Experimental Investigations on Pitcher Irrigation: Yield Optimization and Wetting Front Advancement

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***Abstract*— This study presents details about experimentation with Pitcher Irrigation (PI) for growing horticulture crops performed at village Jiva of Surendranagar district of Gujarat state (India). Representative soil sample taken from the farm was tested for soil classification in accordance with IS 2720 (Part-IV) – 1985 and IS 460- 1978. The results of irrigation water quality test and soil nutrient test suggested that the electrical conductivity (EC) of the irrigation water and the soil was very high. Optimum yield is obtained when the plants of peas (Pisam Sativum) are at a distance of 9 cms and the plants of tomato (Lycopersicon esculentum) are at a distance of 13 cms from the corresponding pitcher's outer wall. The size of pitchers does not significantly affect the yield. However, for maximum economic returns small pitchers having capacity of 11 litres shall be utilized. The wetting pattern was like a balloon and extended to a horizontal distance of 25 cms and to a depth of 70 cms from the ground level. The wetting front had started reducing after 120 hours and was completely gone after 9 days. In view of the observed moisture distribution under pitchers for alkaline soil with saline irrigation water some shallow rooted vegetables crops (up to 30 cm depth) such as celery, lettuce, onions, potatoes, radish, and moderately deep rooted (30-60 cm depth) vegetable crops such as broccoli, beans, cabbages, carrots, cauliflower, cucumbers, muskmelon, peppers, tomatoes, and zucchini can be grown by employing pitcher irrigation technique. The Benefit-Cost ratio from small sized pitcher irrigation was 136.82% higher than the Benefit-Cost ratio from large sized pitcher irrigation. The experimentation confirmed the fact that this indigenous method can be successfully employed even for unfavorable land and water. The cost to be incurred for adopting these methods is quite less in comparison to drip irrigation and thus can be adopted by small and medium scale farmers. The method is labor intensive. Adoption of PI at large scale requires a cistern and a pipe network for frequent filling-up of pitchers. The use of this method is more suited to small-scale irrigated agriculture. PI has no environmental impacts, is cost effective, and most importantly is also not using any electricity for its operation. Efficient water management by using this indigenous technique can offer a solution to looming water crisis world over.**

***Keywords*— Pitcher Irrigation (PI), indigenous, looming water, horticulture crops, electrical conductivity (EC)**

I. INTRODUCTION

Irrigation systems such as drip and sprinkler do save half of the water presently used for irrigation but technical, economic, and socio-economic factors prevent the adoption of these technologies [1]. Cultural practices, poor irrigation water quality and lack of market for farm products are discouraging factors for the adoption of drip irrigation [2]. Besides, for voluntary adoption of sustainable irrigation practice extensive resources must have to be fittingly supported by the non-voluntary catalyst such as regulation and incentives [3]. Moreover, the use of micro-irrigation technologies also tend to increase the marginal productivity of water and with the effect of subsidy schemes which indirectly reduces the marginal cost, the demand for irrigation water increases and thus a rational farmer continues to use more water [4]. However, other enhanced scientific methods can be used to improve the water use efficiency in agriculture. Gupta et al. (2008) [5] has noted that customary methods of subsurface irrigation, such as pot and pitcher irrigation (PI) have been used in numerous countries. Such methods comprises of burying a pot or a pitcher close to the plant roots and typically filling it with water manually, or by means of a flexible plastic hose using a hydraulic arrangement. Quite a few researchers have studied various aspects of this irrigation technique. Research work carried out at college of Agriculture and Technology, Bhubaneswar, Orissa, India by Naik B.S. et al. (2008) [6] suggests that local irrigation for the most part is important and is a major innovation for reducing moisture stress and controlling soil salinity. The authors describes that PI is one of the cheapest techniques amongst the most recent progress in localized methods of small scale irrigation. The authors also elucidates that while evaluating the flow hydraulics and various management alternatives, other researchers had reported that PI is a practical option to drip irrigation and extremely competent in terms of water conservation and can be accepted as an irrigation method with high frequency and low depth. Further, the same authors inferred that plants can be grown around pitchers using highly saline waters without sustaining any moisture stress.

Field experiments carried out by Abu-Zreig et al. (2009) [7] have revealed that clay pitchers were able to supply water at a rate directly proportional to crop requirement represented by crop reference evapo-transpiration (ETo) and soil moisture level. Further, their research has also shown that water seepage from pitchers is a self-regulative process and is a function of soil moisture conditions which is affected by evapo-transpiration rate. Their results also indicted that pitchers can release higher quantities of water in dry soil compared to that in wet soil, indicating that pitchers can auto-regulate water supply to plants. From the field experiments carried out at the research farm in the Matura District of Sri Lanka by Navaratne et al. (2006) [8] it is quite evident that the yield gained from the crop grown under pot irrigation systems was twofold the yield of crop grown under manual irrigation throughout the dry seasons.

Padma Vasudevan et al. (2011) [9] has recognized this method as emerging and highly promising method for localized small scale irrigation. The 'Ethiopian Agriculture Water Management' policy [10] has identified that even in urban areas, pitchers have much capability for backyard vegetables and flower production. It has been well confirmed that irrigation by this technique results in yield increase between 30-45 % and water saving between 50-70 %. The crops that flourish under this system include tomatoes, grapes, leaf vegetables and cauliflower, maize, beans and fruit trees. Pitcher irrigation as an alternative to drip or sprinkler irrigation can be a viable option for water scarce area particularly for farmers those are looking to eke a living out of their small holdings of land [11].

Enough research has taken place about the use of pitcher irrigation for arid and semi-arid places. It has also been proved that it is possible to use saline water with PI. However, no evidences of experimentation with PI on alkaline soil with saline water can be found in any of the literature. Further, the details about the preferred plantation distance of horticulture crops from pitchers outer-wall with PI also could not be found in the literature. Consequently, the present study would be very much important from water resources, irrigation and agricultural point of view.

II. EXPERIMENTAL SECTION

A. Location

The localized method of 'Pitcher Irrigation' was experimented with on an agricultural farm at village Jiva of Surendranagar district of Gujarat state. The experimental plot was approximately 23.0 kilometers by road from Halvad city.

B. Experimental Set-up

Large and small sized pitchers both 27 in nos. were buried ¾ of its depth into the soil and was planted with the seeds of peas (Pisam Sativum) on two sides and brinjal (Solanum melongena) on the other two sides at varying distance from the outer wall of the pitcher. Since, most of the germinated plants of brinjal (being highly sensitive to freezing temperatures) could not survive the cold wave that lasted for more than 45 days in the region; on farm germinated plants of tomato (Lycopersicon esculentum) had to be transplanted in place of brinjal around the pitchers. To have a better understanding of the effect of soil and water on the yield using PI no fertilizer was used during the entire experimentation except few quantity of organic fertilizer that too during the installation phase of pitchers. The centre to centre distance between all the pitchers was 1.5 m. The pitchers were shut with an earthen lid at the top to prevent evaporation from the same. The details of the pitchers are given at Table 1.

C. Laboratory Tests

Representative soil sample taken from the farm was tested for soil classification in accordance with IS 2720 (Part-IV) – 1985 and IS 460- 1978. Soil nutrient test was also performed on the soil sample. Water that was used for irrigation was also tested. The experiments were performed at Lukhdhirji Engineering College, Morbi.

D. Yield

The yield of peas was calculated for a crop period of 81 days and for tomatoes the crop period was taken as up till 125 days. The water consumption was accordingly considered for the respective crop periods.

E. Wetting Front Movement

A 4.2 m long, 1.6 m wide, and 1.35 m deep open excavation (pit) was dug in the farm near the experimental plot to study the distribution of moisture beneath soil surface around the pitchers, The pitchers were installed on the edge of the vertical side of the pit such that both the horizontal and vertical spread of moisture was visible.

In order to determine the percentage moisture content in the soil for studying the moisture distribution around the pitchers, the soil samples were collected by spatula by making a grid of 15 cms originating from the neck of pitchers. The moisture content in the soil around the pitcher was determined by the Gravimetric Method.

F. Benefit-Cost Analysis

Using the data of actual cost incurred for seeds, pitchers, labour etc total expenditure per acre for irrigation with pitchers was worked out. Similarly, using the market survey method the monetary benefits accrued by selling the yield at market price the total benefits from the method of irrigation employed for the experimentation was computed. From these computations the benefit-cost ratio (B/C) was worked out.

Table 1: Dimensions of pitchers

Parameters	Dimensions	
	Small	Large
Neck Level Capacity (liters)	11.0	15.0
Maximum outside diameter of pitcher (cm)	28.0	31.50
Thickness (cm)	0.7	0.7
Area of opening (cm^2)	167.85	191.15

III. RESULTS AND DISCUSSION

(a) Quality of Irrigation Water and Soil:

The soil of the experimental farm (as per IS 1498- 1970) was classified as 'Fine Sand' (SP-Poorly Graded Sand) and the results of permeability test showed that the average co-efficient of permeability (K) / hydraulic conductivity of the soil of the experimental farm was 4.266 x 10-5 cm/sec which is in accordance with the normal values specified for fine sand.

The results of irrigation water quality test and soil Nutrient test suggested that the electrical conductivity (EC) of irrigation water was very high. Such water is totally not suitable under normal circumstances. The water had objectionable level of chloride. Further, the water that was used for irrigation was having high salt content. Salts had accumulated on the surface of pitchers. It was also seen that the rate of diffusion of water through the pitchers was reduced. High electrical conductivity of the soil too suggested that the availability of water to the plant was slight to moderately problematic.

(b) Yield of Crops:

The yield of crops is presented at table 2. The total water consumed by the plants is presented at table 3. It was observed that the water consumption for large pitchers was higher than the water consumption for small pitchers. The higher water consumption by the crops around large pitchers cannot be attributed to the higher water requirement of the crop as the same crops were also planted on the same time around the small pitchers and hence the same evapo-transpiration needs. Further, the wall thickness of both the types of pitchers was almost same; it too cannot be the reason for the disparity between the flows through the pitchers. The soil and water quality too was same for both the types of pitchers. Due to the higher hydraulic gradient towards soil from large pitchers as compared to small pitchers the soil beneath the large pitchers was having more moisture than soil beneath the small pitchers. According to Israelsen and Hansen, 1962 [12], other conditions being same, roots of a plant in moist soil will extract more water than the roots of the same plant growing in dryer soil. For this reason, once the soil beneath the large pitchers becomes damper than the soil beneath the small pitchers, large pitchers will continue to seep more water and hence will consume more water.

(c) Crop Yield Optimization:

The comparison of average yield of peas and tomatoes obtained per matured plant are presented at Fig. 1 and Fig.2 respectively. From the analysis of the data obtained about the yield of peas the optimum yield is obtained when the plants are at a distance of 9 cms from the corresponding pitcher's outer wall (Fig.1). It is seldom possible in the actual farm to plant the seed such that the plants germinate at a distance of 9 cms. Moreover, the difference in yield for distance from 7 cms to 12 cms is very small and hence instead of using one value of distance for plantation of peas, a range of distance from 7-12 cms shall be adopted in order to optimize the yield of peas. Though, the preferred range shall be 8-11 cms as a difference of about 100 grams per plant can mean a lot when the plantations are undertaken on a large scale. Similarly, optimum yield is obtained when the plants of tomatoes are at a distance of 13 cms from the corresponding pitcher's outer wall (fig.2). However, the distance range from the corresponding pitcher's outer wall for obtaining optimal yield of tomatoes was found to be 11-17 cms.

Table 2: Yield of Crops

Sl.	Name of the Crop	No. of Plants Matured #	Size of the Pitcher in Liters	Total Yield Obtained in Kg.	Yield Per Plant in Kg.
1	Green peas	48 (48)	15 (Large)	27.412	0.571
2	Green peas	52 (54)	11 (Small)	28.544	0.548
3	Tomatoes	53 (54)	15 (Large)	55.78	1.052
4	Tomatoes	50 (54)	11 (Small)	55.15	1.103

Table 3: Water Consumption of Crops

Size of Pitcher used for Irrigation	Water Consumption in liters.			Average Water Consumption per plant in liters.		
	Peas & Tomatoes (81 days)	Only Tomatoes (44 days)	Total water consumption in liters. (125 days)	Peas & Tomatoes (81 days)	Only Tomatoes (44 days)	Total Average Water Consumption per plant in liters. (125 days)
Small Pitcher 11.0 liters	2133.45	772.80	2906.25	20.916	15.456	28.492
Large Pitcher 15.0 liters	2529.85	987.60	3157.45	25.048	18.634	31.261

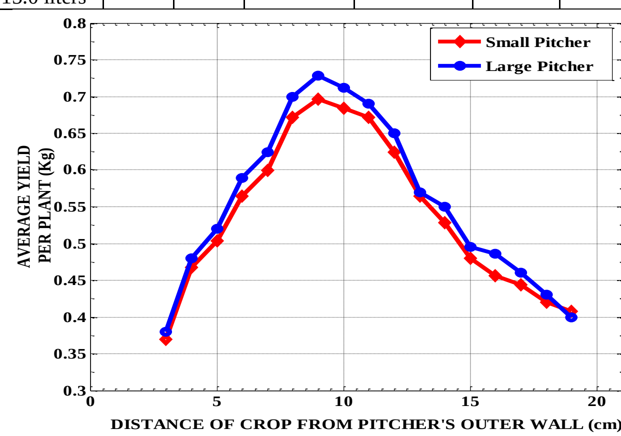

Figure 1: Comparison of average yield of peas

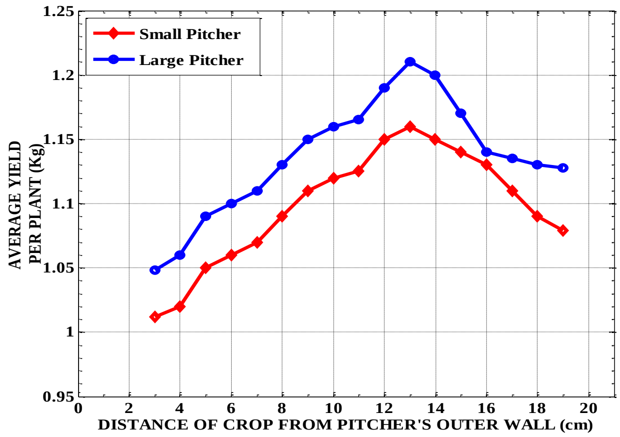

Figure 2: Comparison of average yield of tomatoes

(d) Wetting Front Advancement:

The results of the moisture measurement shows that the maximum moisture content of the soil was 9.25 % which is very close to the moisture holding capacity of fine sand type of soil. The lower moisture content near the surface could be the result of evaporation from the soil. As was expected, the moisture movement was more vertical than horizontal. The wetting front movement (% Moisture) after 24, 72 and 144 hours is shown at fig. 3, fig. 4 and fig. 5 respectively. It was observed that after 72 hours, for a depth ranging from 40 cms to 60 cms from the Ground Level (GL) the moisture was in the range of field capacity of soil whereas, after 24 hours the moisture had not reached the level of 60 cms depth from GL. Further, the horizontal spread of water from the pitchers outer wall was quite less at the end of 24 hours while it was more after 72 hours. The wetting pattern was like a balloon and extended to a horizontal distance of 25 cms and to a depth of 70 cms from the GL. This depth is widely accepted as an effective zone for extraction of moisture by plants roots. The wetting front had started reducing after 120 hours and was completely gone after 9 days. The depth of burying the pitcher into the soil has a great effect on the wetting front.

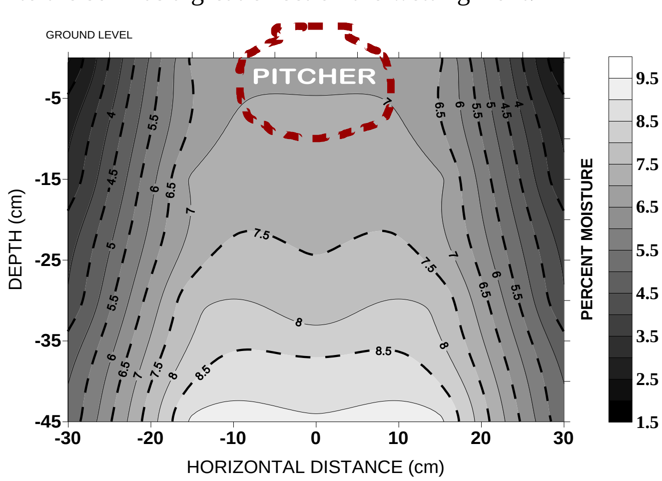

Figure 3: Wetting Front Movement (% moisture) after 24 hours

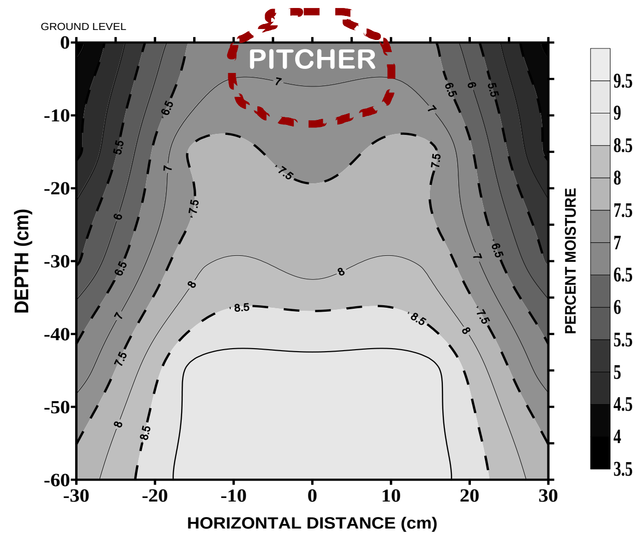

Figure 4: Wetting Front Movement (% moisture) after 72 hours

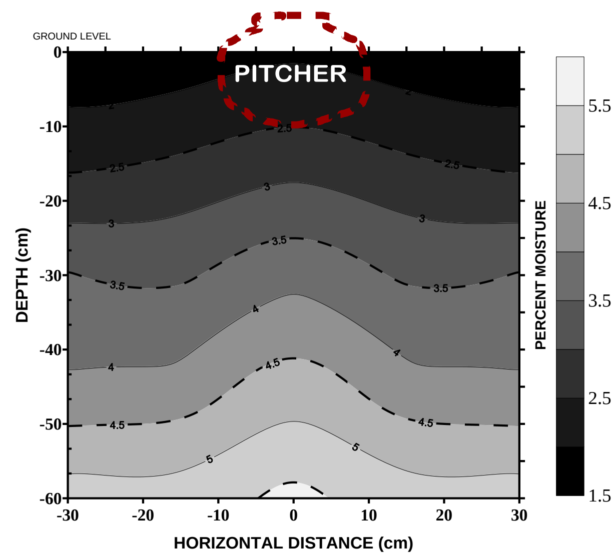

Figure 5: Wetting Front Movement (% moisture) after 144 hours

The deeper the pitchers are installed in the farm the deeper is the movement of the water. For shallow rooted crops such as peas (Root depth about 30-60 cms) the wetting front obtained by the present depth adopted for the experimentation was satisfactory.

However, since the depth of placing the pitcher produces different wetting front for different soil it is advisable that the farmer undertakes a small experimentation with few pitchers and by open excavation/ pit method must check the extent of moisture movement both horizontally and vertically to assess the suitability of crops other than used for the present study.

The analysis of wetting front advance suggest that the distance adopted for the present study was such that there was no merging of wetting front and thus it could be inferred that the land could have been utilized more optimally if the distance between the pitchers could have been less.

(e) Suitable Crops:

Some shallow rooted vegetables crops (up to 30 cm depth) such as celery, lettuce, onions, potatoes, radish, and moderately deep rooted (30-60 cm depth) vegetable crops such as broccoli, beans, cabbages, carrots, cauliflower, cucumbers, muskmelon, peppers, tomatoes, zucchini can be grown using pitcher irrigation method.

(f) Benefit-Cost

The Benefit-cost ratio for small and large sized pitchers employed for irrigation in the present study was 2.75 and 2.01 respectively. The cost of farming on employing small pitchers and large pitchers for irrigation was 72,837 and 99,822 Indian National Rupees (INR) respectively.

The cost as well as benefits largely depend on the local market and may vary from region to region. Also, the experimentation was done in accordance with the minimum distance between two crops as specified by standard agricultural practices. The cost may also vary with variations in planting distance. It is worth noting that the cost of installation of drip irrigation for the same crops and with same distance as adopted for the present experimentation would be about 1,00,000 INR (Rank, 2010) [13].

(g) Limitation for Large-scale Adoption:

The method of PI is labour intensive. Adoption of PI at large scale requires a cistern and a pipe network for frequent filling-up of pitchers for which the farmer has to bear additional expenses. The cistern can be located on an elevated ground so that the pitchers can be filled by gravity and no electricity is required for filling-up of pitchers. When the water is to be drawn from a well the pitchers should be filled with a flexible hose which could be combined to a treadle pump and thus the labour required for filling the pots can be considerably brought down.

PI is difficult to use in rocky soils at the same time the broken pots or capsules can disrupt the irrigation operation and reduce the productivity. Some plants with extended root systems are difficult to cultivate using this technology. In some areas, it may be difficult to purchase or manufacture the clay pots and/or capsules. The use of PI is more suitable to small-scale agriculture.

On the contrary, it is worthwhile noting that in areas of acute shortages, the water for the entire season can be collected by rainwater harvesting. PI technique has no environmental impacts, is cost effective, and most importantly is also not using any electricity for its operation.

For a country such as India where majority of farmers are typically small scale or marginal farmers and only ½ per cent of households farming are farming on more than 10 hectares of land [14] the technique can be more than useful in solving water crisis and can also improve the economic condition of the farmers which can bring down the number of suicides committed by small and marginal farmers in the country.

IV. CONCLUSIONS

- The size of pitchers does not significantly affect the yield. But, for maximum economic returns and water saving, small pitchers having capacity of 11 liters shall be used for pitcher irrigation with saline water on alkaline soils.
- The yields of crops raised by pitcher irrigation method were very close to normal yield values as specified by the normal agricultural standards so the method of pitcher irrigation can be successfully employed with saline irrigation water on alkaline soils.
- Optimum yield is obtained when the plants of peas are at a distance of 9 cms and the plants of tomatoes are at a distance of 13 cms from the corresponding pitcher's outer wall. The distance range from the corresponding pitcher's outer wall for obtaining optimal yield of peas was 7-12 cms and that for tomatoes was found to be 11-17 cms.
- The Benefit-Cost ratio from small sized pitcher irrigation was 136.82% higher than the Benefit-Cost ratio from large sized pitcher irrigation. The cost to be incurred for adopting this method is quite less in comparison to drip irrigation and thus can be adopted by small and medium scale farmers.
- In view of the observed moisture distribution under pitchers for alkaline soil with saline water for irrigation some shallow rooted vegetables crops (up to 30 cm depth) such as celery, lettuce, onions, potatoes, radish, and moderately deep rooted (30-60 cm depth) vegetable crops such as broccoli, beans, cabbages, carrots, cauliflower, cucumbers, muskmelon, peppers, tomatoes, and zucchini can be grown by employing pitcher irrigation technique.
- Efficient water management by using this indigenous technique can offer a solution to looming water crisis and would help bring more and more of the un-irrigated area under the irrigation in the country.

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