimental field.

Table 1. soil physical properties

Properties	Depth (0-30 cm)	Depth (30-60 cm)
Sand (%)	89	82
Silt (%)	5	7
Clay (%)	6	11

Treatments and experimental design

The experiment comprised of twelve treatments including pitcher (R_1), drip (R_2) and surface (R_3) irrigation systems with different plants consisted of Ligustrum vulgare (Wild privet)(P_1), Berberis thunbergii (Japanese barberry)(P_2), Pyracantha (Firethorn)(P_3) and Rosa hybrid (Bush Rose)(P_4), which were arranged in Completely Randomized Design(CRD) with three replications. These species are locally common in urban landscapes. There were 36 experimental plots, each having a size of $1\text{m} \times 0.5\text{m}$ (0.5m^2) with a spacing of 1.5m.

Experimental materials and procedures

Three mainline irrigation pipes were installed to convey water from the reservoir to the plots with the same irrigation system discretely, each having a volumetric water counter and control valve in order to measure and manage water delivery. Drip irrigation laterals were normally installed to manifolds which were supposed to receive water from the mainline.

Suitable clay pots were provided with respect to the crop varieties, aforementioned soil textures and planting density. The saturated hydraulic conductivity of pitchers were measured using the falling head method which is simpler and faster than constant head method (Abu-Zreig and Atoum 2004) to ensure that the moisture reaches the outer surface and also water seeps out sufficiently. Planting holes were dug about three times as wide and two times as deep as the pitchers in order to place the clay pots easier. Clay pots were buried under the soil up to their necks and they were placed about 2cm above the surface of the surrounding soil (Bainbridge 2001). Pitchers were placed at suitable distances from each other to ensure that the root zone was not unintentionally dry (Siyal *et al.* 2009).

Planting and Irrigation

Cuttings, which had been propagated in the nursery, were planted in the experimental field on 19 June 2011. In order to ensure that the plants have become stable in the field, they were irrigated by hand for a month.

Therefore, data recordings started from 19 July 2011 and ended on 18 October 2011. Water consumed was recorded weekly by utilizing volumetric water counters. Irrigation intervals and the times that system was operating per irrigation were specified to be three days and three hours for drip irrigation system, respectively. The same intervals were determined for surface irrigation; however, the system operating time was fixed for two minutes per irrigation. Both aforementioned intervals and periods are locally common in urban landscape irrigation which amounts were obtained by asking from local gardeners. Pitchers were refilled regularly and efforts have been made to keep them away from becoming completely dry as recommended by researchers (Bainbridge 2001). Pitcher irrigation replenishing intervals varied from one to two weeks over the growing season as a result of auto-regulative capability of pitchers (Abu-Zreig *et al.* 2006, Gopinath and Veeravalli 2011).

Data collection and statistical analysis

Some plant growth parameters were measured within the experiment biweekly including height of plants, average number of leaves on stems and qualitative plant appearance score (QPAS). We defined five qualitative descriptions and their corresponding scores in order to characterize how good the appearance of treatments are and also translated them into quantities. QPASs and their descriptions are shown in Table 2. An expert was asked to score the plants based on parameters in the table. Height of plants was measured biweekly using samples which had been selected from plants in the middle of the experimental plots. Moreover, the total leaf area, fresh and dry weights were determined at the end of the experiment. Therefore, the aforementioned samples were collected and weighed freshly. Then stems, roots and leaves were carefully cut and weighed separately. Leaf area was immediately determined in laboratory using leaf area meter with resolution of 0.1 mm^2 to get precise and rapid measurements. The parts of the plants were subsequently oven dried at 70$^\circ C$ for 24 hours (Kirkham 2004), and dry weights of separated parts were eventually recorded as well. The summation of dry weights of the separated parts were calculated to obtain the total dry weight of plant. In all cases, water content was calculated using the following equation:

$$\text{water content } (\%) = \frac{\text{fresh weight (g)} - \text{dry weight(g)}}{\text{fresh weight (g)}} \times 100 \qquad (1)$$

Plant water content changes with age and under different conditions; nevertheless, it is suitable and fast to compare the amounts of water in different parts of plants, which were collected at the same time and under the same circumstances. Higher amount of plant’s water content shows more pleasant conditions for root water absorption; performed by irrigation system. Additionally, more plant water content refers to closer situations to turgidity which keeps plant cells healthy (Campbell 1993).

Table 2. Qualitative descriptions and their corresponding scores

Score	Description
1	Plants are completely dry and almost all leaves are yellow. There is no defense response against pests or drought stress.
2	Plants with droopy and curled yellow-green leaves. Plant growth is approximately stopped. It is hard to refine the plants under this situation.
3	Plant under drought stress which growth rate is slowed down. Serious considerations should be performed to improve the plants.
4	This group consists of well-grown plants. Even if rare droopy leaves are observed, there is no pest infestation or lacking of nutrients. In this situation, Plants could be improved to highest level under a little more considerations.
5	Perfectly grown plants including stocky plants with multiple stems, solid dark green leaves, without any pest, healthy terminal and lateral buds. No drought stress is observed.

Analysis of variance for the parameters recorded was done by IBM SPSS Statistics for Windows, Version 22.0 and treatment mean comparison was performed using Duncan's multiple range test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Seasonal water use

The cumulative amount of water applied, which was recorded by volumetric water counters, shows that the pitcher irrigation system can save the most amount of water. The total amounts of water consumed through pitcher, drip, and surface irrigation systems were 0.192, 0.265, and 0.480 $\frac{m^3}{m^2}$, respectively.

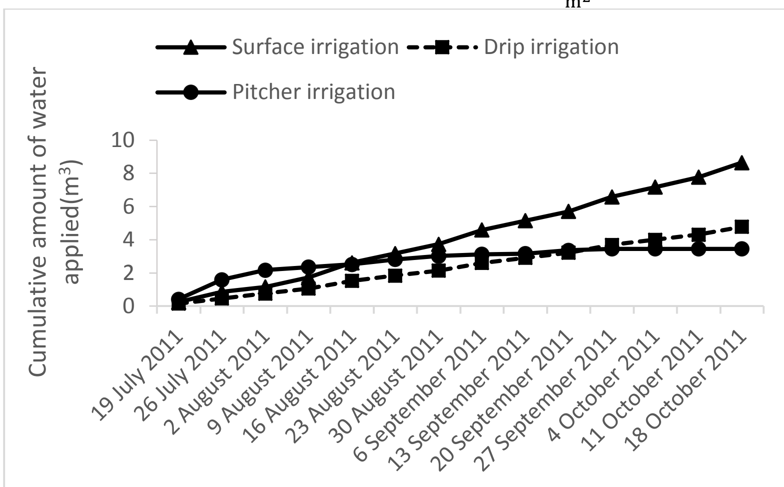
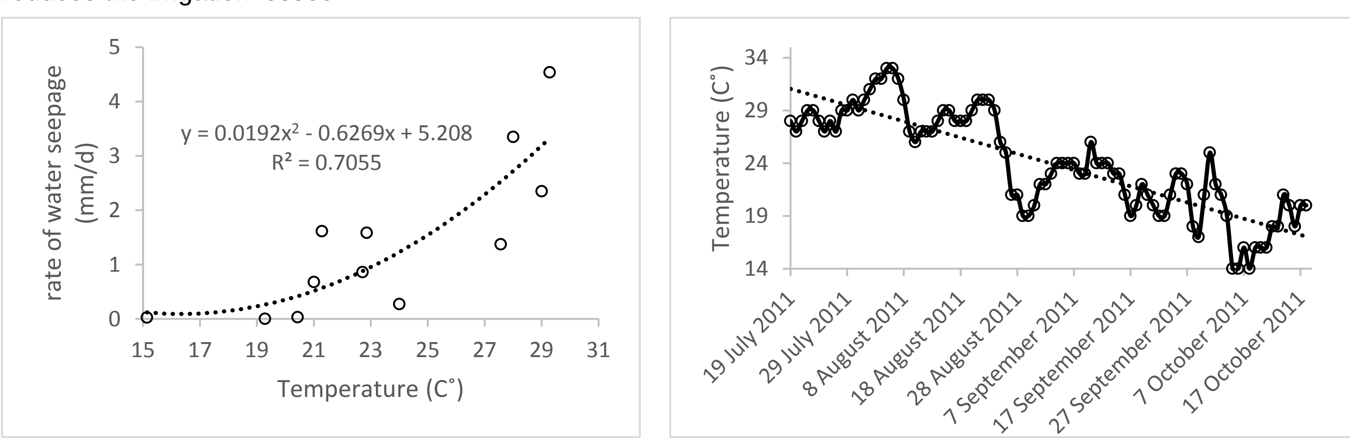


Figure 1. Comparison of water applied through irrigation system during the experiment

The rate of water seepage to pitcher-irrigated plots was comparatively slowed down from 9 August 2011 and it led to a difference between drip and pitcher irrigation systems with surface irrigation system as shown in Figure.1. It is clear that surface irrigation requires more amount of water than drip irrigation because of more percentage of wetted soil surface.

To clarify how the difference between pitcher and drip irrigation occurred, daily mean temperature was measured during the experiment. Correlation and regression analysis were performed to indicate the effect of temperature on seepage through pitchers. Mean temperatures were calculated weekly to make matchable data with weekly depletion readings. As shown in Figure. 2.a, there is a weak and positive relationship between temperature and the rate of water seepage. Further analysis indicated that the temperatures lower than 18C˚ may lead to negligible seepage. It is also shown in Figure 2.b that temperature gradually falls during experiment and results in the reduction of seepage rate in pitchers. The seepage rates were about 5 and 1mm.d^{-1} in weekly mean temperatures of 29 and 20 C˚. It confirms the auto-regulative capability of pitcher irrigation systems which simply reduces the irrigation losses.



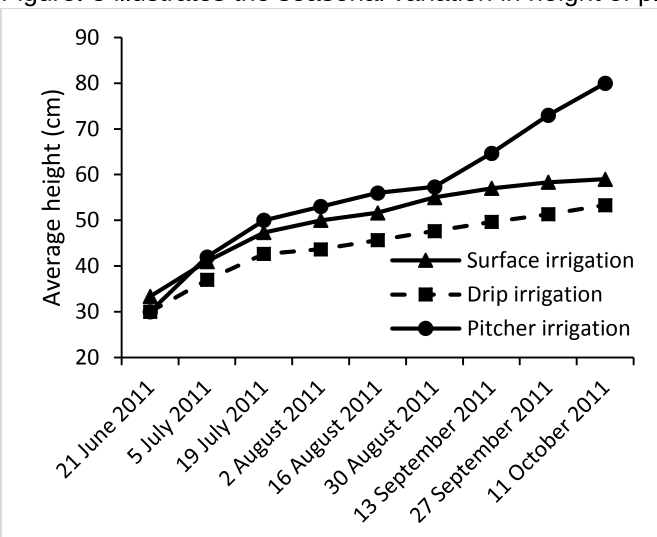
2.a 2.b

Figure 2. (a) Relationship between temperature and water seepage rate through pitcher irrigation (b) variation in temperature during the experiment

Variation in Height of plants

A comparison between average heights of R_1P_3, R_2P_3, R_3P_3, measured biweekly, indicates that the height of Pyracantha was significantly (P<0.05) increased under pitcher and drip irrigations. However, it is slightly higher under pitcher irrigation.

The total height of Rosa hybrid treatments $\mathrm{R_1P_4, R_2P_4, R_3P_4}$ shows that even though the plants had approximately the same initial heights, the ones under pitcher irrigation are significantly(P<0.05) higher than drip and surface irrigations. Similarly, Pitcher irrigation had the best effect on the height of Ligustrum vulgare treatments including R_1P_1, R_2P_1, R_3P_1 and no significant difference (P>0.05) was observed for Berberis thunbergii treatments under three irrigation systems. Nevertheless, a stiff jump is observed in the middle of the growing season under pitcher irrigation which is gradually slowed down at the end. The statistical analysis is shown in Table 3, and Figure. 3 illustrates the seasonal variation in height of plants within the experiment.



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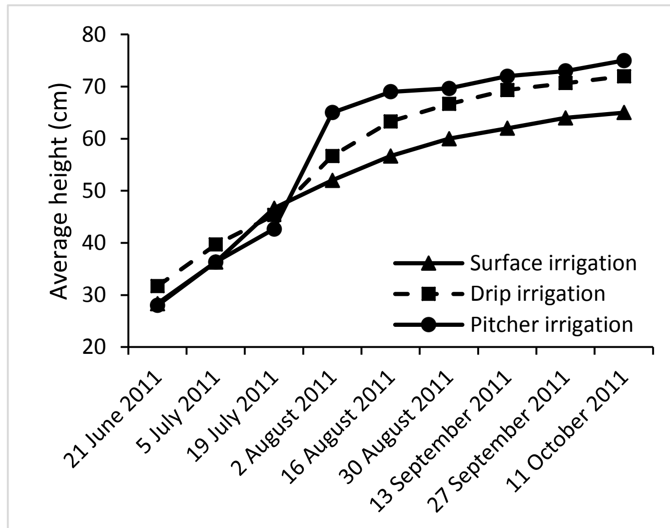

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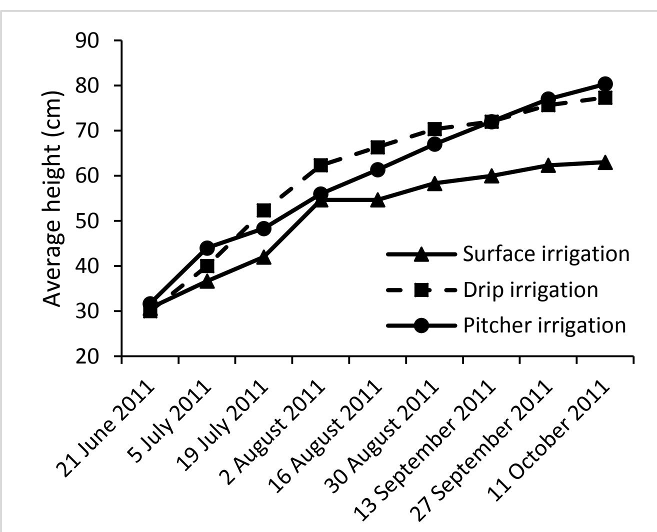

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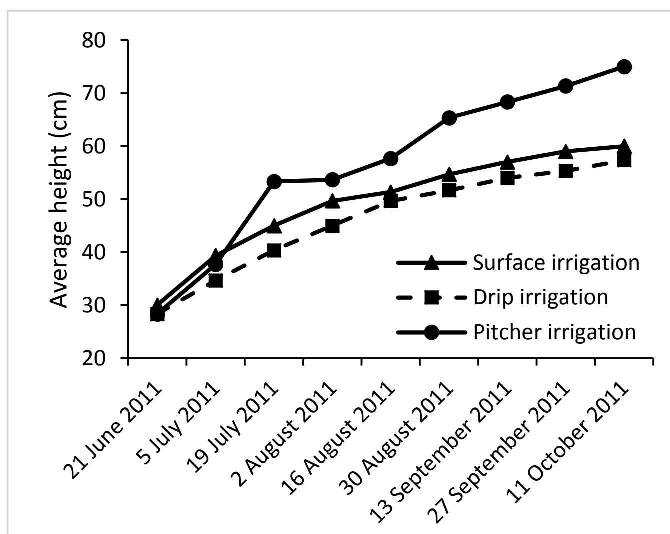


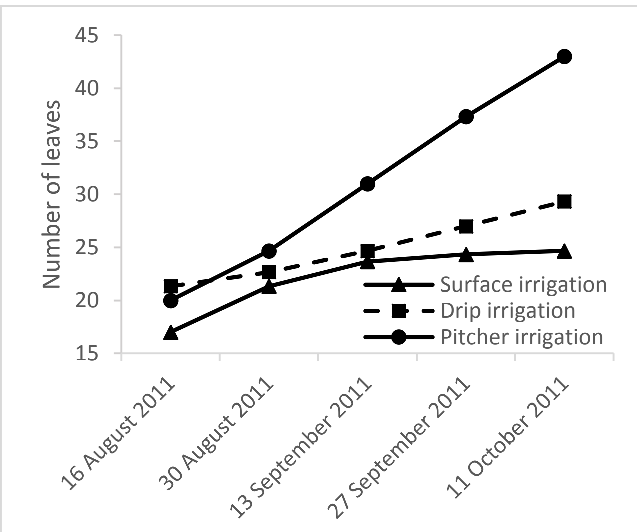
3.d

Figure 3. Seasonal variation in Height of (a) Ligustrum vulgare (b) Berberis thunbergii (c) Pyracantha (d) Rosa hybrid during the experiment under surface, drip, and pitcher irrigation systems

Number of leaves

Similar to previous section, samples were selected and number of leaves were counted biweekly from 16 August 2011 to 11 October 2011.In all cases pitchers had an acceptable effect on plants.

Data analysis (Table 3) shows that the effect of irrigation system is not significant (P>0.05) on number of leaves of Ligustrum vulgare to grow; however, it was observed that twenty-three leaves were typically added within the experiment under pitcher irrigation whereas eight leaves were grown under drip and surface irrigations. Data analysis of Pyracantha treatments clarifies that pitcher irrigation can make the best condition for leaves to grow. Thirty-five leaves were added under pitcher irrigation compared to thirteen leaves grown under surface irrigation. Drip irrigation had a normal effect on Pyracantha while twenty leaves were totally added during the experiment. Even though the difference between pitcher and drip irrigation systems is negligible, a significant (P<0.05) difference is observed between pitcher and surface irrigation systems. On the other hand, it is found that the three irrigation systems have the same effect on Rosa hybrid treatments. However, the most number of leaves grew under pitcher irrigation. An insignificant difference is observed among Berberis thunbergii treatments, but pitcher irrigation is slightly preferable. Twenty-five, nineteen, and seventeen leaves were added under pitcher, drip and surface irrigation systems, respectively. The variation in number of leaves is illustrated in Figure. 4 within the experiment. In almost all treatments, graphs show an initial steep slope and it gradually slows down as it proceeds.



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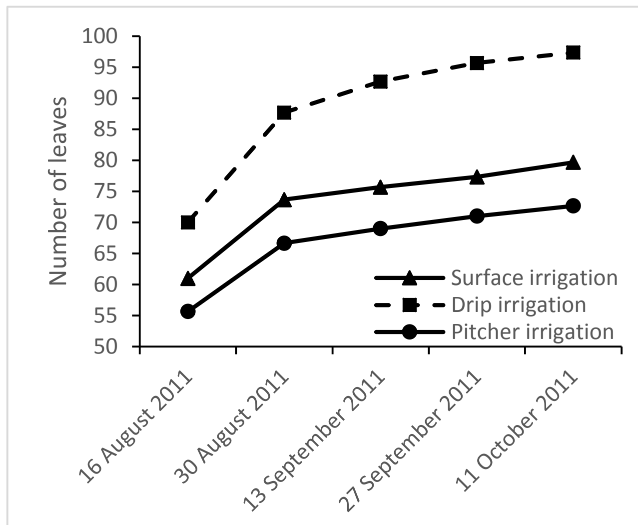

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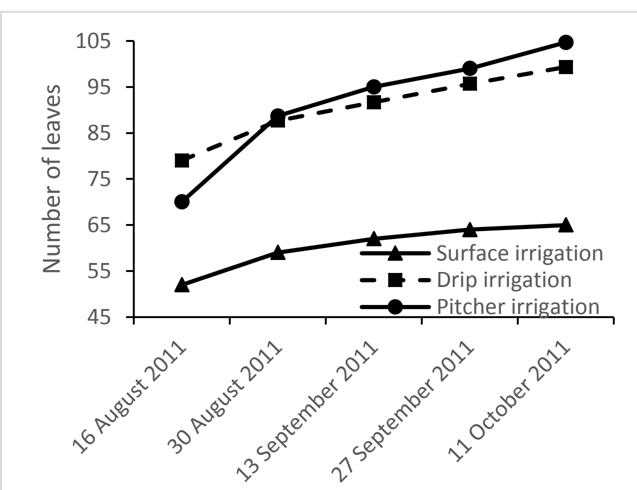

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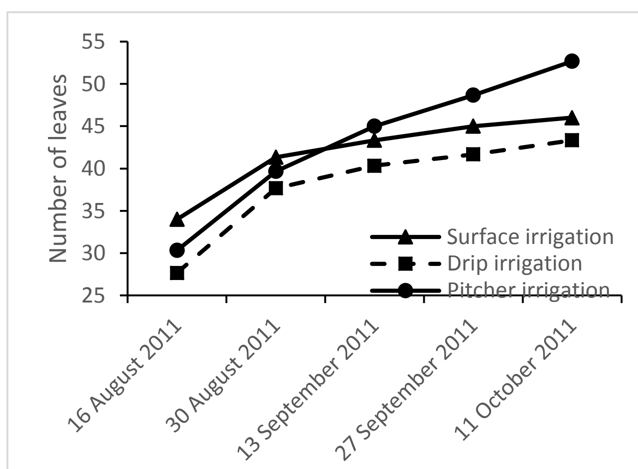


4.d

Figure 4. Number of leaves grown within the experiment under surface, drip and pitcher irrigation systems for (a) Ligustrum vulgare

(b) Berberis thunbergii (c) Pyracantha (d) Rosa hybrid

Qualitative plant appearance score (QPAS)

A local expert gardener was asked to determine QPASs biweekly based on parameters which were described on previous sections. The plants were irrigated suitably by hand and conserved perfectly before starting the experiment. The initial score were determined as five by the expert. Then, Plants were gradually affected by irrigation systems.

The QPASs of treatments were significantly affected by irrigation systems. Analysis showed that plants under pitcher irrigation had the best QPASs. The best seasonal scores were obtained for Ligustrum vulgare, Rosa hybrid and Pyracantha under pitcher irrigation with the corresponding scores of 4.96, 4.93, and 4.89, respectively.

The QPASs of Ligustrum vulgare treatments were significantly ($P<0.05$) affected under various irrigation systems. Pitcher and surface irrigations had better seasonal QPAS than drip irrigation; however, it was negligibly more under pitcher irrigation system. The same results were obtained for Rosa hybrid. There was also a significant difference among Berberis thunbergii treatments under different irrigation systems. In this case the difference between pitcher and drip irrigations was negligible, but it was significantly low ($P<0.05$) under surface irrigation. As mentioned, Pyracantha under pitcher irrigation had the best amount of QPAS; however, the differences among treatments were insignificant ($P>0.05$). Table 3 summarizes the aforementioned analysis.

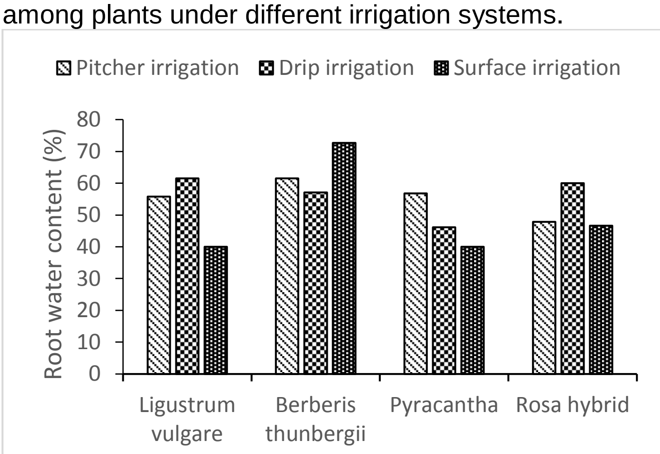
Table 3: Results of variation in Height, Number of leaves and qualitative plant appearance score Duncan's test. Values with the same superscript letter(s) in the same column are not significantly different ($P > 0.05$). P_1, P_2, P_3, and P_4 show Ligustrum vulgare, Berberis thunbergii, Pyracantha, and Rosa hybrid treatments. R_1, R_2, and R_3 show pitcher, drip, and surface irrigation, respectively.

Treatment	**variation of Height**	**Number of leaves**	**Qualitative plant appearance score**
P_1R_1	50^{a}	23^{ab}	4.96^{a}
P_1R_2	23.33^{e}	8^{b}	4.15^{bcd}
P_1R_3	25.67^{de}	7.67^{b}	4.67^{abc}
P_2R_1	47^{ab}	17^{ab}	4.26^{abcd}
P_2R_2	40.33^{abcd}	27.33^{ab}	4.59^{abc}
P_2R_3	36.67^{abcde}	18.67^{ab}	3.67^{d}
P_3R_1	48.67^{ab}	34.67^{a}	4.89^{ab}
P_3R_2	44.67^{abc}	20.33^{ab}	4.63^{abc}
P_3R_3	32.33^{bcde}	13^{b}	4.56^{abc}
P_4R_1	46.67^{ab}	22.33^{ab}	4.93^{ab}
P_4R_2	29^{cde}	15.67^{ab}	4.07^{cd}
P_4R_3	30^{cde}	12^{b}	4.33^{abcd}
CV (%)	22.78	57.02	9.02

Root, stem, leaf, and total water content

Samples which were chosen to measure height and number of leaves, were also used to measure root, stem, leaf and total plant water contents. Therefore, fresh plants were collected and weighed immediately in laboratory. Water content percentages were calculated afterwards by determining the weight loss of the samples after oven drying at 70 $^{\circ}C$ for 24 hours. Root, stem and total water contents were affected by irrigation systems; however, the differences among leaf water contents were negligible Figure. 5.

A comparison of Ligustrum vulgare treatments indicated that plants under drip irrigation system had the most water content. Further considerations revealed that the difference between root, stem and leaf water contents under pitcher and drip irrigations was slight. Stem water content of Ligustrum vulgare under drip irrigation was about 10% more than pitcher irrigation, which was the highest difference observed between water contents of the three aforementioned parts of plant. The total water content of plants grown under drip and pitcher irrigations were 60.47% and 54.55%. Except for leaves, Berberis thunbergii treatments under surface irrigation had the most percentage of water content. Their root, stem and total water contents under surface irrigation were 11.19%, 19.88%,and 13.28% more than pitcher irrigation, which their treatments had generally more water contents than drip irrigation. Among Pyracantha treatments, pitcher irrigation could suitably affect water content percentages. No considerable difference was observed between plants grown under pitcher irrigation and those of drip irrigation, i.e. the highest difference was 10.67%, related to root water contents. It was hard to determine the most effective irrigation system for Rosa hybrid based on its water contents, because no noticeable preferences were observed among plants under different irrigation systems.



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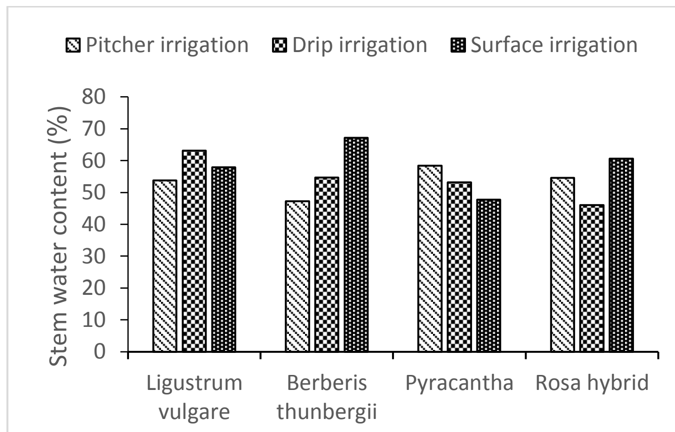

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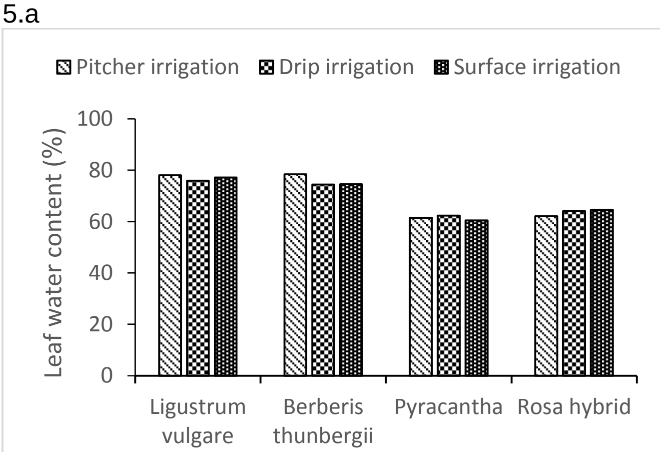

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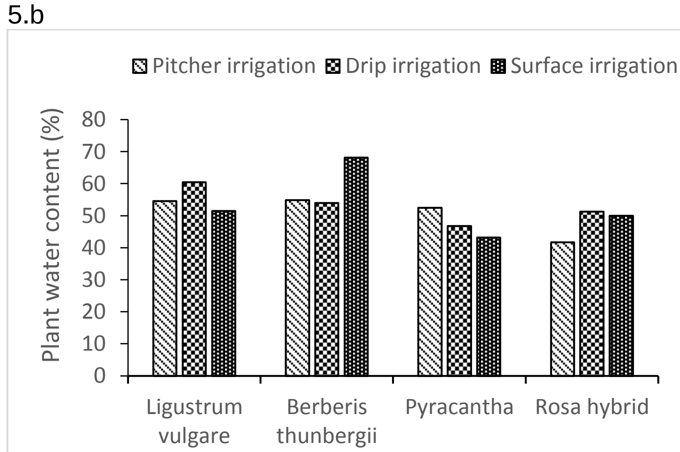


5.d

Figure 5. The (a)Root, (b) Stem, (c)leaf, and (d) total water content of plants

Leaf area

Leaf area, which shows plant canopy, was determined for each treatment distinctly using a lab leaf area meter with conveyor to obtain precise measurements ($\pm 0.1\ \mathrm{mm}^2$). Results showed Figure. 6 that drip irrigation had the best effect on leaf area of Ligustrum vulgare which had the amount of 139.38 cm^2; whereas it was 6.52% and 20.95% lower under surface and pitcher irrigations, respectively. The same results were obtained for Berberis thunbergii. In this case, treatments under drip irrigation had also the most leaf area, which was 124.23cm^2. It was 25.13% and 30.37% more than that of surface and pitcher irrigations. Among Pyracantha treatments, there was not any considerable difference. The most amount of leaf area was observed under surface irrigation and it was just 8.13% and 11.57% more than that of drip and pitcher irrigations. The amounts of leaf area for Pyracantha under surface, drip and pitcher irrigations were 111.35, 102.30, and 98.47cm^2 respectively. Pitcher irrigation resulted in higher leaf area among Rosa hybrid treatments. There was a negligible difference among treatments grown under pitcher irrigation and those of drip irrigation i.e. the leaf area for Rosa hybrid treatments grown under pitcher irrigation was 257 cm^2 and it was only 0.51% more than that of drip irrigation. However, high difference of about 47% was observed among pitcher and surface irrigations.

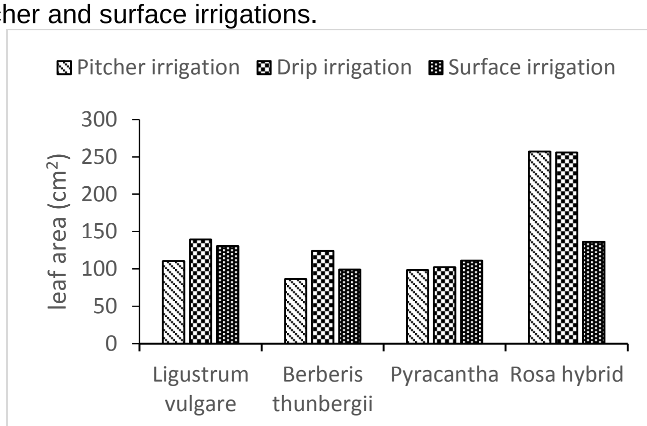


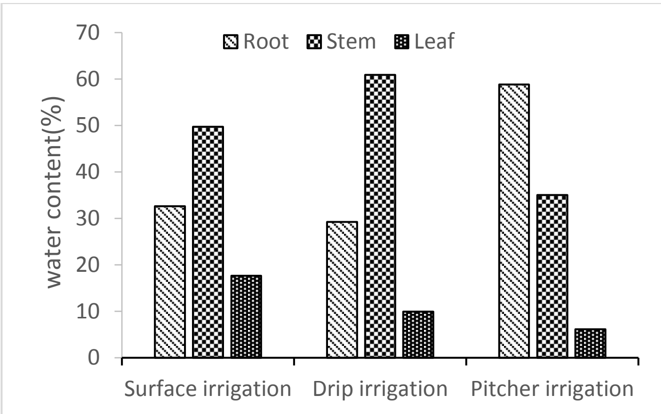
Figure 6. Leaf area of plants

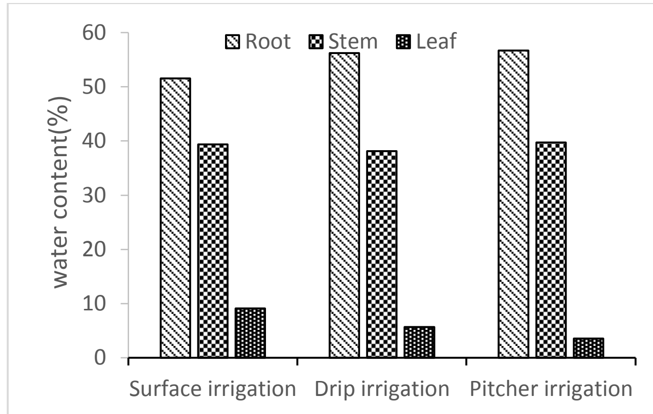
Distribution of water in parts of the plants clarified that except for Berberis thunbergii, stems conserved the most percentage of water. Roots conserved the most percentage of water among Berberis thunbergii treatments. Considering Ligustrum vulgare treatments, a serious difference was observed among percentage of water conserved in root of plants grown under pitcher and that of the other two irrigation systems i.e. root of plants under pitcher irrigation comprised 26.18% and 29.6% more water than those of surface and drip irrigations. On the other hand, such a difference was not observed among Berberis thunbergii and Rosa hybrid treatments (the difference was about 7% at most). The same differences for water percentage in roots of Pyracantha treatments were 17.3% and 18.14%, respectively. The high water percentage in root of Berberis thunbergii (more than 51.5 %) and that of Rosa hybrid treatments (more than 34.5%) shows that suitable moistening of the root zone under pitcher irrigation is achievable. On the other hand, the highest amount of water is obviously absorbed through the roots, and its close relation with xylem and leaves leads to sufficient amount of water in plants. Comparing water contents and percentage of water conserved in roots, it is concluded that pitcher irrigation makes the best root zone moistening and facilitates water absorption due to its continuous seepage.

CONCLUSIONS

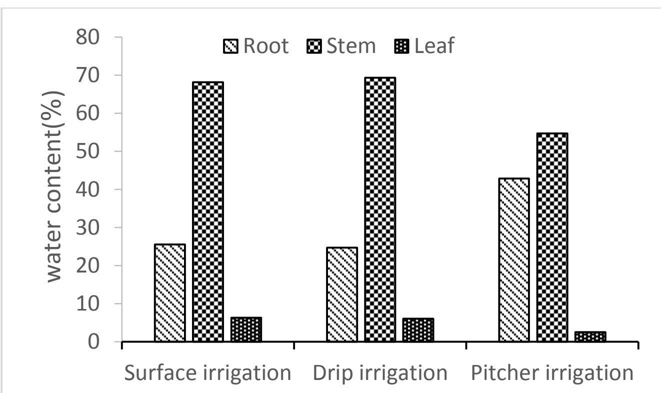
This study showed that the pitcher irrigation could save up to 60% and 30% of water compared to surface and drip irrigations. In almost all cases, pitcher irrigation acceptably affected the plants. Further variation in height, more number of leaves grown, and great QPAS were obtained under pitcher irrigation. Comparison of water contents clarified that best results for Ligustrum vulgare and Pyracantha were obtained under pitcher and drip irrigation systems. The same result was obtained under pitcher and surface irrigations for Berberis thunbergii. Water content of Rosa hybrid treatments under three irrigation systems were approximately the same. Results also showed that plants under drip irrigation had more leaf area; however, a negligible difference was observed for Rosa hybrid under pitcher irrigation as well as Ligustrum vulgare under surface irrigation. No considerable difference between leaf area of Pyracantha treatments was observed. It might finally be concluded that pitcher irrigation can facilitate water absorption due to high water percentages conserved in roots.

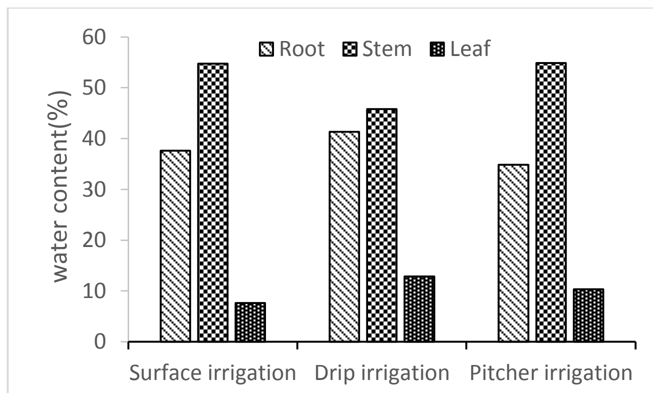
As shown, plants were successfully grown under pitcher irrigation. Even though some preferences were observed in some treatments under surface and drip irrigations, pitcher irrigation is comparatively preferable due to economic aspects and its simplicity.





7.a 7.b





7.c 7.d

Figure 7. Distribution of water in parts of (a) Ligustrum vulgare (b) Berberis thunbergii (c) Pyracantha (d) Rosa hybrid

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