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Effect of Sprinkler and Basin Irrigation Systems on Yield and Water Use Efficiency of Canola Crop

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ABSTRACT

An experiment was conducted to assess the yield potential and Water Use Efficiency (WUE) of Canola crop grown under sprinkler and basin irrigation techniques on a clay loam soil. The experiment was designed by the Principles of Randomized Complete Block Design (RCBD) with two treatments, viz. T_1 (sprinkler irrigation method) and T_2 (basin irrigation method), replicated four times. Marginal quality water with Electrical Conductivity (EC_w) of 1.83 dS/m and pH of 8.2 was used for irrigation. The crop yield obtained under T_1 and T_2 treatments were 1,407.9 and 1,123.8 kg ha^{-1}, respectively; 20% more yield was observed under T_1 treatment. In the given order of treatments (T_1 and T_2), the Canola crop used 3,605 and 4,453 m^3 ha^{-1} of irrigation water, hence, 19% water saving was achieved by T_1 treatment. The WUE attained under T_1 and T_2 treatments were 0.39 and 0.25 kg m^{-3} respectively; therefore, 35.8% WUE was enhanced under T_1 treatment. While comparing the agronomic parameters of the crop under the two procedures, all the observed parameters (plant height, number of branches $plant^{-1}$, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and biomass $plant^{-1}$) were superior in case of T_1 treatment than T_2 treatment. The soil Electrical Conductivity (EC_{se}), Sodium Absorption Ratio (SAR), and Exchangeable Sodium Percentage (ESP) increased, and pH decreased under both the treatments, however, the maximum increase in EC_{se}, SAR and ESP, and maximum decrease in pH occurred under T_2 treatment. Statistical analysis showed that the crop yield, irrigation water use, WUE, EC_{se}, pH, SAR, ESP, and all the agronomic parameters differed significantly ($p < 0.05$) under the two treatments.

Keywords: Sprinkler, Basin, Irrigation, Canola, Yield, Water Use Efficiency.

1. INTRODUCTION

Climatically, Pakistan is situated within the zones of arid to semi-arid. The precipitation rate here varies from less than 100 mm to more than 1,050 mm annually with average annual ET_p (Potential Evapotranspiration) rate of about 1,778 mm; implying that there exists a significant difference between the precipitation and ET_p rates. Moreover, precipitation and ET_p rates also vary temporally and spatially. Thus, for the successful growth of crops, water requirements are met through the artificial application of water.

In Pakistan, with an increase in population, industrialization, and urbanization, the stress on available water resources is increasing with time. Increase in population and changing life standards are pressing for additional food, fiber, domestic water and

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water for environmental needs. Since the inception of the country, its population has increased manifolds; it had risen from 32.4 M in 1948 to 168 M in 2010, and it is projected that it will increase to 221 M in 2025, implying that there will be further stress on available water resources [1]. In 1951, per capita available water was 5,260 m^3, whereas, presently it has declined to less than 1,000 m^3, thus, placing the country in the list of water-stressed countries [2]. Under the given scenario of not having much scope for augmenting additional water resources to meet ever increasing demand for water, the gap between water supply and demand is continuously widening with time.

In Pakistan, agriculture utilizes about 93% of good quality water. The country possesses a vast network of open channel systems, through which water is delivered to agricultural lands. Water is applied to crops by inundating the agricultural fields by using conventional irrigation techniques (basin, border, and furrow). By use of these techniques, WUE varies between 30-50%. Thus, a substantial amount of water is lost due to deep percolations or as surface runoff. Consequently, this results in rising of the water table, and thereby, inducing problems of water-logging and salinity [3]. The precious resource of fresh water is lost unprofitably and ultimately causing a shortage of water for potential users. Moreover, the rise of water table establishes the movement of groundwater towards the river-stream system thereby inducing the transportation of residual fertilizers, pesticides and other unwanted toxic elements towards the system, thus, deteriorating the water quality in the river-stream system for lower riparian and aquatic life.

In contrast to conventional irrigation techniques, the High-Efficiency Irrigation Systems (HEIS), such as sprinkler, bubbler, and drip irrigation systems are the potential technologies to enhance WUE. By use of these technologies, a substantial amount of water can be saved for other rational uses, as well as the associated problems as discussed above can be resolved to a better extent. Sprinkler irrigation technique, besides water saving, also offers several other benefits, such as it protects soil from erosion, avoids deep percolation, feasible for uneven topography and sloping grounds, involves lesser labor, results in healthy crop and greater yields. While comparing the benefits of sprinkler method of irrigation over border method, it had been reported that water can be saved up to 56% and thereby saving in water charges can be attained up to Rs. 7,491/ha [4]. Similarly, while comparing the sprinkler method over basin irrigation techniques, saving in water and enhancement in crop productivity can be achieved up to 50 and 40%, respectively [5]. Likewise, in another investigation, while weighing rain-gun sprinkler irrigation method against basin irrigation, it is reported that WUE and crop yield can be enhanced by 30.8 and 5.64%, respectively by growing sunflower crop [6]. For wheat crop, 27% higher yield was attained in addition to the water saving of 41% under rain-gun sprinkler system as compared to border irrigation technique [7]. For rice crop, 18% more yield is reported in addition to water saving of 35% when the crop is grown under the sprinkler technique in contrast to basin irrigation technique [8].

For the last 20 years, in Pakistan, cultivation of oilseed crops has been rising at a rate of 2.6% annually, whereas, consumption of oil is increasing at 9% annually. In the country, total consumption of edible oil is 2.764 M Tons; of which 0.857 M Tons (31%) are produced locally, while 1.907 M Tons (69%) are imported annually [9]. As a result, a substantial amount of the national budget, about US$ 800 M, is incurred on the import of the edible oil yearly [10]. Thus, there exists an immense need to increase the production of oilseed crops to bridge this gap. A large gap also exists between potential yield and existing extent of yield (per unit area) of the oilseed crops in the country. As a result of various factors, almost 74% of the yield potential is not harvested in case of these crops [11]; of these factors, irrigation technique is one of the most important factors affecting this phenomenon. Canola (Brassica Napus L.) oil is one of the major edible oil of the world; this oil possesses erucic acid lesser than 2%, glucosinolates more than 30 μMg^{-1} and saturated with a smaller amount of fats (5-8%) in comparison to other edible oils [12]. Since the Canola crop has low erucic acid contents and high yielding capacity [13]; therefore, in 1995, this crop was introduced into the country.

The objective of the present research study is to assess the effect of sprinkler and basin irrigation techniques on Canola crop yield, its water use, and WUE. Additionally, since, marginal quality water is used for irrigation purpose, therefore, any change in soil chemical properties (soil salinity) is also assessed by analyzing the soil EC_{se}, pH, SAR, and ESP.

2. MATERIALS AND METHOD

2.1 Experimental Site and Design

The study was conducted in the experimental field of the Drainage and Reclamation Institute of Pakistan (DRIP), Tando Jam, Sindh, Pakistan, during 2013-2014. The Institute is located at 25° 25' 10.6" North latitude and 68° 31' 35.2" East longitude and an average altitude of 12.8 m above the mean sea level. The experiment was set up as per the principles of RCBD with two treatments, viz. T_1 (sprinkler irrigation method) and T_2 (basin irrigation method) and four replications. For each treatment and replication, plot size was kept as identical (36.9×27.4m). The soil texture of the experimental site is clay loam. Throughout the cropping period, for irrigation purpose, marginal quality water with EC_w = 1.83 dS/m and pH = 8.2 was used.

2.2 Land Preparation, Seed Planting, and Fertilization

At the outset, the land was thoroughly plowed twice using the disc-harrow and cultivator type of plows. A soaking dose of water was then applied to all the experimental plots. When the field reached the working condition, once again the entire area was plowed by using the cultivator type of plow, and after that, all plots were leveled conventionally. A local variety of Canola seed, known as Surhan, was sown by drilling method using a single colter hand drill. The spacing from inter-row and intra-row was maintained at 30.5 and 20 cm, respectively. As per the recommendations made in [14], fertilizer (NPK) dose was applied at the rate of 90-60-0 kg ha^{-1}. The nitrogen was applied in the form of Urea, and phosphorous in the form of Di-Ammonium Phosphate. The entire dose of phosphorus was used all at once during the land preparation phase; while, nitrogen dose was split into three equal parts, and a part of that was applied after each irrigation exercise.

2.3 Application of Irrigation Water

Altogether three irrigation exercises were done. Following the recommendations made in [15], the first irrigation water was applied after 21 days of crop sowing (early vegetative stage), while second irrigation was exercised after 56 days of crop sowing (flowering stage) and the third irrigation was exercised after 93 days of crop sowing (seed formation stage). At each stage, the depth of water required for irrigation purpose was computed by using the formulation given in equation (1):

$$R = \frac{(F_C - M_C)}{100} \times B \times D \qquad (1)$$

where, R is the required depth of irrigation water (cm), F_C represents field capacity(g/g), M_C denotes soil moisture content (g/g), B signifies the dry bulk density of the soil (g/cm^3) and D stands for root depth of the crop at the time of irrigation (cm).

Veihmeyer and Hendricksen [16] method was used for determination of the field capacity. Just one day before the application of irrigation water, the available moisture content in root zone depth was determined by gravimetric technique. The root zone depth is calculated by its growth rate (8 mm/day) as reported by [17]. Thus, for first, second and third irrigation, soil moisture content was determined from 0-12, 0-40, and 0-70 cm, respectively. The dry bulk density was determined by core method [18].

2.4 Yield Response and WUE

The yield of the Canola crop from each replication was measured in kilograms and averaged, then converted into units of kg ha^{-1}. The yield response (increase in yield) in percent is calculated as per the equation (2).

$$\text{Increase in yield (\%)} = \frac{(Y_1 - Y_2)}{Y_1} \times 100 \qquad (2)$$

where, Y_1 is the total yield of Canola crop obtained under sprinkler irrigation system (kg ha^{-1}) and Y_2 denotes the total produce of the crop obtained under basin irrigation system (kg ha^{-1})

The WUE for the Canola crop grown under sprinkler and basin irrigation systems is calculated by using the equation (3):

$$WUE = \frac{Y}{R} \times 100 \quad (3)$$

where, WUE is the Water Use Efficiency (kg m^{-3}), Y denotes yield of the Canola crop (kg ha^{-1}) and R symbolizes for the total quantity of water consumed by Canola crop for its production (m^3 ha^{-1}).

Since the water used for irrigation purpose was of marginal quality with EC_w = 1.83 dS/m and pH = 8.2, therefore, to assess any change in soil salinity, soil samples were collected before the sowing and after the harvest of the crop for the soil salinity status analysis. The soil samples were collected at the depths of 0-15, 15-30, 30-45 and 45-60cm. The pH and EC_{se} were determined by 1:2 soil-water-extract method [19] with the help of digital pH and EC meter, respectively.

Soluble Ca^{2+} and Mg^{2+}were determined by EDTA titration method, while Na^+ was analyzed by the EEL-Flame Photometer [20]. The formulations for computation of SAR and ESP are presented in equations (4-5), respectively:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (4)$$

$$ESP = \frac{100(-0.0126\times0.01475\times SAR)}{1+(-0.0126+0.01475\times SAR)} \quad (5)$$

2.5 Performance of Sprinkler System

The sprinkler system installed at the DRIP is a fixed rotary system, which covered entire experimental blocks. In total, there are 18 sprinkler heads, each having a precipitation rate of 0.44 liters sec^{-1}. Of these, eight sprinklers are designed to cover half circle, while, rest of them are designed to cover the full circle. Before execution of the experiment, performance of the sprinkler system was assessed; the performance parameters included, assessment of Uniformity Coefficient (CU) and Distribution Uniformity (DU). The CU is determined by the Christiansen formula [21, 22]; and the DU is computed by the equation proposed in [23]; the formulations for CU and DU are reproduced in equation (6):

$$CU = \left[1 - \frac{\sum_{i=1}^{n}|x_i-\bar{x}|}{n\times\bar{x}}\right] \quad (6)$$

where, CU is the uniformity coefficient in %, X is denotes the mean water depth collected in all catch-cans, n is stands for the total number of catch-cans and X_i is the water depth collected in an individual catch-can in Equation (7).

$$DU_{lq} = \frac{\bar{V}_{lq}}{\bar{V}} \quad (7)$$

where, DU_{lq} is the DU in the lowest quarter in%, $\overline{V}_{lq}$ denotes the mean of the lowest quarter volume (or depth) of water collected in the cans, $\bar{V}$ is stands for the average volume (or depth) of water collected by all catch-cans.

The performance test was carried out for each sprinkler head. In total, forty-eight catch-cans were used covering an area of 144 m^2 (**Fig. 1**). The spacing between catch-cans was maintained as per recommendations made in [24]. The diameter and height of each catch-can were 76 and 80 mm, respectively. All sprinkler heads were operated for half an hour, and the volume of water collected in each catch-can was measured.

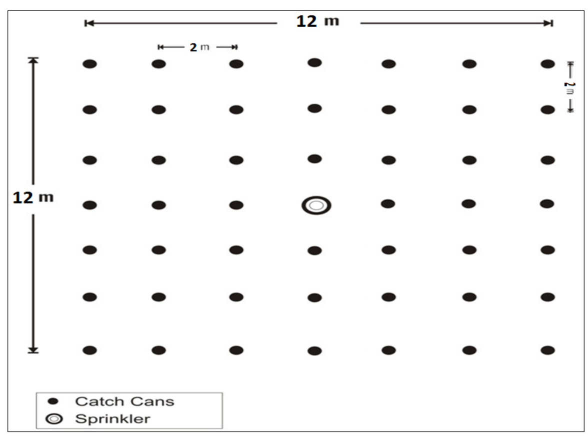

Fig. 1: Layout of Catch-Cans around a Sprinkler Head

2.6 Statistical Analysis

All the collected data were statistically analyzed using Statistic software (Version 8.1).

2. RESULTS AND DISCUSSION

3.1 Performance of Sprinkler Irrigation System

The CU and DU of the present sprinkler system were determined under an operating pressure head of 28 psi. According to [22], a sprinkler irrigation system is categorized as satisfactory if it's CU > = 84% and DU varies between 80-85% [25]. The CU and DU, for the present system, are estimated at 86.9 and 81.6%; thus the performance of the system is rated as satisfactory.

3.2 Irrigation Water Use

Fig. 2 presents the volume of irrigation water used for growing Canola crop under the two irrigation systems. The crop used 3,605 and 4,453 m^3 ha^{-1} of irrigation water under T_1 and T_2 treatments, respectively. The higher amount of irrigation water was used by T_2 treatment than its counterpart. The amount of irrigation water saved under T_1 treatment is 19% as compared to T_2 treatment; this is because lighter irrigation is exercised under the sprinkler system; hence, runoff and deep percolation losses are negligible here. Thus, field application efficiency under T_1 treatment is higher than the T_2 treatment. In contrast, under basin irrigation system, the entire field is flooded with water. Thus, there are more percolation and runoff losses; hence, field application efficiency under T_2 treatment is inferior to its counterpart. These results are also supported by [5, 6]. Statistically, the water used by the crop under T_1 and T_2 treatments were significantly different ($P < 0.05$).

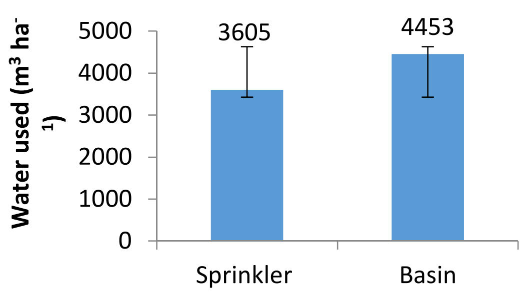

Fig. 2: Volume of Water used for T_1 and T_2 treatments

3.2 Crop Yield

The yield of the crop under the two treatments is presented in **Fig. 3.** The yield attained under T_1, and T_2 treatments are 1,407.9 and 1,123.8 kg ha^{-1}. Noticeably, a higher yield is attained under T_1 treatment than in T_2 treatment. The increase in yield under T_1 treatment is attributed to the lighter dose of irrigation waters, relatively uniform distribution of irrigation waters and better aeration in the root-zone profile of the crop. Under T_1 treatment, the crop yield increased by 20.17%in comparison to its counterpart. Similar results are also reported by [6-8]. Statistically, the crop yield attained under T_1, and T_2 treatments were significantly different ($P < 0.05$).

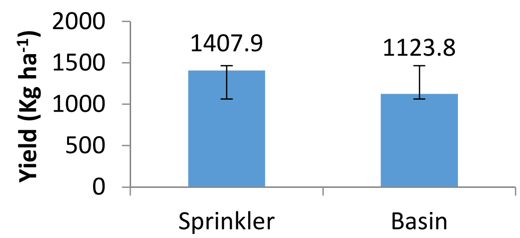

Fig. 3: Yield of crop obtained under T_1 And T_2 treatments

3.3 Water Use Efficiency

The WUE attained under T_1, and T_2 treatments for the growing of Canola crop is 0.39, and 0.252 kg m^{-3}, respectively as presented in **Fig. 4**. Obviously, the water use efficiency attained under sprinkler irrigation system is higher than its counterpart. The WUE attained under T_1 treatment is higher by 35.38% over the T_2 treatment. The reason for higher WUE in T_1 treatment is because of the lesser consumption of irrigation water and higher yield attained. Similar findings were also reported by [5]. Statistically, the WUEs attained under T_1, and T_2 treatments were significantly different ($P < 0.05$).

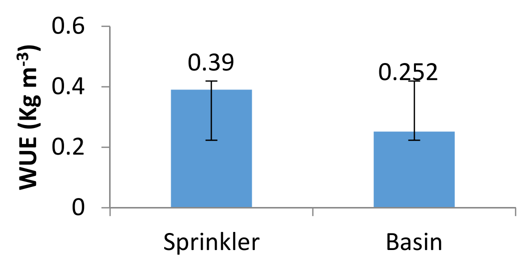

Fig. 4: WUE attained under T_1 and T_2 Treatments

3.4 Agronomic Parameters

During the study, agronomic parameters of the crop, such as; plant height, number of branches $plant^{-1}$, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and plant biomass, were also studied. The data on these parameters are presented in **Table 1**. From the Table 1, it can be seen that for all the agronomic parameters, higher values are attained under T_1 treatment as compared to its counterpart. Superior values of the agronomic parameters under T_1 treatment were attributed to the lighter dose of irrigation waters, relatively uniform distribution of irrigation waters and better aeration in the root-zone profile of the crop. Statistically, all the agronomic parameters attained under T_1, and T_2 treatments differ significantly ($P < 0.05$).

Table 1: Agronomic Parameters for Canola Crop

Agronomical Parameters	Irrigation Methods	
	Sprinkler	Basin
Plant height (cm)	116	111
Number of branches plant^{-1}	12	09
Number of pods plant^{-1}	69	51
Pod length (cm)	2.6	2.4
Number of seeds pod^{-1}	25	21
Biomass plant^{-1} (g)	0.47	0.41

3.5 Soil Chemical Properties

Soil (EC_{se}): In T_1 and T_2 treatments, the EC_{se} of the soil samples obtained before sowing of the crop was estimated at 1.63 and 1.48 dS m^{-1}, respectively; likewise, the EC_{se} of the soil samples acquired after harvest of the crop was1.81 and 1.69 dS m^{-1}, respectively. The EC_{se} increased by 0.18 and 0.21 dS m^{-1} under the T_1 and T_2 treatments, respectively. The maximum increase in EC_{se} occurred under T_2 treatment; this is because a larger amount of irrigation water was used under T_2 treatment, which in consequence resulted in accumulation of more salts in the soil profile. The magnitude of EC_{se} of the soil samples obtained after harvest of the crop is not comparable to EC_w; this could obviously be attributed to the following reasons: (i) the soil of the experimental plots is of good quality (EC_{se}< 4 dS/m), (ii) some amount of salts is also taken-up by plant body [26-29], (iii) the concentration of salts available in the marginal quality water is diluted/distributed among a bigger mass of soil, and (iv) the mass of water that is added for irrigation purpose is much lesser than the bulk mass of the soil that supports the plant life. It may also be intruded that if marginal quality water is used for irrigation purpose for a longer period without the addition of leaching factor, in that case, the ECse may reach to an equivalent or higher state of ECw.Statistically, the EC_{se} estimated under T_1 and T_2 treatments differ significantly ($P < 0.05$).

Soil pH: In T_1 and T_2treatments, the pH value of soil samples before sowing of thecropwere7.73 and 7.70, respectively. Similarly, the pH values for soil samples acquired after harvest of the crop were obtained as 7.71 and 7.67. The maximum decrease in pH occurred under T_2treatment; this is because the higher quantity of irrigation water was used under this treatment. The fertilizers used under T_2treatment had more opportunity to be dissolved, and thereby it induced a decrease in soil pH. These findings also confirmed by the research results obtained by [30, 31]. According to them, due to the application of synthetic fertilizers, nitrification and acidification processes initiate and also due to the release of H^+ by plant roots, the pH value of soil decreases. The values of soil pH, even after the harvest of crop, is furthermore reduced due to leaching impacts in upper soil layers and dissolved carbonic and organic acids, which remove metal cations (e.g., Ca^{++}, K^+, Mg^{++}) and replace them with H^+ ions [32]. Moreover, plant growth and nutrient uptake also result in some localized acidification (decrease in soil pH) around plant roots through the exudation of acids from the roots [33]. Statistically, the pH value obtained under T_1 and T_2 treatments differed significantly ($P < 0.05$).

Soil SAR: In T_1 and T_2treatments, the SAR of soil samples obtained before sowing was 2.63 and 2.32 and after harvest of the crop were 2.73 and 2.55, respectively. The soil SAR increased by 0.10 and 0.23 under T_1 and T_2 treatments, respectively. The maximum increase in SAR occurred under T_2 treatment. This increase in SAR is attributed to the use of marginal quality irrigation water and also because of more amount of irrigation water used under this intervention. The permissible limit for SAR is less than 7.0 [34]. Statistically, the SAR value obtained under T_1 and T_2 treatments differ significantly ($P < 0.05$).

Soil ESP: In T_1 and T_2 treatments, the ESP of soil samples obtained before sowing was 2.57 and 2.12 and after harvest of the crop were 2.70 and 2.44, respectively. The soil ESP increased by 0.13 and 0.32 under T_1 and T_2 treatments, respectively. The maximum increase in ESP occurred under T_2 treatment. This increase in ESP may be attributed to the use of marginal quality irrigation water and also because of more utilization of irrigation water under this intervention. The ESP values under both the treatments remained within the safe limit (i.e. < 15) [35]. Statistically, the ESP values obtained under T_1 and T_2 treatments differ significantly ($P < 0.05$).

3. CONCLUSION

From the study, it can be concluded that the methods of irrigation (sprinkler and basin) have a significant effect on irrigation water use, crop yield, WUE and agronomic parameters of the Canola crop. Sprinkler irrigation technique can successfully grow the Canola crop with a considerable increase (20.17%) in yield and substantial improvement in WUE (35.38%). The amount of irrigation water saved (19%) by sprinkler irrigation technique in comparison to its counterpart is also sizeable. Since marginal quality irrigation water is used for irrigation purpose, therefore, soil chemical properties (soil salinity parameters) changed under both types of irrigation interventions. Moreover, since, a higher amount of irrigation water is used under basin irrigation system, therefore, more increase in soil salinity parameters occurred under this system, implying that in case of using marginal quality water for supplementing the water requirements of crops under basin method of irrigation in clay loam soil texture, the soil is more venerable towards salinity development.

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