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# Experimental Investigations on Localized Porous Clay Pipe Irrigation Technique for Sustainable Agriculture: A New Paradigm for Soil and Water Management in Rainfed Areas

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Abstract — In India, water use for irrigation is about 86 per cent of the current level of entire water utilization, and this indicates that increasing agricultural productivity per drop of water shall forever remain our chief concern. This study proposes to introduce 'Porous Clay Pipe Irrigation' technique and subsequently on-farm experimentation was effectuated to test out its applicability for growing row crops for water deficient areas of Surendranagar district. The experimental results revealed that 'Porous Clay Pipe' irrigation is quite capable of facilitating adequate moisture to the soil and crop. Judged against Rain-fed agriculture double yield was obtained With 'Porous Clay Pipe Irrigation' and also the growth of crops during the crop period and the quality of yield under 'Porous Clay Pipe Irrigation' was much high-class to the Rain-fed agriculture. Substantial water saving in agriculture can be attained by employing this method of irrigation. Rather than depending only on rain, the farmers can take-up this technique which would help them in improving their economic conditions and thereby the local and national economy. This method can prove to be a useful tool in conserving soil and water in the rainfed areas.

***Keywords***- *Porous Clay Pipe Irrigation, Rainfed Agriculture, Soil and Water Management,Wetting Front Advancement.*

## I. INTRODUCTION

Land products still drive the Indian economy. Indians mostly depend on agriculture for their livelihood. Rain-fed areas that do not have any irrigation facilities accounts for 60 % of the cultivated areas and these areas are also home to the majority of rural poor and marginal farmers of the country (Sebak, 2011) [1]. In India, water use for irrigation is about 86 percent of the contemporary level of entire water utilization, and this indicates that increasing agricultural productivity per drop of water shall forever remain our chief concern. The National Water Policy-2002 [2] and the Gujarat State Water Policy (Draft) -2014 [3] has emphasized cost-effective irrigation options and apt irrigation techniques for improved water use efficiencies at individual and at the project level. To accentuate, the Planning commission of India in their document "Towards Faster And More Inclusive Growth-An Approach To The 11th Five Year Plan" (2006) [4] has also mentioned that water is a critical input for agriculture; this demands more efficient utilization of existing irrigation potential and expansion of irrigation where it is possible at an economic cost and better water management in rain-fed areas where secure irrigation is not feasible. Given that, the penalties involved in the inappropriate exploitation of water resources have long-lasting implications (Maeda, 2011) [5] water will increasingly remain as a primary input for our agriculture.

The biggest problems that pose a threat to the sustainability of the irrigated agriculture are low irrigation efficiency, high saline irrigation water, heavy soil texture, and lack of adequate field drainage systems (Kuman et al.,2011) [6]. Due to these issues, efficient utilization of water for the irrigation use would turn to be yeoman's service for the country.

Prinz & Malik (2004) [7] concludes that lessons learned from the variety of projects are an illustration that the implementation of a new irrigation system is influenced by farmer's capacity to finance and operate irrigation system, as well as on the type of crop being produced. In this context, a modernized surface irrigation might be a superior water saving modus operandi than drip or sprinkler irrigation in a certain location; the latter ones are time and again not easy on the pocket. A modernized 'old' system can more effortlessly be taken up by farmers given that it is closer to traditional practices. Methods that comprises of burying pots or pitchers near the plant roots and typically filling it with water to make available the required moisture to the crop has long been executed by countries such as Brazil, Mexico, Bolivia, Zimbabwe, China, Pakistan and many others. Neelkanth Bhatt et al. (2013 & 2017) [8,9] has noted that despite adverse land and water conditions, Pitcher Irrigation can offer a viable solution to the looming water crisis for small and medium-scale cultivation. Even, methods such wick irrigation as an indigenous method can be successfully employed even for unfavorable land and water (Neelkanth Bhatt et al., 2017) [10].

In traditional sub-surface pipe irrigation systems, perforated or porous pipes are buried in the soil. Water seeps from the pipe into the soil and spreads out in the root zone due to capillary forces. Batchelor et al. (1996) [11] and Bainbridge (2002) [12] found that traditional sub-surface irrigation methods have high water use efficiency, i.e., high crop production per amount of applied water. Nevertheless, not much work has been done focusing specifically on traditional sub-surface systems. An improvement on the traditional method of subsurface irrigation is to use porous clay pipe, in which both conveyance and seepage of the water can be carried out instantaneously by the same pipe.

Pitcher irrigation is not suitable for crops in row pattern; hence by this study, it was proposed to introduce 'Porous Clay Pipe Irrigation' technique and subsequently examine its applicability for growing row crops for water-deficient areas of Surendranagar district. On-farm, experimentation was therefore carried out on Cotton (variety-Gujarat-13) (Gossypium herbaceum) crops which were irrigated using 'Porous Clay Pipe Irrigation' technique at the Village Bajrangpura, Taluka-Lakhatar, Dist.-Surendranagar Gujarat (India).

## II. METHODOLOGY

### 2.1. Manufacturing of Porous Clay Pipes :

The unglazed hollow clay pipes were manufactured by women from a mixture of Than clay (locally available) and saw dust in the ratio of 3:1 and with a sufficient porosity ranging from 50 - 60% at a local Manufacturing unit primarily manufacturing Filter Clay Candles. The porous clay pipes were made as unglazed to retain their natural porosity, i.e., the walls remain micro-porous. The pipes were then tempered by burning them in a pit fire from firewood at an undetermined temperature to eliminate the swelling and shrinking properties of clay, which would cause cracking of the pipes. The outer diameter of the clay pipe was 5 cm, the inner diameter of the clay pipe was 3 cm and length of the pipe was 17.5 cm. Clay pipes were connected using a plastic (PVC) coupler of suitable size and pipes were then assembled to produce a required length of pipe that can be installed in respective rows. Figure 1 shows typical hollow porous clay pipes and assembly. The porosity of porous pipes was determined based on the difference in weights of dry and saturated pipes. The saturated hydraulic conductivity of porous pipes was found using the constant head method.

Fig. 1 Typical Porous Clay Pipes & Pipes made from PVC Coupling for Installation in the Field

### 2.2. Porosity and Hydraulic Conductivity of Porous Clay Pipes :

The porosity of porous pipes was determined based on the difference in weights of dry and saturated pipes. The saturated hydraulic conductivity of porous pipes was found using the constant head method. This approach was adopted for determining the saturated hydraulic conductivity of the clay pipe having high permeability. Porous clay pipe was submerged in water for three days before testing. When the outflow became the certain constant amount of water was collected for a specific time, and the value of saturated hydraulic conductivity (K) of the clay pipe was determined using the relation:

$$K = VL/Aht \qquad \text{(Eq. 1)}$$

Where,

V = volume of collected water in cubic centimeter
L = average wall thickness of the pipe in cm.
A = surface area of the clay pipe in square cm
h = constant head in cm.
t = time taken in second

### 2.3. Field Preparation and Installation of Pipes :

The field was leveled by cultivation and digging a trench before the installation of porous clay pipe to the field. Longer pipe segments were formed by connecting two pipes with PVC coupler. 15 m long pipes were built with these segments and were then placed in the trench (Figure 2). Total 4 beds/rows using 'Porous Clay Pipes' were employed for the study. The pipes were placed horizontally 20cm away from the crop rows along the entire length of the beds by laying them end-to-end in a leveled trench of 30cm depth, and lateral spacing between two rows of pipe was 228cm. The trench was then backfilled with soil.

 

Fig. 2 Installation of Porous Clay Pipe on Farm

**2.4. Irrigation through Porous Clay Pipes :**

The experimentation was carried out on Cotton ‘Gossypium’ during the Crop period of 230 days. Total annual rainfall for study area during the crop period was approximately 575mm. Irrigation Water was fed to the porous clay pipes from an above surface storage tank. Water was applied to 15 cm long porous clay pipes at the 70cm constant head. The water seeped from the pipe wall into the soil and spread out in the root zone due to capillary forces. Figure 3 shows the schematic arrangement for irrigation with porous clay pipes.

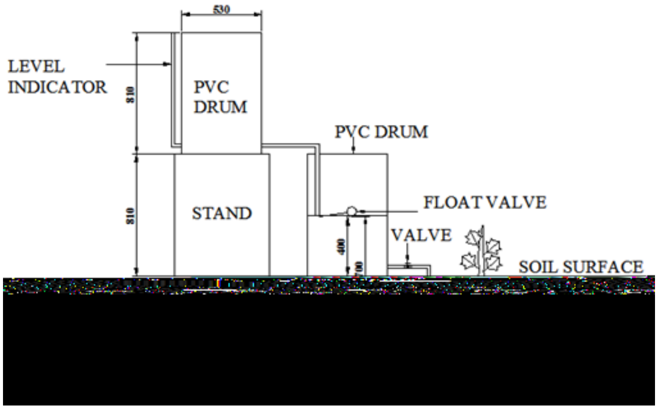


Fig. 3 Schematic Sketch of ‘Porous Clay Pipe Irrigation’ Method

**2.5. Wetting Front Movement under ‘Porous Clay Pipe’ :**

Observation on Wetting Front Advancement in the field was done by ‘soil pit method’ in which soil water flow is monitored by observation of the wetting front on the face of a soil pit, the soil samples are then collected, and moisture percentage can be found out using Gravimetric Method. Battam et al. (2003) [13] in his study had suggested the soil pit method in detail. For the present experimentation too, the faces of the pit were trimmed vertically, and buried pipe was installed about 0.3 m back from the pit face. The wetting pattern was visible as a darkening area at the pit face, and the observations were recorded.

## III. RESULTS AND DISCUSSION

**3.1. Porosity and Hydraulic Conductivity of Porous Clay Pipe :**

The porosity of the porous clay pipe was found to be 59.80 % which is relatively higher than average values specified for clay soil elsewhere. This could be attributed to the fact that sawdust was added to the soil to increase the porosity of the manufactured pipe. The porosity of the clay pipe is a significant factor for the development of wetting front beneath and around the pipe. The types of crops that can be raised by this method depend on the wetting pattern which is a function of pipe porosity and may be different for different soils. For the present experimentation, the higher porosity of the pipe material was selected because with the time due to deposition of silt and debris or salts the porosity of the pipe would reduce and thus the quantity of water applied to the soil for a given duration would also be affected. Furthermore, the higher initial porosity would also increase the duration for which the pipes can be used in the field without the problem of clogging. The amount of water required by the crops through higher porosity could be regulated by providing water to the pipes for a shorter period. Though, this would necessitate the calculation of water requirement of a particular crop and accordingly apply water to the pipes for the required duration.

The Mean saturated hydraulic conductivity of clay pipe was found to be $1.598 \times 10^{-5}$ cm/sec. The saturated hydraulic conductivity was determined using the constant head method as owning to the high porosity of the pipe material there would have been too fast falling in the manometer tube to measure accurately. Consequently, only the constant head method was employed. The results commensurate with the values specified elsewhere with the standard hydraulic conductivity which is sufficient to provide required moisture to the soil and the crops.

### 3.2. Water Requirement of Crops :

For the present experimentation, the water requirement of the crops was estimated by observing the soil moisture visually and by the feel of the soil by the hand. This method was preferred over other technical methods because the farmers seldom carry out complex mathematical calculation rather they rely on visual and feel test of the soil for determining the water requirement/water stress.

### 3.3. Irrigation through 'Porous Clay Pipes' :

Table 1 shows details of irrigation water applied to each row and the amount of rainfall that occurred on the farm during the study. For irrigating 1 hectare of land using 'Porous Clay Pipe Irrigation' technique a total of 2, 04,380 liters of water would be required. The farmer can harvest the necessary water during the rainy season with due storage arrangement on the field.

Table 1 Detail of Irrigation(s) and Rainfall(s)

| **Irrigation Event** | **Amount of water in liters applied to each row** | **Duration of irrigation (Minutes)** | | | | | **Rainfall Event** | **Quantity** |
|---|---|---|---|---|---|---|---|---|
| | | 1st row | 2nd row | 3rd row | 4th row | Mean duration | | |
| 1st | 100 | 57 | 53 | 60 | 56 | 56.50 | 1st Rainfall | 125 mm |
| 2nd | 100 | 62 | 60 | 65 | 63 | 62.50 | 2nd Rainfall | 25 mm |
| 3rd | 100 | 61 | 63 | 66 | 61 | 62.75 | 3rd Rainfall | 100 mm |
| 4th | 100 | 63 | 67 | 64 | 64 | 64.50 | 4th Rainfall | 100 mm |
| 5th | 100 | 68 | 62 | 64 | 65 | 64.75 | 5th Rainfall | 50 mm |
| 6th | 100 | 67 | 66 | 68 | 65 | 66.50 | 6th Rainfall | 75 mm |
| 7th | 100 | 71 | 69 | 68 | 69 | 69.25 | 7th Rainfall | 25 mm |
| | | | | | | | 8th Rainfall | 75 mm |

The irrigation frequency for the experimentation was of 10 days. This duration was selected because the soil was clay loam which has higher field capacity as compared to soils such as sand, sandy loam. Further, from the previous experiences of the farmer, it was known that the soil was capable enough to hold the moisture for a relatively longer duration. Total 2800 Liters of water was applied to the 0.0137-hectare field under experimentation. The water requirement for the entire season could also be collected by harvesting rainwater to be utilized later for irrigation

### 3.4. Soil Moisture and Wetting Front Advancement under 'Porous Clay Pipes' :

Figure 4 shows a photographic view of moisture movement under 'Porous Clay Pipe' as observed in soil pit. Table 2 illustrates the development of wetting front advancement under 'Porous Clay Pipe.' The moisture was observed on the second day and tenth day after applying water to the crops. The observation was also made for both the conditions viz. irrigated with a porous clay pipe and un-irrigated (Rain-fed condition). With the increase in-depth from the ground surface the moisture content too increased. There was a sharp decline in the rate of moisture depletion for the first 15 cms depth. With an increase in the soil depth, the loss of moisture too was less, the reason being the fact that water evaporates from the top surface of the ground. Even after ten days following water application to the crops the amount of moisture retained by the soil was higher when compared to the unirrigated soil. Thus, it was possible to make available to the crops the required moisture.

Fig. 4 Observing Wetting Front Advancement

Table 2 Wetting Front Advancement

| Time in Minute after Applying Water | Wetting Front Advancement | | | |
|---|---|---|---|---|
| | Distance Vertically Upward From Center of Pipe (mm) | Distance Vertically Downward From Center of Pipe (mm) | Distance Horizontally Right From Center of Pipe (mm) | Distance Horizontally Left From Center of Pipe (mm) |
| 30 | 85 | 125 | 88 | 88 |
| 60 | 100 | 140 | 99 | 99 |
| 90 | 115 | 155 | 109 | 109 |
| 120 | 130 | 170 | 119 | 119 |

The wetting pattern in soil is essential for the design and management of an irrigation system. Different soil types have a different wetting pattern which is dependent on the amount of water applied, application time and the soil properties itself. Finer textured soils may have the bigger wetting pattern, but coarser is opposite. However, the extended application may result in a great storage of water in soils.

### 3.5. Yield under 'Porous Clay Pipe Irrigation' and Rain-fed Agriculture :

The Yield that was obtained under the two system of irrigation is presented in Table 3. The yield using the porous clay pipe method of irrigation was approximately double when compared to crops raised only by rain-fed irrigation method. It was found that monetary benefit or Indian National Rupees 1, 17,000/- per hectare can be achieved by the farmers if they employ the suggested 'Porous Clay Pipe Irrigation' technique.

The increase in the yield for the 'Porous Clay Pipe Irrigation' could be due to the supply of moisture directly to the roots which were more efficiently utilized by the crops for its metabolism. The method is also more beneficial to the plants when compared to other surface irrigation methods as only the root zone was made damp which did not leach the necessary nutrients, and there was enough possibility for the movement of air within the root zone which again is essential for the healthy growth of the plant. The constant moisture availability made sure that the quality of the product was far superior to the crops that were rain-fed. The reduced yield of the crops that were raised by rain could have suffered from mal-nourishment and thus not only the yield, but the yield quality too was below par.

Table 3 Results of Crop Yield and Water Applied to Crops

| Method of Irrigation | Yield of Cotton (Kg/Hec) | Amount of Water Applied (Lit/Hec) |
|---|---|---|
| Porous clay pipe | 5310 | 204380 |
| Rain-Fed | 2710 | 0 |

### 3.6. Merits, Limitations, and Sustainability of 'Porous Clay Pipe' Irrigation :

From the experimentation, it was observed that uniform delivery of water below ground due to 'Porous Clay Pipes' has resulted in maximum plant growth and optimum plant health. 'Porous Clay Pipes' delivers water at the rate at which soil can absorb, and there is no run-off and, if buried or beneath a mulch layer, has no evaporation and therefore no loss of irrigation water. Also, since the water is applied below the ground near the crops roots, regardless of humidity, temperature or wind, water saving can be achieved using this technique. The top surface of the soil in porous clay pipe irrigation systems remains waterless thereby reducing weed proliferation and direct evaporation of water, deep percolation and competitive consumption of water by weeds. This reduction in water wastage improves the crop water use efficiency.Soil moisture is continuously available almost at field capacity giving the crop full security against water stress. The system inherently checks against over-irrigation. 'Porous Clay Pipe' assembly is simple. It can be manufactured locally and easy to install, operate and maintain. Thus, this technique can not only be useful for water scarce areas but also for irrigated areas which are likely to face problems of water shortage in future. 'Porous Clay Pipes' also considerably lowers irrigation water requirement and that too without reducing yields. Moreover, by enhanced management of rainwater in rainfed systems which is presently generating excessive runoff and is causing soil erosion, use of 'Porous Clay Pipe' Irrigation can help minimize land degradation and can thus be a useful tool for soil and water management.

The 'Porous Clay Pipe' Irrigation has several limitations too. It is initially very highly labour intensive method. If the water used for irrigation is silty, the silt accumulates in the pores, effectively sealing the pipes. If left dry for a long time, the pores will clog due to salt accumulation and precipitation. In the long run, this would reduce the seepage through the pipes which would make it difficult to facilitate required water for its growth. Buried pipes are not conducive to mechanized agriculture.

However, the method does not require any electricity for its operation also the farmers to have knowledge for its operation (as is the case with drip irrigation) makes the method more useful to the farmers than drip irrigation. The farmers still do not get electricity for sufficient duration and when it is needed the most. The crop water requirement does not depend on the availability of electricity rather on the availability of moisture. The proposed method also does not require any filter as is required by the drip irrigation assembly. Furthermore, the porous clay pipes are environmentally friendly and can be easily replaced when they get clogged. The problem of clogging with the porous pipe is much less with this method as compared to drip irrigation. The running maintenance cost of drip irrigation owning to frequent replacing of the filter medium is high. Accordingly, the method of 'Porous Clay Pipe' is highly sustainable.

## IV. CONCLUSIONS

The proposed 'Porous Clay Pipe' irrigation can facilitate sufficient moisture to the soil and crop. There was adequate moisture distribution beneath the porous pipe even after 10 days following water application to the crops. The amount of moisture retained by the soil was higher when compared to the unirrigated soil. The 'Porous Clay Pipe Irrigation' offers double yield as compared to Rain-fed agriculture. The growth of crops during the crop period and the quality of yield under 'Porous Clay Pipe Irrigation' was much superior to the Rain-fed agriculture. Considerable water saving in agriculture can be attained using this method of irrigation. The method is slightly costlier but considering its ease in installation, maintenance and operation, and if the same pipes are used for up to 3-5 years, the cost can be considerably reduced. The persistent use of this technique would pay high returns to the farmer in the long run in areas facing water scarcity. Instead of depending only on rain taking-up of this technique can help farmers in improving their economic conditions and thereby the local and national economy. The method also demonstrates that productive soil and water conservation can be attained using 'Porous Clay Pipe Irrigation' technique.

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