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Effect of Different Design Parameters of Furrow on Irrigation Efficiencies

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This study aims to evaluate the effect of different furrow design parameters on irrigation efficiencies to develop optimized guidelines for sustainable water management in agriculture. The present study was conducted to study the effect of different furrow irrigation designs on irrigation efficiencies and growth parameters of the okra crop. The experiment was carried out at the experimental field of the Department of Land and Water Management, Faculty of Agricultural Engineering and Technology, Sindh Agriculture University, Tandojam. There were four treatments and three replications. Bed widths were considered as treatments; T_1 =0 .5m, T_2 =0.6m, T_3 =0.7m and T_4 =0.8 m. The furrow length was kept at 30 m in each treatment. The height of each ridge was set to 0.5 m, and the overall plot area was 399 m^2. Soil samples were collected at the soil depths of 0–10, 10-20, 20-30, 30-40, and 40–50 cm from the field pre- and post-experiment, to determine density, texture, and soil moisture content. The soil samples were analyzed in the laboratory of the Department of Land and Water Management. The field trial was continued for 28 days with an irrigation interval of 7 days. After 24 hours of water application, the data was collected. The trend of the wetting pattern of the moisture was the same under T_1, T_2, T_3, and T_4, respectively. The maximum moisture content was found at the head of the furrow. The moisture content decreased at the lower side due to the slope of the soil. In this study, the application efficiency is good to better under all the treatments of furrow design. The application efficiency, storage efficiency, and distribution uniformity increased was good under T_4 as the width of the furrow increased, but these decreased as the length of the furrow increased. The yield of the crop increased under T_3 and T_4 as compared with T_1 (control). On the basis of the study, it is recommended that T_4 be adopted for cultivation okra crop, because application efficiency, storage efficiency, distribution uniformity, and crop yield were maximum under this treatment.

Keywords: Design Parameters, Furrow, Irrigation, Efficiencies

Introduction:

Efficient water management through optimized furrow irrigation is crucial for sustainable agriculture, especially in arid and semi-arid regions where water scarcity threatens crop productivity [1][2]. Furrow irrigation performance depends critically on design parameters such as furrow width, bed dimensions, furrow length, inflow rate, slope, and cut-off time [3][4]. While prior research has explored modeling tools like WinSRFR and AQUACROP to simulate these factors [1][2], field-based experimental studies that directly test bed width and furrow length under controlled cropping conditions remain limited. Bed width and furrow geometry significantly influence soil moisture distribution, infiltration, and crop response [3][1]. Optimizing ridge–furrow ratios has been shown to enhance soil water consumption, root growth, crop yield, and water use efficiency in wheat systems [3]. Likewise, variations in furrow bottom width and depth exert marked effects on irrigation uniformity, advance and recession times, and percolation losses [4]. Modeling studies using decision-support platforms such as WinSRFR have identified interactions among furrow length, inflow rate, cut-off time, and storage efficiency. For instance, reducing furrow length and increasing inflow rate enhanced application efficiency and distribution uniformity, while longer furrows tended to increase deep percolation losses and reduce uniformity. Despite these insights, most research remains model-based or limited to specific contexts like maize or wheat. Field trials evaluating the effect of bed width variation on irrigation metrics such as application efficiency, storage efficiency, distribution uniformity, and crop yield, especially for horticultural crops like okra, are sparse. In Ethiopia, work on maize under varying furrow irrigation systems demonstrated that conventional furrow irrigation with deficit regimes could improve water use efficiency significantly (up to 2.80 kg m^{-3}) while maintaining yields. Other studies in the North Nile Delta compared cut-off versus tailwater reuse methods for canola and reported that application efficiency exceeded 90% when design parameters were optimized [2]. A recent review also highlights that field traffic (e.g., tractor compaction) can significantly influence infiltration rates and runoff in furrow systems, decreasing irrigation uniformity [5]. However, systematic trials manipulating bed widths under controlled slope and soil texture conditions remain under-represented in the literature. Furthermore, while modeling studies emphasize cut-off timing and inflow management, few experiments couple these with furrow geometry in live cropping systems. The present study addresses these gaps by experimentally evaluating the effect of four selected furrow bed widths (0.5 m, 0.6 m, 0.7 m, and 0.8 m) on irrigation efficiencies and growth of okra under standardized field conditions in Sindh, Pakistan. Soil moisture profiles were monitored at multiple depths (0–10 cm to 40–50 cm), and the irrigation interval was set uniformly at 7 days over a 28-day cycle. Metrics assessed include application efficiency, storage efficiency, distribution uniformity, wetting patterns, and yield responses. This research builds upon and extends prior findings in several ways: It applies to okra, a horticultural crop less commonly studied in hydro-engineering irrigation research, supplementing the bulk of studies focused on cereals like maize and wheat [1][3][2]. Whereas many studies rely on simulation, this work is an in-situ field trial with replication across treatments. Simultaneously analyzes bed width, soil moisture stratification, irrigation scheduling, and crop growth metrics. Conducted in semi-arid conditions of Sindh, Pakistan, where water scarcity necessitates efficient irrigation design, echoing the urgency expressed in regional studies [1][2]. Accordingly, this study aims to generate practical guidelines for setting ideal bed width and furrow geometry to maximize irrigation efficiency and okra yield under field conditions. The results may inform farmers and extension services in resource-scarce regions by identifying configuration(s) that offer the best trade-off between water use and productivity. By doing so, the research contributes new empirical evidence to the global body of furrow irrigation optimization literature and supports sustainable agricultural water management.

Objectives:

To determine the soil moisture distribution patterns of different designed furrow irrigation methods.

To evaluate the irrigation efficiencies under different designed furrow irrigation methods.

Novelty Statement:

This study presents a novel investigation into the optimization of furrow irrigation design by analyzing the impact of varying bed widths on irrigation efficiencies and crop response, specifically focusing on okra cultivation. Unlike previous studies that primarily evaluate irrigation methods in general terms, this research offers a detailed comparative assessment of furrow configurations (T1–T4) under uniform environmental conditions. Conducted at Sindh Agriculture University, Tandojam, this study uniquely integrates soil moisture distribution profiling at multiple depths and evaluates both irrigation efficiency metrics and crop performance over a fixed irrigation schedule. The findings reveal a direct correlation between increased bed width (up to 0.8 m) and improvements in application efficiency, storage efficiency, distribution uniformity, and yield. This work contributes new, field-based evidence supporting the use of wider furrows (T4) as a sustainable and efficient irrigation practice for okra, potentially guiding future furrow irrigation strategies in semi-arid regions.

Materials and Methods:

Flow Diagram:

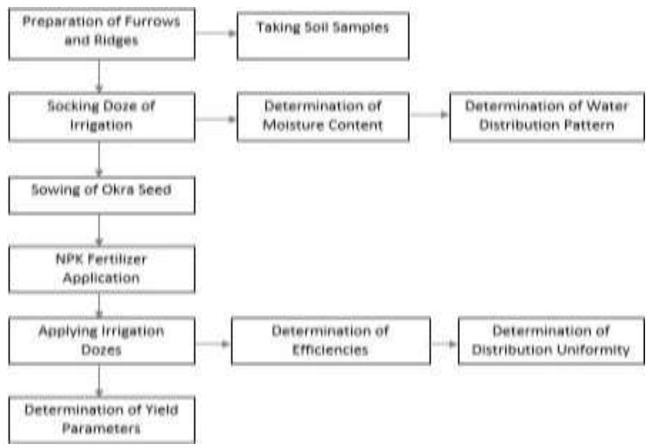

Figure 1. Flow diagram

Experimental Location:

The experiment was carried out at the experimental field of the Department of Land and Water Management, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam. The study area is located at 25.4281° N, 68.5307° E, and has an elevation of 23 m.

Experimental Setup and Crop Sowing:

The field experiment was conducted with four treatments and three replications Figure 2. The bed width was considered as a treatment: T_1 0.5 m (Control), T_2 0.6 m, T_3 0.7 m, and T_4 0.8 m. The furrow length was kept at 30 m in each treatment. The height of each ridge was set to 0.5 m, and the overall plot area was 399 m^2. The okra crop was sown on both sides of the ridges by hand. The recommended dose of NPK was applied twice. A total of four irrigations were applied, 7 DAS, 14 DAS, 21 DAS, and 28 DAS, having the same interval.

Soil Sample Collection and Analysis:

Soil samples were collected pre- and post-experiment, at soil depths of 0–10, 10-20, 20-30, 30-40, and 40–50 cm from the field to determine density, texture, and soil moisture content. The soil samples were analyzed in the laboratory of the Department of Land and Water Management, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam.

Irrigation Application:

The field trial was continued for 28 days with an irrigation interval of 7 days. After 24 hours of water application, the data was collected.

Soil Moisture Analysis:

For the determination of the soil moisture content of the field, the soil samples were taken from the field at two depths, 0-30 and 30-60 cm. To determine the soil moisture content, the wet weight of soil samples was taken from the field at each depth and weighed with a digital weight balance. Then, soil samples were oven-dried at 105 ºC for 24 hrs. The oven-dried soil samples were weighed to obtain dried weight, and the gravimetric moisture content of the soil was determined using this equation:

$$\theta\% = \frac{Wwet - Wdry}{Wdry} X100 \quad (1)$$

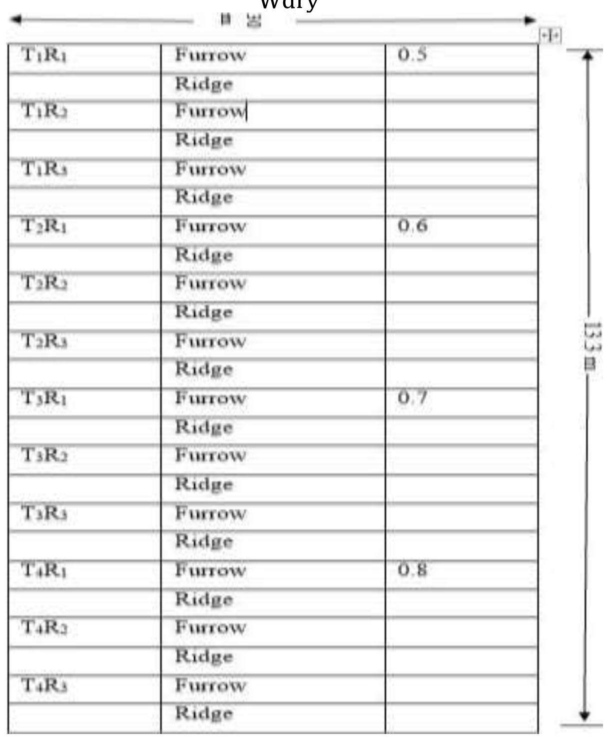

Figure 2. The field layout

Where:
θ %= Moisture content (%),
Wwet = Wet weight of soil (g),
Wdry = Dried weight of soil (g)

Moisture Distribution Pattern:

Soil samples integrated over depths of 0 to 30 and 30 to 60 cm were taken after 22 hours of irrigation to assess the infiltration front and determine the amount of soil moisture content infiltrated during the experiment period. The spacing of auger samples was at a 5 m interval for a 30 m furrow length. This helps to understand the soil moisture distribution and the amount of soil water infiltrated at different root zones. Initial soil moisture samples were also recorded in order to judge the amount of soil water deficit compared to field capacity.

Efficiencies:

Application Efficiencies:

The application efficiency was determined by the following equation, which is given by [6].

$$Ea = \frac{Zs}{Z} \text{ x } 100 \quad (2)$$

Where:
Ea = Application efficiency (%)
Zs = depth of water stored in the root zone (mm),
Z = depth of water applied to the furrow (mm)

Storage Efficiency:

The storage efficiency was determined by the following method, according to [6].

$$Es = \frac{Zs}{Zreq} \text{ x } 100 \quad (3)$$

Where:
Es = storage efficiency (%),
Zs = depth of water stored in the root zone (mm)
Zreq depth of water required to refill the root zone (mm)

Distribution Uniformity:

The distribution uniformity was determined by the following equation, according to [7]

$$Du = \frac{Zmin}{Zav} \times 100 \quad (4)$$

Where:
Du = distribution uniformity (%)
Zmin = the minimum infiltrated depth (mm),
Zav = the mean of depths infiltrated over the furrow length (mm)

Results and Discussions:

Wetting Pattern of Moisture Content Under Different Furrow Designs:

The results of the moisture distribution pattern under T_1, T_2, T_3, and T_4 are shown in Figure 3. The results of moisture distribution represent that at the depth of 0-30 m, the moisture content was 46.06, 33.33, 26.54, 23.10, 20.51, 18.42 and 17.19 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 m respectively under T_1. The highest moisture content was found at 0 m distance, and the minimum at 25-30 m at the depth of 0-30 m. When the moisture content was determined at 30-60 m depth of soil, it was found 17.65, 15.27, 14.37, 14.35, 12.20, 11.67, and 10.52 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm respectively under T_1. The maximum soil moisture pattern was found at a distance of o m, and the minimum moisture content was found at a distance of 25-30 cm. The results of moisture distribution represent that at the depth of 0-30 m, the moisture content was 46.06, 33.33, 26.54, 23.10, 20.51, 18.42 and 17.19 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 m respectively under T_2. The highest moisture content was found at 0 m distance, and the minimum at 25-30 m at the depth of 0-30 m. When the moisture content was determined at 30-60 m depth of soil, it was found 17.65, 15.27, 14.37, 14.35, 12.20, 11.67, and 10.53 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm respectively under T_2. The maximum soil moisture pattern was found at a distance of o m, and the minimum moisture content was found at a distance of 25-30 cm. The results of moisture distribution represent that at the depth of 0-30 m, the moisture content was 52.82, 37.68, 36.90, 34.15, 30.73, 28.87, and 27.27 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 m respectively under T_3. The highest moisture content was found at 0 m distance, and the minimum at 25-30 m at the depth of 0-30 m. When the moisture content was determined at 30-60 m depth of soil, it was found 28.11, 26.29, 24.00, 23.29, 20.25, 18.48, and 16.02 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm respectively under T_3. The maximum soil moisture pattern was found at a distance of o m, and the minimum moisture content was found at a distance of 25-30 cm. The results of moisture distribution represent that at the depth of 0-30 m, the moisture content was 57.25, 40.22, 38.55, 35.80, 30.73, 29.53, and 25.00 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 m respectively under T_4. The highest moisture content was found at 0 m distance, and the minimum at 25-30 m at the depth of 0-30 m. When the moisture content was determined at 30-60 m depth of soil, it was found 31.75, 30.32, 29.17, 27.66, 25.00, 21.95, and 19.32 % at the distance of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm respectively under treatment No.4. The maximum soil moisture pattern was found at the distance of o m and minimum moisture content was found at the distance of 25-30 cm. The wetting pattern of moisture content depends on the size of the furrow, the depth of water applied, and the slope of the soil. Under this study, the furrow width was changed under all treatments, but the length of the furrow and slope of the soil were the same under all treatments. The trend of moisture content remained the same under all designs. The soil samples were taken from two furrow depths and seven distances at an interval of 5 meters. The maximum moisture content was determined at the upper side of the furrow because the flow of water started from the upper side. Slowly and gradually, the moisture content decreased at the lower side due to the slope of the soil. The results of the study are in matching with the outputs drawn by [8]. They said that around 40% of the water used for irrigation is lost owing to infiltration and surface runoff, which has a detrimental impact on agricultural productivity, drainage system dependability, and the amount of water available to irrigated areas. Using this kind of irrigation accelerates the degradation and transfer of organic matter and transportable forms of nutrients in the root zone, reducing soil fertility. In 2016, researchers Ranjit et al. investigated that, to irrigate a field using the conventional technique of furrows, soil moisture levels might be anywhere from near the field's capacity to almost half of what they were previously.

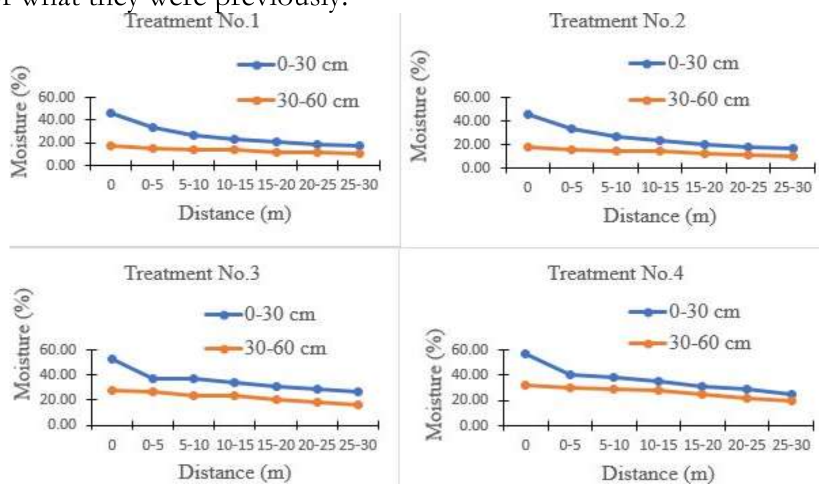

Figure 3. Wetting pattern of moisture content

Application Efficiency Under Different Furrow Designs:

The results of the water application efficiency of different furrow designs are shown in Figure 4. The results describe that the application efficiency was found to be 56.33, 55.07, 53.53, 52.33, 50.87, 49.67, and 48.13 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_1. The maximum application efficiency was found at a distance of 0 m, and the minimum application efficiency was at 25-30 m. The application efficiency was found to be 57.33, 56.67, 56.00, 55.00, 54.33, 53.33, and 52.67 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_2. The maximum application efficiency was found at a distance of 0 m, and the minimum application efficiency was at 25-30 m. The results show that the application efficiency was found to be 58.00, 57.00, 56.53, 55.33, 54.73, 53.67, and 5280 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_3. The maximum application efficiency was found at o m, and the minimum application efficiency was at 25-30 m. The results describe that the application efficiency was 59.00, 57,67, 56.93, 55.73, 54.73, 53.47, and 52.73 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_4. The maximum application efficiency was found at 0 m, and the minimum application efficiency was at 25-30 m. Application efficiency is the efficiency of the irrigation method that is adopted in the field. It is the ratio of water applied to the furrow and water stored in the root zone of the crop. In the furrow irrigation method, the application is good when it is 80% or above. In this study, the application efficiency is good to better under all the treatments of furrow design. In all the treatments, the application efficiency is above 60 % without T_1. In T_1, the furrow width was 0.5 m, because it is kept as a control treatment, and this practice is done conventionally. The application efficiency is decreasing slowly and gradually under all the treatments because of the slope of the furrow, the time of flow, and the infiltration of the soil. The result of this study is matching with the results of [9], who concluded that furrow irrigation is great for growing crops that are susceptible to fungal root rot since water does not pool and does not come into contact with plant components. Further, he said that Furrows provide for more efficient irrigation since just a fraction of the soil's surface has to be wetted, leading to less water loss via evaporation, less runoff from heavy soils, and the opportunity to cultivate the soil sooner after irrigation. The result of this study is matching with the conclusions of [10] , who concluded that an improvement option, both inflow rate and cutoff time, was changed, and the performance of furrow irrigation significantly improved. Further, they described that application efficacy and deep percolation performance indicators were significantly improved, but distribution uniformity was not changed. The result of this study is in agreement with the study of [11], who concluded that the well-designed and managed furrow irrigated systems have the potential to operate at application efficiencies above 90%. This study is in contrast with the study done by [12], they have resulted that On-farm water application efficiency was evaluated from the amount of water applied and soil moisture measurements. Performance of the irrigation scheme was poor, mainly due to illegal water abstraction, sedimentation of canals, and inadequate operation and maintenance provisions.

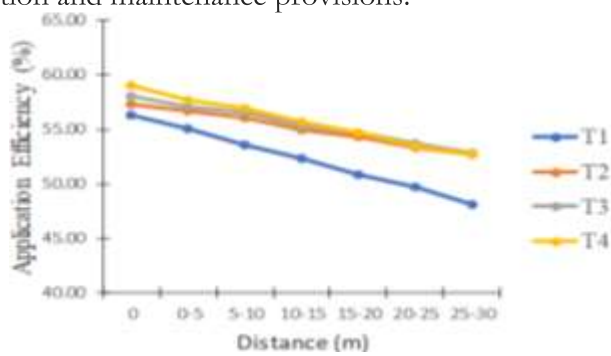

Figure 4. Water application efficiency under different furrow designs

Storage Efficiency Under Different Furrow Designs:

The results of water storage efficiency of different furrow designs are shown in Figure 5. The results describe that the application efficiency was found to be 87.33, 84.67, 81.33, 80.00, 79.33, 78.00, and 76.67 % at distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_1. The highest storage efficiency was found at o m and the minimum storage efficiency was at 25-30 m. The results describe that the storage efficiency was found to be 89.33, 87.33, 86.33, 84.33, 82.33, 80.00, and 78.33 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_2. The highest storage efficiency was found at o m and the minimum storage efficiency was at 25-30 m. The results describe that the storage efficiency was found to be 90.67, 87.67, 86.33, 85.33, 82.33, 80.33, and 79.00 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_3. The highest storage efficiency was found at o m, and the minimum storage efficiency was at 25-30 m. The results describe that the storage efficiency was found to be 92.33, 90.33, 88.67, 87.00, 85.00, 83.67, and 80.67 % at distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_4. The highest storage efficiency was found at o m and the minimum storage efficiency was at 25-30 m. Storage efficiency is the efficiency of the irrigation method that is adopted in the field. It is the ratio of water in the rootzone and water required for the rootzone to refill the rootzone of the crop. In the furrow irrigation method, the storage efficiency is good when it is 80% or above. In this study, the storage efficiency is good to better under all the treatments of furrow design. In all the treatments, the storage efficiency is above 80 %. The storage efficiency is decreasing slowly and gradually under all the treatments because of discharge in the furrow, the time of flow, and the percolation of the soil. In contrast to the conventional approach of flooding, the furrow method is now the most common way to irrigate row crops [9]. [13] conclude that furrow irrigation reduces soil salinity, improving the overall health of the crop. The result of this study is similar to the research of [10], who concluded that storage efficiency depends upon deep percolation of the soil. The result of this study matches matching of [14], who compared surface irrigation and micro furrow irrigation methods, and found good results in the furrow irrigation method. [12] also reported good storage efficiencies under the furrow irrigation method.

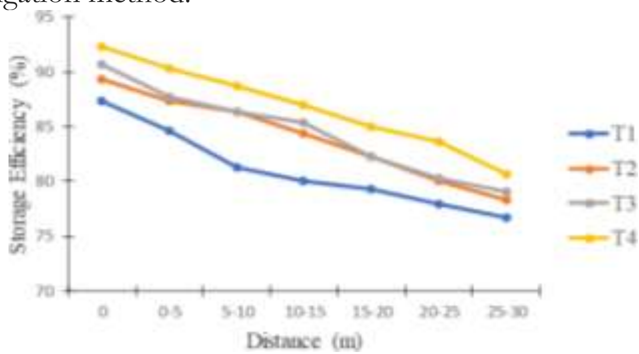

Figure 5. Storage Efficiency under different furrow designs

Distribution Uniformity Under Different Furrow Designs:

The results of water distribution uniformity of different furrow designs are shown in Figure 6. The results describe that the distribution uniformity was found to be 73.33, 72.82, 70.89, 69.01, 68.71, 67.52, and 66.16 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_1. The highest distribution uniformity was found at o m, and the minimum distribution uniformity was at 25-30 m. The results describe the distribution uniformity was found 88.33, 86.91, 83.90, 82.04, 80.58, 78.83, and 77.57 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_2. The highest distribution uniformity was found at o m, and the minimum distribution uniformity was at 25-30 m. The results describe that the distribution uniformity was found to be 90.67, 88.59, 86.64, 85.92, 83.81, 82.48, and 83.65 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_3. The highest distribution uniformity was found at o m, and the minimum distribution uniformity was at 25-30 m. The results describe that distribution uniformity was found to be 92.67, 88.93, 88.01, 86.62, 85.61, 84.31, and 82.13 % at the distances of 0, 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 m, respectively, under T_4. The highest distribution uniformity was found at o m, and the minimum distribution uniformity was at 25-30 m. The distribution uniformity is the measure of the uniform distribution of water in the field. The distribution of water depends on the soil type, the application method of water, and the soil slope. If the land is levelled, then the distribution uniformity may be more uniform. The distribution uniformity of the furrow irrigation method increases the growth and yield of the crop. The results of this study show that the distribution uniformity is good to better under all treatments. The maximum distribution uniformity is under T_3 and No.4 because the furrow width of greater than that of T_1 and T_2. If the width of the furrow is increased, the distribution uniformity is also increased. The results of this study are in a similar trend to the study of [15], who concluded that the distribution uniformity is higher in alternating furrow irrigation when compared to the traditional furrow irrigation method. [16] also found that the alternate furrow irrigation reduces deep percolation losses and enhances the uniformity of water distribution across the field. The results of this study are matching with the results of [17] and [18], who showed that water is sent straight into the ground, where plant roots may easily drink it up.

The Yield of Okra Crop Under Different Furrow Designs:

The results of the yield of the okra crop under different furrow designs are shown in Figure 7. The crop yield was picked 7 times after maturity from each ridge, then packed in polythene bags and weighed on an electric balance in the laboratory. The weight of okra yield was 3914, 4018, and 4162 g from R_1, R_2, and R_3, respectively, under T_1. As well as the weight of okra yield was 4406, 4518, 4167 g from R_1, R_2, and R_3, respectively, of T_2. While the weight of okra yield was 5119, 4920, and 4978 g from R_1, R_2, and R_3, respectively, under T_3. Finally, the weight of the okra crop was 5524, 5769, and 5715 from R_1, R_2, and R_3, respectively, under T_4. The yield per treatment was determined as 12.09, 13.08, 15.02, and 17.01 kg under T_1, T_2, T_3, and T_4, respectively. The projected yield was 1343.32, 1322.22, 1390.71, and 1453.84 kg/ha under T_1, T_2, T_3, and T_4, respectively. The maximum yield was obtained under T_4, and the minimum yield was obtained under T_2. The yield of the okra crop was assessed under different designs of furrow irrigation method and compared with the traditional furrow irrigation method. The yield was increased as the furrow width was increased; this may be because of increased water application efficiency, water storage efficiency, and distribution uniformity. If the irrigation water is applied properly to the crop, the crop yield may be increased. The result of this study is matching with the study of [8], who said that productivity depends on evaporation, infiltration, and surface runoff. If the evaporation, infiltration, and surface runoff are high, then the crop faces deficit irrigation, which for the crop yield. In furrow irrigation, there is no runoff and less deep percolation, so the crop receives appropriate water for growth and yield. [19] reported that furrow irrigation is a useful strategy to improve production and quality, and storability. It involves stopping or reducing the amount of water applied to the crop during certain growth stages, which can help the plant develop a more extensive root system and become more resilient to drought stress. [20] reported that furrow slope showed significant variation in growth parameters. [21] examined the relationship between furrow irrigation and the irrigation performance of crops, crop yield, and deep percolation, and recommended parameters for the design, management, and operation of furrow irrigation systems.

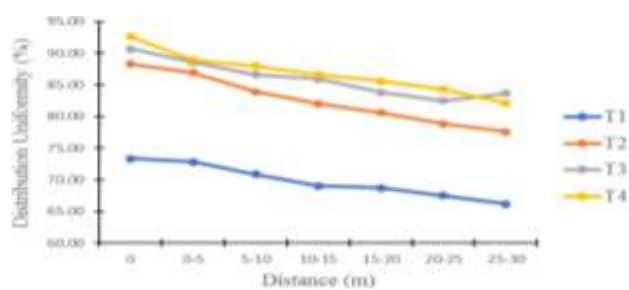

Figure 6. Distribution Uniformity under different furrow designs

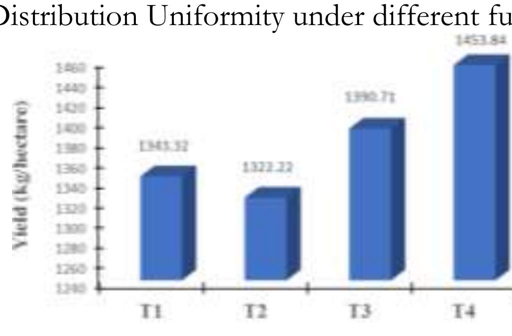

Figure 7. The yield of the okra crop under different furrow designs

Conclusions:

The trend of the wetting pattern of the moisture was the same under T_1 0.5 0.5 mm m), T_2 (0.6 m), T_3 (0.7,) and T_4 0.8 mm 0.8,) respectively. The application efficiency, storage efficiency, and distribution uniformity increased as the width of the furrow increased, but these decreased as the length of the furrow increased. The yield of the crop increased under T_2 (0.6 m), T_3 (0.7 m), and T_4 (0.8 m) as compared with T_1 (0.5 m control).

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