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IDENTIFYING SOIL INFILTRATION USING BLOCKED FURROW INFILTROMETER

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ABSTRACT

An essential part of effective water management in agriculture is infiltration, or the process of water entering the soil profile. The rate of infiltration is a critical measure for crop water delivery at a given irrigation interval since factors such as soil characteristics, antecedent soil moisture, and cultivation techniques impact it. Crop production is adversely affected by inefficient infiltration since it reduces the amount of water available to crops and increases runoff rates, which in turn cause soil erosion, organic matter loss, and nutrient depletion. Moreover, pollutants and sediments produced by soil erosion have the potential to impair the quality of existing water supplies. Increasing water use efficiency in agriculture is crucial because freshwater resources are limited. This study explores soil infiltration's vital role in water management by emphasizing the use of a blocked furrow infiltrometer. In particular, a blocked furrow infiltrometer is used in this study to assess the soil infiltration characteristics of a field that receives irrigation using furrows. The study highlights the value of wide ridges for water conservation and stresses the importance of using them for long-term, sustainable water resource management. The study also emphasizes the soil infiltration rate of a furrow and determines cumulative infiltration into a furrow.

Keywords: Infiltration, water management, blocked furrow, cumulative infiltration

1. Introduction

The scarcity of water stands as a significant menace to contemporary crop production. The ramifications of water stress are anticipated to impact various agricultural processes, with the potential for increased repercussions under evolving climatic conditions (Zaib et al., 2023). Infiltration is the movement of water into a soil profile. The rate at which infiltration occurs is controlled by the inherent properties of the soil, antecedent soil moisture prior to irrigation, and different cultivation methods applied for crop production (Shmuel 2013). Infiltration rates play an important role in managing water for irrigation because it determines the soil's ability to fulfill crop water demand in a given irrigation interval and also affect runoff rates, leading to accelerated soil erosion and the loss of organic matter and nutrients, which negatively impact crop production (W. R. Gardner et al., 1970). Soil tillage has the potential to lead to a depletion of organic matter in the soil. The act of tilling can bring about changes in the physical structure of the soil, expediting the breakdown of organic materials, especially when performed intensively or frequently (Zaheer et al., 2023). The sediments and contaminants caused by soil erosion influence the quality of available water resources (Poesen, J. 1986). Therefore, this study was planned to determine the soil infiltration properties of a furrow-irrigated field.

Many experiments show that wide ridges laid in the field are more effective in saving water than other small ridges. Water is the most important input in agriculture. The available fresh water resources are scarce so it is important to utilize its efficiency. The losses needed to be controlled in the whole irrigation system starting from its sources till the final application for crop production. Some of the surface irrigation methods commonly used in Pakistan are flat basins, furrow beds, and border irrigation.

A flat basin is comprised of a flat area of land surrounded by low bunds. The bunds prevent the water from flowing to the adjacent fields. In general, the basin method is suitable for crops that are unaffected by standing in water for long periods (e.g., 12-24 hours). Flat basin irrigation is generally not suited to crops that cannot stand in wet or waterlogged conditions for periods longer than 24 hours. The size of the bund for the basin is also influenced by the depth (in mm) of the irrigation application. If the required irrigation depth is large, the bund height should be large. Similarly, if the required irrigation depth is small, then the basin should be small to obtain good water distribution (D.L. Bjorneberg 2013)

There are two methods to supply irrigation water to the basins. The direct method, in which the water is led directly from the field channel into the basin through siphons, spiles or bundbreaks. The second is the cascade method on sloping land, where terraces are used and the irrigation water is supplied to the highest terrace, then allowed to flow to a lower terrace, and so on. Borders are long, sloping strips of land separated by bunds. They are sometimes called border strips. Irrigation water can be fed to the border in several ways: by opening up the channel bank, using small outlets or gates, or by means of siphons or spiles. A sheet of water flows down the slope of the border, guided by the bunds on either side (D.L. Bjorneberg 2013). Furrows are small channels that carry water down the land slope between the crop rows. Each furrow is irrigated individually. Water infiltrates into the soil as it moves along the slope. The water also moves laterally. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops and for crops that cannot stand in water for long periods (e.g., 12-24 hours). Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate. Average water saving by furrow irrigation is up to 32% as compared to border irrigation (Khan et al., 1998).

Many factors may affect soil infiltration. These include soil texture, soil structure, initial moisture content, surface sealing, crusting, air entrapment, etc. Soil porosity and pore size distribution are the main factors that determine soil infiltration. Similarly, the surface area, size, and shape of soil particles influence pore size, shape, and continuity with other pores. The chemical and physical nature of the sediments, the head of the applied water, the depth of the groundwater, the chemical quality and turbidity of the applied water, and the temperature of the water and the sediments also influence the infiltration rate.

Although particle size and particle distribution may be major determinants of infiltration rates, i.e. the pore size distribution is modified by organic matter content, aggregation, tillage, compaction vegetation, and land use (Walker and Skogerboe, 1987).

Numerous methods have been developed for measuring the infiltration rates of soils in the field. Classified infiltration measurement techniques for irrigation purposes that use stagnant or ponded water conditions (cylinder infiltrometer and blocked furrow infiltrometer), those that use flowing water (furrow and border infiltrometer), and prediction from measurement of water advance (Abdel wahab, et. al 2000). However, the following methods for measuring soil infiltration are commonly used in Pakistan: The single-ring apparatus typically consists of a cylindrical ring 30 cm or larger in diameter that is driven about 5cm into the soil. The upper surface of the ring is often covered to prevent evaporation. The volumetric rate of water added to the ring sufficient to maintain a constant head within the ring is measured. Alternatively, if the head of water within the ring is relatively large, a falling head type test may be used, wherein the flow rate, as measured by the rate of decline of the water level within the ring, and the head for the later portion of the test are used in the calculations. Infiltration data is terminated after the flow rate has approximately stabilized (Bouwer et., al 1986). The infiltrometer is removed immediately after termination of infiltration, and the depth to the wetting front is determined either visually, with a penetrometer-type probe, or by moisture content determination for soil samples.

The double-ring infiltrometer is another way of measuring water infiltration. It consists of an inner and outer ring inserted into the ground. Infiltration can be estimated for the soil when the water flow rate in the inner ring is in a steady state. The rate of infiltration is determined by the amount of water that infiltrates into the soil per surface area per unit of time. A double-ring infiltrometer is preferred because the outer ring helps reduce the error that may result from lateral flow beneath the ring. Each ring is supplied with a constant head of water, either manually or from Marriott bottles. The outer ring facilitates the downward vertical flow of water within the inner ring, simplifying calculations by eliminating the necessity to consider lateral flow. Lateral flow is the most serious limitation to the use of single-ring infiltrometer (Hills 1971). The major components of the ponded infiltrometer are a Mariotte reservoir, a valve base, a containment ring, and a tripod (Prieksat et al., 1992). Optionally, a data logger connected to two pressure transducers at the top and base of the water column can be used for automating the water flow measurements. Prieksat et al., 1992 describe the design for an automated, self-regulating ponded (single-ring) Infiltrometer. Commonly, the water reservoir and the base are constructed of plastic polycarbonate. A rubber stopper is used to seal the top of the reservoir after filling. Pressure, created by pushing the stopper into the reservoir, starts water flow out of the base when the base valve is opened. The base consists of a bubble chamber and bubbling tube, a high-flow air-impermeable nylon membrane, two ports, and a two-port valve. The bubble tube regulates the height of water ponded on the soil to +/-1mm. The bubble tube is adjusted up or down within the bubble chamber to raise or lower, respectively, the height of the ponded water in the ring from 0.5 to 1.0 cm. This means that the water level in the containment ring can be adjusted without having to raise or lower the entire Mariotte reservoir, as required by previous designs. Because water flow from the device is partly determined by the ponded water height, water heights of < 1.0 cm will minimize the size of the water reservoir required to make infiltration measurements.

The ponded infiltrometer is a variant of a single-ring infiltrometer. (Bouwer 1986) stated that cylinder infiltrometers are typically 0.30m in diameter but that infiltrometers of 1m in diameter or greater should be used to obtain meaningful results. However, driving large cylinders into most soils may disrupt soil macrospores and other structural features affecting infiltration. Soil variability necessitates infiltration measurements at many locations to characterize infiltration accurately on a field scale. Because of the size and set-up time required for existing cylinder infiltrometers, infiltration measurements at multiple sites are difficult to obtain in a reasonable length of time.

In blocked furrows, a section of the furrow is blocked and water is added to it. The record of water addition and time is kept until the rate of water infiltration reaches a steady state. The accuracy of water addition and change in profile soil moisture is checked through soil moisture monitoring using the gravimetric method. Some factors can influence soil infiltration rates in furrows. For instance, furrow compaction (Kemper et al., 1982) can reduce furrow infiltration, while an increase in the wetted perimeter of the furrow may increase the furrow infiltration rate (Ramsey, 1976; Fangmeier and Ramsey, 1978).

In our study, we selected the blocked furrow method because of its simplicity, accuracy, availability of equipment, and suitability for a furrow-irrigated field. Moreover, the wetting front is distinct, easily determined and resembles actual field conditions. This method takes two-dimensional infiltrations by allowing both horizontal and vertical components of infiltration to occur.

2. Material and Methods

This study was conducted in a furrow-irrigated field with maize crops at the NARC farm. The soil type was sandy clay lam. The maize crop was at the establishment stage when the experiment was conducted. The main equipment used during the experiment were steel plates, measuring tape, scales, 14-liter cans for adding water, a graduated cylinder of 1-liter size, a plastic sheet, a king tube 120cm, cans for collection of samples, a weighing scale, marker, tape, note pad, stopwatch, electric oven, etc.

The experiment commenced by adding water to a 2 m section of a furrow isolated with steel sheets on both sides inserted in such a way that seepage from the sides is blocked. This set-up was replicated three times. The three blocked furrow sections were covered with polythene sheets, and a measured quantity of water was added to fill the furrows to a marked position. After filling the water, all three polythene sheets were carefully removed by sliding them below the standing water to ensure spelling correct flow of water. The water level in the furrow at furrow full was marked using scales immediately after sliding the polythene sheets in all three replicates.

The water level, set at the condition of a full furrow, remained consistent throughout the experiment by consistently replenishing water until a stable infiltration rate was attained at the end of the experiment. Whenever the water level deviated from its initial position, cans of a predetermined volume were introduced, and this procedure was sustained for multiple hours. The recorded data includes soil moisture profiles (0-100 cm) before and after the experiment at the depth of 0-15 cm, 15-30 cm, 30-60 cm, and 60-100 cm. Measurements were taken at different locations within the furrow, including the furrow center, bed edge, and bed middle. Additionally, data on the initial bed furrow configuration (e.g., top width, middle width, bottom width, and depth), water input, and time were recorded for each furrow section throughout the experiment. The soil samples were immediately weighted to avoid loss of soil moisture and were kept in an electric oven for more than 48 hours at 105^{0}C. The dry samples were re-weighted and the weight of each can was determined separately.

The gravimetric soil moisture was calculated using the following formula 1:

$$W\,(\%) = \frac{(\text{Soil mass (wet)} - \text{Soil mass (dry)})}{\text{Soil mass (dry)}} \text{X } 100\% \quad --- \; 1$$

The gravimetric soil moisture was converted to volumetric soil moisture or water depth by multiplying it with the bulk density of the corresponding layer.

The soil infiltration rate was calculated by dividing the volume infiltrated by the time of infiltration. This calculation determined the soil infiltration rate. Then adding the total volume of water infiltrated at different time intervals gives the cumulative infiltration during the experimental period.

The data was plotted using Excel spreadsheet. The experimental field conditions are shown in Figure 1.

Figure 1. Experimental field conditions at NARC Farm Islamabad

3. Results and Discussion

3.1. Bed furrow configuration

The dimension of furrows at the time of the experiment is presented in table 1. The data showed that the furrows were deeper at this early stage of crop growth because no prior irrigation, sedimentation, and other seasonal changes did not reduce the furrows sizes yet.

Table 1. Bed and Furrow sizes at the time of experiment

Parameter	Furrow Dimensions (cm)				
	T.W	M.W.	B.W.	T.D	Spacing
Average (cm)	56	30	12	16	130
*SD	3	2	1	2	0

*SD = standard deviation

3.2. Soil moisture before and after the experiment

The results show nearly uniform soil moisture across the bed (furrow center to bed middle) before the experiment. However, soil moisture tends to increase towards bed edge as compared to bed middle after the experiment. This shows greater absorption of water near the bed edge than the bed middle.

Results showed 21% greater and 17% less soil moisture absorption near the bed edge and bed middle respectively.

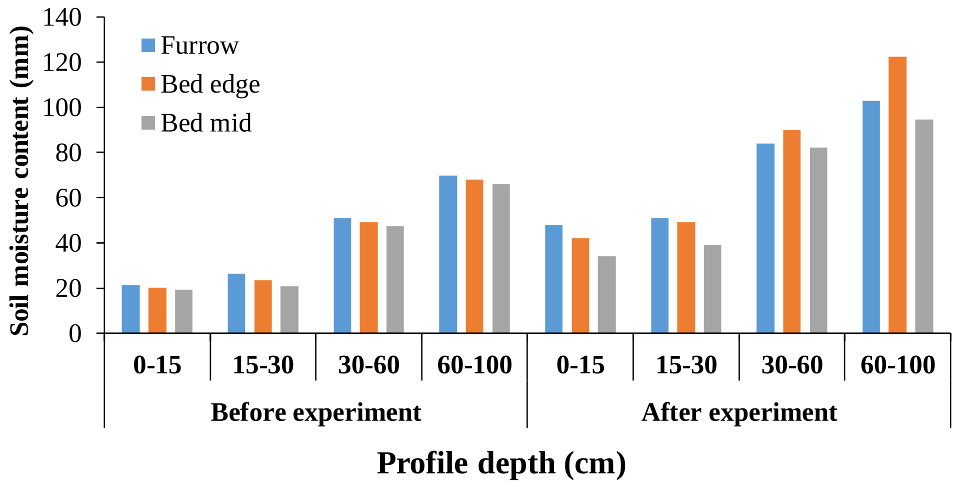

Figure 2. The soil moisture before and after the experiment determined at the furrow centre, bed edge, and bed middle. The X-axis represents the Profile depth in (cm) while the Y- axis represents the soil moisture of the 100 mm profile before and after the experiment.

3.3. Soil infiltration rate

The soil permeability rate graphed over time demonstrated a higher rate of infiltration at the beginning of the experiment, followed by a gradual decline until the experiment's conclusion the final steady state infiltration (0.12 cm/hr) was identified at around 5 hours after the start of the experiment. The detailed data is given in Appendix 1.

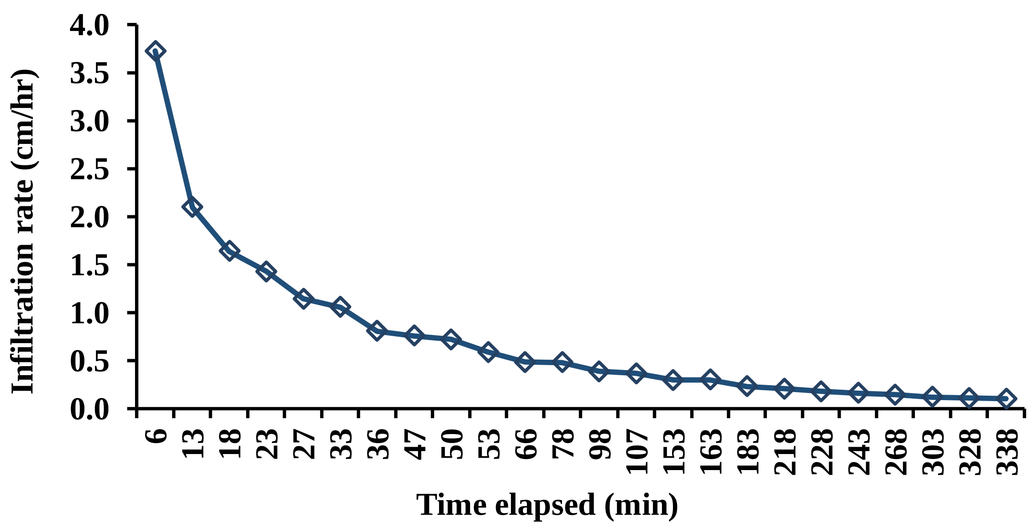

Figure 3. The soil infiltration rate plotted with time elapsed showed a greater infiltration rate when the experiment commenced and then dropped gradually till the end of the experiment as displayed. The X-axis represents the time elapsed in minutes while Y- axis represents the Soil infiltration rate in cm/hr per 1 m furrow length and average furrow width.

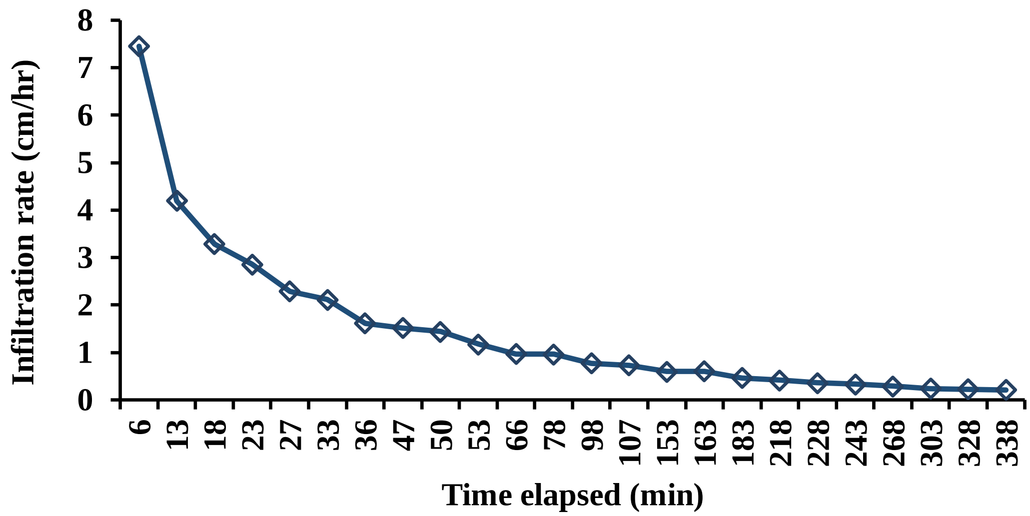

Figure 4. The soil infiltration rate for 2 m furrow length is shown where the X-axis represents the time elapsed in minutes while Y- axis represents the infiltration rate in cm/hr per 2 m furrow length and average furrow width.

Comparison of Figure 3 and 4 indicate that increasing the furrow length increased the infiltration rate and the rate of increase is proportional to the furrow length

3.4. Soil cumulative infiltration

The cumulative infiltration of 1 m furrow length and furrow width area in cm showed a constant increasing trend. However, this increase was greater during the early time of the experiment as compared to the latter stage when the infiltration rate reached the steady state condition.

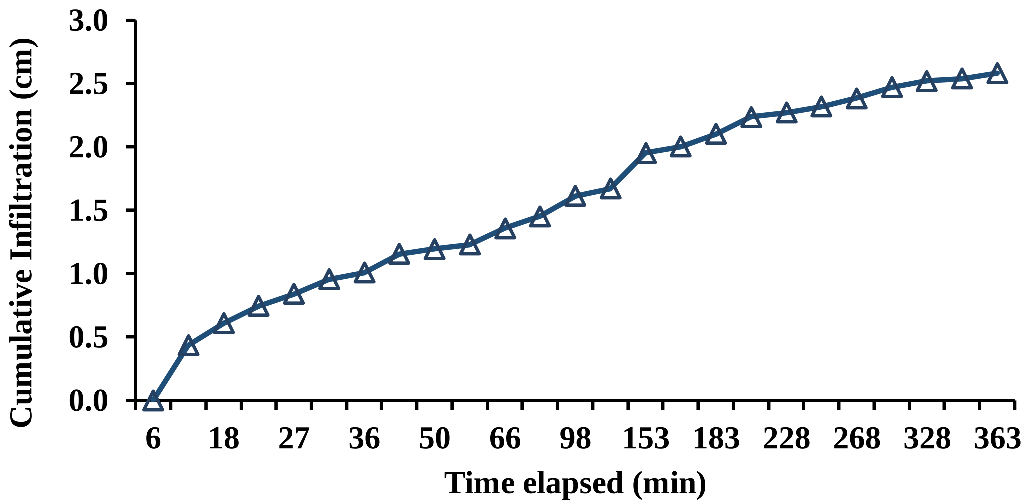

Figure 5. The cumulative infiltration of 1 m furrow length and furrow width area in cm plotted against time. The X-axis represents the time elapsed in minutes while Y- axis represents the cumulative infiltration in cm into 1 m furrow length and furrow width.

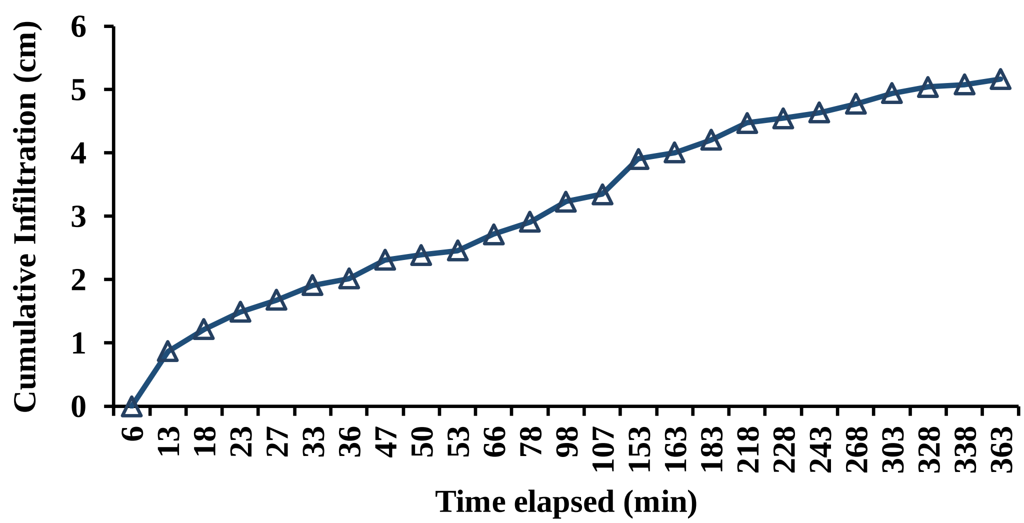

Figure 6. Cumulative infiltration into 2m furrow length and average furrow width. The X-axis represents the time elapsed in minutes while Y- axis represents the cumulative infiltration in cm into 2m furrow length and average furrow width.

Discussion

Soil infiltration is an essential parameter in irrigation management. Assessing soil infiltration poses a significant challenge in irrigation studies, primarily because the selection of the technique for determining infiltration model parameters is crucial. Moreover, the choice of the technique to determine soil infiltration characteristics must align appropriately with the study's objectives (Holzapfel et al., 1988: Walker and Busman, 1990). Social conduct is one component contributing to greater than predicted demand and inefficient water usage, which is related to the dearth of an integrated assessment of environmental and cognitive factors that affect water use activity (Ali zeshan et al., 2023).If irrigation is applied more than the soil infiltration rate then the soil will not absorb the applied water and runoff may occur. This will cause loss of water and will make the irrigation inefficient. Similarly, if the irrigation application is not optimized to account for the infiltration rate influenced by specific field conditions, it will impact the uniformity of irrigation advance, leading to uneven fulfillment of crop water requirements across the field. (Akbar, McHugh, et al. 2011). Therefore, determining soil infiltration in the field is important in irrigation management. In furrow irrigation, the volume of infiltrated water is influenced by both the shape and dimensions of the furrow. This is due to the fact that an increase in size leads to a greater water perimeter and a larger contact area between the soil and water within the furrow (Trout, 1992). By increasing the furrow length twice, will increase the cumulative infiltration by 100%. The largest infiltration values are obtained from the advanced infiltration technique while the lowest are obtained from the one-point method, which is in agreement with the results of Esfandiari and Maheshwari (1997). Fangmeier and Ramsey (1978) demonstrated a linear correlation between intake rate and wetted perimeter in precision-made furrows. In the investigations conducted by Izadi and Wallender (1985), it was observed that, in both stagnant and flowing blocked furrow tests, infiltration rates exhibited a positive correlation with wetted perimeter. Additionally, cumulative infiltration was found to be correlated with wetted perimeter only in the stagnant tests. In this study, the blocked furrow infiltrometer method was used. This approach enhances comprehension of the soil infiltration phenomena, by accurately calculating the cumulative infiltration and soil infiltration rate. This method enables the recording of both lateral and vertical movements of water. Furthermore, employing this technique allows for a comprehensive consideration of soil moisture measurement, equipment usage, and data analysis. This preliminary analysis was conducted and the results achieved conform to the general trend line of soil infiltration rate and cumulative infiltration curves in literature (Philip 1969).

Conclusions

The distribution of soil moisture was found to be uneven among the furrow, bed edge, and bed middle. Particularly the bed edge received ~21% larger and the bed middle 17% lesser soil moisture when compared with the furrow However, soil infiltration evaluated in the field using the blocked furrow infiltrometer method adequately quantified the soil infiltration rate and cumulative infiltration. The soil infiltration rate varied from 3.75 cm/hr to 0.12 cm/hr per 1 m furrow length and the steady-state infiltration rate was 0.12 cm/hr for 1 m furrow Length. Meanwhile, the cumulative infiltration curve depicted increased infiltration with the increase in time of wetting and a total of 2.5 cm of infiltration was identified for 1 m furrow length in five hours of wetting time. In addition, it was also observed that increasing the furrow length increased the infiltration rate and cumulative infiltration. On a smaller scale, the blocked furrow method can be used, taking into account the possible variation in soil texture within the furrow. Although the blocked furrow method works better than the water inflow and outflow method for determining infiltration rates, it is essential to note that in terms of accuracy, the blocked furrow method falls short of the precision achieved by the ring infiltrometer or double-ring infiltrometer methods.

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Appendix 1: Data analysis and details of infiltration calculations

S.N	Time (Pst)	Time (hrs)	Time elap (min)	Volume (cans)			Volume added (litres)			Infiltration rate (lit/min)/ 2m				Infiltration rate (cm/hr)/ 2m furrow length				
				a	b	c	a	b	c	a	b	c	Ave	a	b	c	Ave	STDEV
1	11:42	0.00	0	8.00	8.00	8.00	112.00	112.00	112.00									
2	11:48	0.10	6								0.00	0.00		0.000	0.000	0.000	0.000	0.00
3	11:55	0.22	13	1.25	1.35	1.25	17.50	18.90	17.50	1.35	1.45	1.35	1.38	7.085	7.788	7.479	7.451	0.35
4	12:00	0.30	18	1.00	1.00	1.00	14.00	14.00	14.00	0.78	0.78	0.78	0.78	4.094	4.167	4.321	4.194	0.12
5	12:05	0.38	23	1.00	1.00	1.00	14.00	14.00	14.00	0.61	0.61	0.61	0.61	3.204	3.261	3.382	3.282	0.09
6	12:09	0.45	27			1.00			14.00	0.53	0.53	0.52	0.53	2.815	2.866	2.881	2.854	0.03
7	12:15	0.55	33	1.00	1.00	1.00	14.00	14.00	14.00	0.42	0.42	0.42	0.42	2.233	2.273	2.357	2.287	0.06
8	12:18	0.60	36		1.00	1.00		14.00	14.00	0.40	0.39	0.39	0.39	2.090	2.083	2.160	2.111	0.04
9	12:29	0.78	47	1.00	1.00		14.00	14.00		0.30	0.30	0.33	0.31	1.568	1.596	1.685	1.616	0.06
10	12:32	0.83	50			1.00			14.00	0.28	0.28	0.28	0.28	1.479	1.523	1.556	1.519	0.04
11	12:35	0.88	53	1.00			14.00			0.26	0.27	0.27	0.27	1.390	1.451	1.485	1.442	0.05
12	12:48	1.10	66		1.00	1.00		14.00	14.00	0.23	0.21	0.21	0.22	1.209	1.136	1.178	1.175	0.04
13	13:00	1.30	78	1.00	1.00	1.00	14.00	14.00	14.00	0.18	0.18	0.18	0.18	0.945	0.962	0.997	0.968	0.03
14	13:20	1.63	98	1.25	1.25	1.25	17.50	17.50	17.50	0.18	0.18	0.18	0.18	0.940	0.957	0.992	0.963	0.03
15	13:29	1.78	107	1.00	1.00	1.00	14.00	14.00	14.00	0.13	0.13	0.13	0.13	0.900	0.701	0.727	0.776	0.11
16	14:15	2.55	153	1.45	1.50	1.50	20.30	21.00	21.00	0.13	0.14	0.14	0.14	0.698	0.735	0.763	0.732	0.03
17	14:25	2.72	163	1.35	1.25	1.25	18.90	17.50	17.50	0.12	0.11	0.11	0.11	0.610	0.575	0.596	0.594	0.02
18	14:45	3.05	183	1.50	1.45	1.45	21.00	20.30	20.30	0.11	0.11	0.11	0.11	0.604	0.594	0.616	0.605	0.01
19	15:20	3.63	218	1.50	1.25	1.25	21.00	17.50	17.50	0.10	0.08	0.08	0.09	0.507	0.430	0.446	0.461	0.04
20	15:30	3.80	228		1.00	1.25		14.00	17.50	0.00	0.06	0.08	0.05	0.486	0.329	0.426	0.414	0.08
21	15:45	4.05	243	1.50	1.00	1.00	21.00	14.00	14.00	0.09	0.06	0.06	0.07	0.455	0.309	0.320	0.361	0.08
22	16:10	4.47	268	1.50	1.00	1.00	21.00	14.00	14.00	0.08	0.05	0.05	0.06	0.412	0.280	0.290	0.327	0.07
23	16:45	5.05	303	1.50	1.00	1.00	21.00	14.00	14.00	0.07	0.05	0.05	0.05	0.365	0.248	0.257	0.290	0.07
24	17:10	5.47	328		1.00	1.00		14.00	14.00	0.00	0.04	0.04	0.03	0.260	0.229	0.237	0.242	0.02
25	17:20	5.63	338	1.00	1.00	1.00	14.00	14.00	14.00	0.04	0.04	0.04	0.04	0.218	0.222	0.230	0.223	0.01
26	17:45	6.05	363	1.00	1.00	1.00	14.00	14.00	14.00	0.04	0.04	0.04	0.04	0.203	0.207	0.214	0.208	0.01

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Infiltration per 1 m furrow length					
Ave. Infil. Rate (cm/hr)	Stdev	Ave Cum Infil (cm)	Stdev	Ave. Infil. Rate (lit/hr)	Ave Cum Infil (lit)
3.725	0.176	0.435	0.021	41.46	4.837
2.097	0.058	0.609	0.023	23.33	6.782
1.641	0.045	0.746	0.025	18.26	8.303
1.427	0.017	0.841	0.026	15.88	9.362
1.144	0.032	0.956	0.028	12.73	10.635
1.056	0.021	1.008	0.029	11.75	11.222
0.808	0.031	1.157	0.033	9.30	12.928
0.760	0.019	1.195	0.034	8.45	13.350
0.721	0.024	1.231	0.035	8.07	13.754
0.587	0.018	1.358	0.032	6.58	15.179
0.484	0.013	1.455	0.035	5.38	16.256
0.481	0.013	1.615	0.039	5.36	18.042
0.388	0.054	1.673	0.031	3.93	18.631
0.366	0.016	1.954	0.044	4.07	21.753
0.297	0.009	2.003	0.043	3.31	22.304
0.302	0.006	2.104	0.044	3.37	23.426
0.231	0.020	2.239	0.036	2.57	24.924
0.207	0.040	2.273	0.035	1.38	25.154
0.181	0.041	2.318	0.030	2.02	25.659
0.164	0.037	2.387	0.029	1.83	26.420
0.145	0.033	2.471	0.038	1.62	27.364
0.121	0.008	2.521	0.040	0.85	27.719
0.112	0.003	2.540	0.040	1.24	27.927
0.104	0.003	2.583	0.041	1.16	28.409