Evaluation of Movement of Wetting Front Under Wick Irrigation in Black Cotton Soil

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Abstract Irrigation of the crop is a necessity for group growth. Several irrigation techniques have been used for watering the crop and cultivating the crops for maximum production. Applying the different irrigation techniques to crops depends on crop-land suitability; however, finding the optimum water requirements to crop is the primary aim of this case study. The present research aims to identify wetting front movement while using wick irrigation technique. The method has been executed to demonstrate and find the developed wetting front at a small farm in Velavadar, Surendranagar in Gujarat. This study reviews an experiment with capillary wick irrigation for cultivating raw crops. IS 2720 (Part-IV)–1985 and IS 460–1978 were used to analyze a representative soil sample taken from the farm. The electrical conductivity (E.C.) of the irrigation water and the soil was relatively high, according to water quality and soil nutrient tests. The knowledge of wetted width, depth, and maximum wetted width beneath the soil's surface is required to design and manage an efficient wick irrigation system. It can essentially be auto regulated by wick discharge and time of micro-irrigation. Temporal movement of wetting in horizontal and vertical directions under the surface point source was studied in an experimental box size of 1 * 1 * 1 m. The wick diameter considerably impacts the yield as per the types of crops. However, a small underground reservoir with 7 L is used for the

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best economic returns. The wetting pattern was shaped like a balloon and stretched 30 cm horizontally and 50 cm vertically from the ground level. After 120 h, the wetting front faded and was gone after 12 days. Some shallow-rooted vegetable crops (up to 50 cm depth) such as 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 observing moisture distribution under capillary wick for alkaline soil with saline irrigation water. Tests suggest that this indigenous technology could be used successfully even in adverse land and water conditions.

Keywords Micro-irrigation · Wetting front · Black cotton soil · Optimum water requirement

1 Introduction

Agriculture is a vital aspect of the economy in a country like India. Agriculture is practiced in the sense of providing a service rather than a business or a trade. With a growing population and dwindling natural resources, it is imperative to increase agricultural production (Kumar and Sharma 2020). Increased agricultural productivity necessitates the use of pure water. Food and fiber need has increased significantly as the world's population has grown tremendously (Talaviya et al. 2020). To meet the rising demand, agricultural yield per unit volume of water application must be optimized. Water is one of the essential resources that is inextricably linked to food production (Manjunatha et al. 2011). Most countries and regions face water scarcity, posing a significant challenge to global food security. India has a population of 1.21 billion people and is expanding at a rate of 17.64% per year (2001–11), compared to the global average of 1.3% per year (Ghosh 2019). The rapid rise of India's population has put pressure on the country's agriculture to produce more and more to feed its 1.21 billion people, but having only 141 million hectares of cultivable land, of which 62 million hectares are exclusively irrigated. Groundwater is still the most significant source of irrigation water. The quality and quantity of groundwater water are deteriorating daily (Kishore et al. 2021). Simultaneously, the need for water is growing by the day. Groundwater levels have dropped dramatically in the recent decades (Manjunatha et al. 2011). Soil fertility is lowered as a result of poor water quality. People gradually rely more on rainfed agriculture, resulting in irrigation water scarcity. Water is the most significant input and is crucial in the plant's critical growth phases. As a result, it must be managed (Sharma et al. 2010). As a result, water management is required, and the most suited option is "micro-irrigation," which provides water to the plant root zone while increasing water efficiency (Rouzaneh et al.2021; Vyas et al. 2022). Micro-irrigation spread quickly in the 1990s, reaching 0.3 Mha, and its current coverage in India is estimated to be around 3.4 Mha (Saxena et al. 2018).

Each irrigation method has its benefits, drawbacks, and limitations. Irrigation practices depend on location, water availability, cropping practices, water quality, soil types, topography, climate, and the socioeconomic status of the farmers. Farmers must, therefore, carefully select a way most strongly related to their tradition while suiting the local specific environment (Gopal and Lassaad 2009). Micro-irrigation systems can yield more crops with less water in such water-scarce regions (Rouzaneh et al. 2021). The need for water remains high in the traditional irrigation system of agriculture. Drip and sprinkler irrigation systems save half of the water used for irrigation, but technical, economic, and socioeconomic barriers impede their adoption. Drip irrigation adoption is hampered by cultural traditions, low irrigation water quality, and a lack of market for farm products (Abdelraouf et al. 2020). The adoption of micro-irrigation technologies also enhances water's marginal productivity. With the influence of subsidy schemes that indirectly reduce the marginal cost, demand for irrigation water increases, and a rational farmer continues to consume more water. On the other hand, other innovative scientific methods can be utilized to improve agricultural water use efficiency.

The experiment's capillary week irrigation method is an innovative micro-irrigation technique that provides water according to the crop's needs and is entirely automated (Semananda et al. 2020). Capillary wick irrigation has been utilized to grow crops such as flowering plants and vegetables (Wesonga et al. 2014). Many positive results have been obtained using this method. By developing the procedure and conducting trials, good results can be obtained when utilizing this method to test the viability of additional crops. It is important to understand how the capillary wick irrigation method enhances water flow in the soil. Wetness in the soil was measured in this experiment using the capillary wick irrigation method for black cotton soil. Relative to drip irrigation, these systems are much less expensive, making them accessible to small and medium-scale farmers. On a broad scale, capillary wick irrigation methods required the installation of a cistern and a pipe network to allow for a frequent refill of the setup. Developed using results obtained for temporal changes in parameters of wetting geometry like the horizontal surface wetting width, maximum wetting depth, and maximum horizontal wetting width at a high correlation value. This study conducted laboratory tests, including a capillary rise test and an upward infiltration test, to determine black cotton soil's unsaturated hydraulic conductivity function.

The instantaneous profile technique and wetting have some similarities and differences. The method of front advancing was discussed. The data interpretation, demand specifics, and aspects seen throughout the test process and implementation of the capillary rise and downward infiltration tests were all summarized and examined. The method's flaws and countermeasures were discussed. This technique is better suited for small-scale irrigated agriculture. This technology has no negative environmental effects, is cost-effective, and does not require any electricity to operate. Efficient water management employing this indigenous technology can help alleviate the world's future water issues. The maximum wetted radius at and beneath the soil surface increased. The water and soil samples used in the experiment were tested in the lab to determine the various parameters. The soil moisture is measured using rapid moisture meters.

2 Experimental Section

2.1 Study Area

The agricultural farm in the Surendranagar area of Gujarat state, the localized approach of "capillary wick irrigation" was tested. By road, the experimental site was around 23.0 km from Surendranagar city. In the district's south, southwest, and central regions, the soils may be categorized into three primary categories: medium black soils, red sandy soils, and silty soils. Medium black soils are found at shallow depths (less than 5 m) when the primary rock block's basalts/shale is exposed on the surface. In the central uplands, silty soils may be found in a small strip near the little Rann of Kachchh in the northeast, as well as shallow alluvial tracts and hard rock areas. Cotton accounts for 59% of the district's agricultural production, followed by cereals (12%), sesamum (11%), bajra (8%), and wheat 4%.

2.2 Experimental Setup

To construct and maintain an effective wick irrigation system, it is necessary to understand the wetted breadth, depth, and maximum wetted width under the soil's surface. Black cotton soil, a 7-L P.V.C. pipe, and a wick with a diameter of 1 mm have all been included in the experiment box. Wick discharge and the timing of micro-irrigation may essentially auto-regulate it. In this study, an experimental setup consisting of a cubic container with dimensions 2 $\times$ 2 $\times$ 2 feet was utilized to investigate the temporal behavior of moisture distribution within soil. The focus was on both horizontal and vertical propagation of moisture from a point source located beneath the soil surface. The investigation centered on the temporal variations of key wetting geometry parameters, specifically, the maximum depth of wetting, the maximum width of horizontal wetting, and the width of wetting on a flat surface. Notably, a strong positive correlation was observed among these parameters. To accurately characterize the unsaturated hydraulic conductivity function of black cotton soil, a crucial aspect in this research, the study employed the wetting front advancement technique. This technique involved a series of laboratory tests, including capillary rise experiments and upward infiltration assessments. A comparative analysis was conducted between the primary profile method and the progressive advancement approach for soaking the front. The data interpretation for capillary rise experiments and downward infiltration tests required meticulous attention, necessitating a comprehensive compilation and examination of procedural aspects and practical applications.

Fig. 1 Experimental box

Identifying certain limitations inherent to the method, the study outlined potential remedies for the observed drawbacks. Notably, on one side of the experimental container, acrylic material was integrated to mimic water flow dynamics, thereby enabling real-time monitoring of the phenomenon. This research contributes to the broader understanding of soil moisture dynamics and its hydraulic properties, shedding light on the complex interplay between wetting behavior and soil characteristics. On one side of the experiment box, acrylic was used to simulate water flow that could be observed with the self-monitoring (Fig. 1).

2.3 Laboratory Tests

Soil Quality Test: According to IS 2720 (Part-IV)–1985 and IS 460–1978, a representative soil sample from the farm was analyzed for soil classification. A test for soil nutrients was also carried out on the soil sample. Testing of soil conducted at Gujarat State Fertilizer and Chemicals Limited (GSFCL), Morbi. As part of the recommendations given by GSFCL, mix well-composted compost while preparing the land in consideration of the laboratory's report on the soil sample. Necessary biological

Table 1 Details of quality testing of soil

OC %	0.76
P_2O_5 (kg/Ac)	27.00
K_2O (kg/Ac)	175.00
PH (1:2)	7.98
EC (1:2)	1.39
S ppm	16.20
Zn	1.20 (ppm)
Fe	8.56 (ppm)
Mn	27.94 (ppm)
Cu	1.88 (ppm)

Table 2 Detailed quality of water utilized for irrigation

CO_3	70 (ppm)
HCO_3	466 (ppm)
CL	710 (ppm)
SO_4	602 (ppm)
Ca++	72 (ppm)
Mg	48 (ppm)
Na	775 (ppm)
PH	7.33
Electric conductivity	3060

hazards such as azotobacter and phosphate culture should be used to increase agricultural yield, mix nitrogen, phosphorus, potassium (N.P.K.), and Urea, D.A.P., using such fertilizers is necessary. The report of the minerals present in the soil is given in Table 1, according to the soil testing report.

Water Quality Test: Water quality test was also conducted in GSFCL. The quality report suggested that the utilizing of this water is not recommended for irrigation. This water is harmful to the land and crop. Using this water for irrigation, thoroughly mix the gypsum into the soil. As often as possible, irrigate using the micro-irrigation method to maintain agricultural productivity with the right balance of soil and water. According to the water test report, the minerals in water can be seen in Table 2.

2.4 Wetting Front Movement

Wetting front movement is the horizontal and vertical movement of water in soil. It can be seen from the laboratory test of soil and water that it is possible to make agriculture only by changing the irrigation method and artificial changes in soil

Fig. 2 Rapid moisture meter to measure water moisture in soil

minerals required for agriculture. Irrigation is done by the capillary wick irrigation method. At the same time, this method is used to study how moisture progresses in the soil, and raw crops are grown using the capillary wick irrigation method. Moisture in soil is tested with the rapid moisture meter. The amount of water in a soil sample is calculated using the gas pressure that results from the interaction of calcium carbide (an absorbent) and free water, where soil samples were collected from various depths, the moisture percentage was exclusively in the soil. Only the amount of moisture left in the soil from capillary action was measured after filling the underground storage tank with water (Fig. 2).

3 Results and Discussion

The results of soil nutrient testing and irrigation water quality testing indicated that the electrical conductivity (E.C.) of irrigated water was rather high. Such water is completely improper under regular circumstances. The water's chloride content was unacceptable. Additionally, there was a lot of salt in the water used for irrigation. Wick's exteriors were covered in salt. In addition, there was a reduction in the water diffusion rate via the wick. The strong electrical conductivity of the soil further revealed that the plant's access to water was only marginally constrained. The soil's maximum moisture content, as determined by the moisture measurement instrument, was 12.5%, which is quite close to the amount of moisture that soil of the suitable sand can keep.

Evaporation from the soil may cause reduced moisture content close to the surface. The moisture migration was more vertical than horizontal, as anticipated. Figure 3a–d illustrate the wetting front movement (percent Moisture) at 24, 48, 96, and 360 h, respectively. The moisture was found to be in the soil's field capacity range after 96 h for a depth of between 30 and 50 cm from ground level (G.L.), but not at that level after 24 h. The moisture had not gotten to the depth of 50 cm from G.L. after 24 h. Additionally, after 24 h, the horizontal spread of water from the wick's outer wall was far less than it was after 96 h. The wetness pattern resembled a balloon and reached a depth of 50 cm from the G.L. and a horizontal distance of 30 cm.

It is commonly acknowledged that this depth is an efficient zone for plant roots to draw moisture from the soil. After 96 h, the wetness front had begun to diminish, and after 15 days, it had vanished entirely. The wetting front is significantly influenced by how deeply the wick is buried in the dirt. The depth of the water circulation in the box increases with the depth at which the wick was positioned. The wetting front

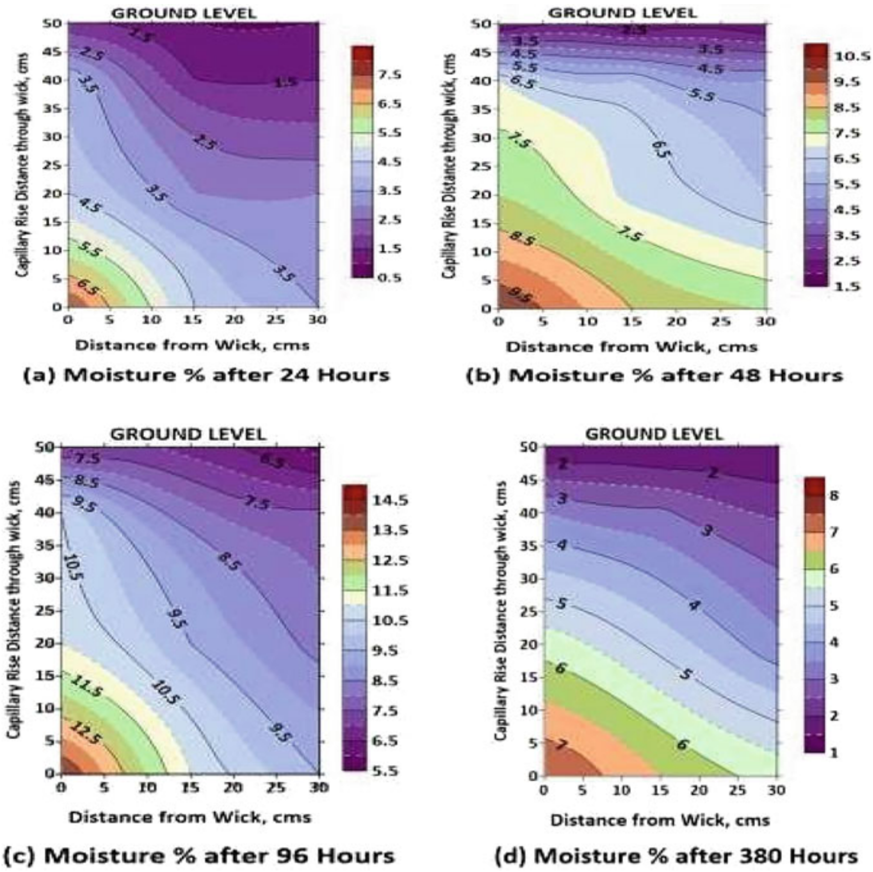

Fig. 3 Moisture level in soil **a** after 24 h. **b** after 48 h. **c** after 96 h. **d** after 360 h

obtained by the current depth used for the experiments was sufficient for crops with shallow roots, such as peas (root depth of 30–50 cm). It is advised that the farmer conducts a small experiment using a few wicks and the open excavation/pit method. This will allow the farmer to gauge the extent of moisture movement horizontally and vertically.

Broken pots or capsules may interfere with irrigation systems and reduce output in rocky soils, where capillary wick irrigation is difficult. It might be challenging to grow some plants with extensive root systems using this method. The clay pots and capsules could be hard to get or make. Small-scale agriculture is more suited for the usage of capillary wick irrigation. Contrarily, it is important to remember that rainwater harvesting may be used to collect enough water for the entire season in locations with scarcity (Bhatt et al. 2018). The essential aspect of the capillary wick irrigation approach is that it operates without electricity, has no adverse effects on the environment, and is affordable. The technique can be extremely helpful in resolving the water crisis. It can also improve the farmers' economic situation, reducing the number of small and marginal farmer suicides in the nation. Only 0.5% of households in India farm on more than 10 ha of land, and most farmers are typically small-scale or marginal farmers (Dagar et al. 2021).

4 Conclusions

As per the experiment, crop root zone depth up to 30–60 cm can be irrigated using the capillary wick irrigation technique, keeping soil moisture solely in effect. Even in places with the adverse condition of soil and water resources, it will be feasible to cultivate using the capillary wick irrigation method. The capillary process speeds up as the depth of the plant's roots grows. The crop will self-regulate as per water requirement of crop. Using this technique, it is essential to recognize row crops where plants thrive. Some shallow-rooted vegetable crops, such as celery, lettuce, onions, potatoes, and radish, as well as some moderately deep-rooted vegetable crops, such as broccoli, beans, cabbages, carrots, cauliflower, cucumbers, muskmelon, peppers, tomatoes, and zucchini, can be grown by using a capillary wick irrigation technique. This is due to the moisture distribution observed under capillary wick irrigation for alkaline soil using saline water for irrigation. In the future, these techniques can be utilized in farm and different types of soil with different types of crops to optimize the water and to save the water during irrigation.

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