Research Article

The Effect of Different Raised Bed Sizes under Furrow Irrigation Method on Salt Distribution in Soil Profile and Yield by Hydrus (2/3D)

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Abstract | The use of raised bed-furrow irrigation method has increased in due to its capability of saving massive amounts of irrigation water. Knowing the importance of raised bed-furrow irrigation (RBFI) in water conservation and salt distribution in profile with three testing treatments viz. T_1 with raised bed size = 0.6 m, T_2 with raised bed size = 0.8 m and T_3 with raised bed size = 1.0 m. The soil samples were collected from depth desired depth to analysis the Physical chemical properties before and after the trial. Irrigation water was measured through cutthroat flume at each irrigation interval and the total water consumed by ridge ground was 500 mm. The solute transport and soil water content in the root zone was also simulated by HYDRUS-2D. The results reveal that the salts moved upward to the top (upper layers) and concentrated at the center of the ridge for treatments T_2 and T_3 but leached down from the furrow bottom. Whereas, the simulations carried out by HYDRUS-2D model showed that with increasing size of raised bed, the center of the raised bed did not get the required quantity of water, hence remained unsaturated. Moreover, the highest crop yield and water productivity were recorded 8,748 kg/ha and 3.74 kg/cm^3 respectively under T_2 treatment as compared to other treatment. Furthermore, the experimental and simulation results of present study concluded that the sides of raised-bed/furrow, where the ridge gourd was sown, received enough water to support the plant growth in all treatments and RBFI with raised bed size of 0.8 m was more water use efficient and suitable method for water scarcity areas.

Received | August 31, 2019; **Accepted** | October 11, 2019; **Published** | January 22, 2020
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Citation | Memon, M.S., K. Ullah, A.A. Siyal, N. Leghari, A.A. Tagar, K.A. Ibupoto, S.T. Ata-ul-Karim, M. Tahir and N. Memon. 2020. The effect of different raised bed sizes under furrow irrigation method on salt distribution in soil profile and yield by Hydrus (2/3d). *Pakistan Journal of Agricultural Research,* 33(1): 113-125.
DOI | http://dx.doi.org/10.17582/journal.pjar/2020/33.1.113.125
Keywords | Conventional irrigation, HYDRUS 2D/3D model, Ridge gourd, Soil pH Simulation, Water Consumption

Introduction

Water supplies worldwide are falling against growing population and situation declares that the water for agriculture, domestic and industrial processes is becoming scarce due to imbalance water availability and uses. Although, the demand for water is increasing day by day, but the attitude towards water and its management globally is not justified (UN-Water, 2013; Connor, 2016; WWAP, 2019). So, the importance of water resources for future food requirements and growing competition for agricultural industry are needed for future prosperity. However, the use of water resources in an efficient way with maximum outputs should be our principal object for sustainable crop yield in both arid and semi-arid region (Kang et al., 2017; Memon et al., 2018). Additionally, climate change will have significant impacts on agriculture by increasing water demand, limiting crop productivity, and reducing water availability in areas where irrigation is most needed or has a comparative advantage. Whereas, a growing number of regions will face increasing water scarcity, thereby climate change will bring greater variation in weather events, more frequent weather extremes, and new challenges requiring the sector to take mitigation and adaptation actions (Turral et al., 2011; Elliott et al., 2014). Moreover, scarcity of water has a huge impact on food production, because without irrigation water farmers do not have a means of watering to their crops and, therefore, it is difficult to provide food for the fast growing population (UNESCO, 2016). Consequently, (Fischer et al., 2005) reported that the agriculture, accounts about 70% of global water withdrawals, and this is constantly competing with domestic, industrial and environmental uses for a scarce water supply. Thus, in attempts to fix this ever-growing problem, many have tried to form more effective methods of water management. different techniques of irrigation water saving are used in agriculture worldwide; some of these are related to water management and others are similar to seedbed preparation according to water availability. Surface flood irrigation is that type of irrigation in which the water is conveyed onto the land by the gravity flow, i.e., border, basin, furrow, etc. (Bainbridge, 2001; Davies et al., 2002). Among this conventional surface irrigation, a method is in which crops are planted on raised ridges between furrows. When applied, irrigation water flows through these furrows. Furrow irrigation method is further modified into raised beds by converting ridges into raised beds to enhance water use efficiency. The raised bed-furrow irrigation is now getting popularity among farming communities where the irrigation water shortage is severe. This technique has shown a considerable improvement, which increased the conservation and water use efficiency in semi-arid areas as compared to flat basin sowing which was the great breakthrough performance (Connor et al., 2003, Fahong et al., 2004a). However, developed countries, facing irrigation water shortage, have replaced their traditional flood irrigation methods with high-efficiency drip and sprinklers irrigation. Although the high-efficiency irrigation methods are an imperative system, and also important for long-term sustainable agriculture (Bouma, 2002; Gardi et al., 2002). Moreover, it is difficult to introduce these methods due to the high cost of installation and operation, the economic level of farmers, provision of energy on the farms, and low farm return, etc. One of such alternative methods is the raised bed irrigation method for efficient irrigation water use. Raised bed-furrow planting method is adopted by many farmers throughout the world (Govaerts et al., 2007). In raised bed-furrow irrigation method, the fields are divided into narrow strips of raised beds separated by furrows for the requirement of the crops. With the lessons learned from research in semi-arid, subtropical highlands, the raised bed planting system is being evaluated and advocated for many crops including cereals and vegetable in South Asia (Singh et al., 2010). Currently, raised beds irrigation method is widely used in many arid and semi-arid areas, while this this method the plants grows on the edges of beds or ridges that are formed between furrows channels that carry irrigation water (Saharawat et al., 2010). This system has been used in semi-arid or dry regions of Central Asia, China and western United States, where irrigation systems were limited and developed in conjunction with the production of row-planted crops (Govaerts et al., 2007).

Raised bed method helps in reducing irrigation requirements of crops and increase crop production even in soils having low permeability, seasonal waterlogging, salinity, and shortage of water supply (Qureshi et al., 2008). In RBFI system the furrows and ridges were developed once and not be destroyed seasonally; only the beds renovated before cropping. Therefore, to grow crops on raised beds, merely shape the beds before planting the next crop and retain all or part of the crop residues on the surface (Derpsch, 2003). However, the size of raised bed has a significant impact on total crop production and water consumption (Kukal et al., 2010). The Large size of bed may result in less crop yield and reduced per acre water requirement. Similarly, more returns with more per acre crop water requirement may be expected for small size bed because water is applied to more area, thus chances of more water loss due to deep percolation and evaporation. Today raised bed cropping technique is recommended because of its many advantages.

(Beecher et al., 2006), studied that maintaining of soil condition with favorable environment improved the cropping growth and yield. In addition, direct drilling methods improved the soil structure and increased the level of organic matter. (Kovach et al., 1983) also determined the effect of combinations of raised bed heights (6 and 8 inches) and widths (24 and 30 inches for cauliflower, 24 and 28 inches for tomato) on crop yield. Cauliflower grown on an 8-inch high and 24-inch wide bed produced a significantly higher number of all other treatments, and the total weight of cauliflower was substantially higher for cauliflower grown on the 8-inch high and 24-inch wide bed than cauliflower grown on a 6-inch high and 30-inch wide bed. Bed height and width did not significantly affect residual soil soluble salt concentration or percent soil moisture.

The numerical simulations are an capable approach to determine the soil water dynamics for optimal irrigation management practices (Masoud et al., 1999; Cote et al., 2003; Aggarwal et al., 2017). Many studies have shown that numerically simulated and modelling of soil water data agree with field data. Whereas, the Hydrus (2D/3D) model by (De Silva et al., 2008) were used efficiently to assess the root water uptake (RWU) and soil water movement in land areas with a mixture of natural vegetative cover (i.e. trees and grasses) and settled that different irrigation amounts and frequencies should be used for different plant species in irrigated strip intercropping fields. Also, (Skaggs et al., 2004) compared Hydrus-2D simulations of water redistribution and infiltration with experimental field data and reported that the Hydrus-2D predictions of the water content distributions were in excellent agreement with field data. Their results supported the use of the Hydrus-2D Model as a tool for determining and designing drip irrigation management practices. Also, in another study by (Bufon et al., 2012), investigated that the Hydrus-2D Model was used to simulate soil water movement under different irrigation frequencies and environmental conditions during cotton growth on beds. Therefore, there is a strong need to conduct a research on the techniques, which would be capable of enhancing the irrigation efficiency and salt distribution in soil profile under different raised bed sizes by Hydrus 2/3D model. The aim of this study is to assess how the different size of raised bed, influence the yield and the salt distribution in the soil profile.

Materials and Methods

Description of site location

The study was performed in a semi-arid region at the experimental field station of the Faculty of Agriculture Engineering (FAE), Sindh Agriculture University Tandojam, Pakistan. The experimental site is located inside the Faculty of Agricultural Engineering, (25°25`28``N 68°32`24``E) on an elevation of 26 m above mean sea level (MSL). Groundwater is the source of irrigation for the experimental field, which was pumped from tube well and distribute into the network of field channels. The area has a high temperate climate, with an average temperature of 36°C with mean precipitation of 150 mm.

Experimental design

The plot selected for the experiment was of size 24 m×10 m (240 m^2) separated by a 0.9 m as path/bund between the treatments. The plot was further divided into three subplots, in which selection of subplot for each of treatments, i.e. T_1= Raised bed width 0.6 m, T_2 = Raised bed width 0.8 m and T_3 = Raised bed width 1.0 m was completely randomized. Each treatment was replicated three times. The length of each raised-bed and furrow was kept same, *i.e.* 10 m in all three treatments, while the areas of subplots were 60 m^2 for T_1, 74 m^2 for T_2 and 88 m^2 for T_3. The layout of the experimental plot is shown as Figure 2.

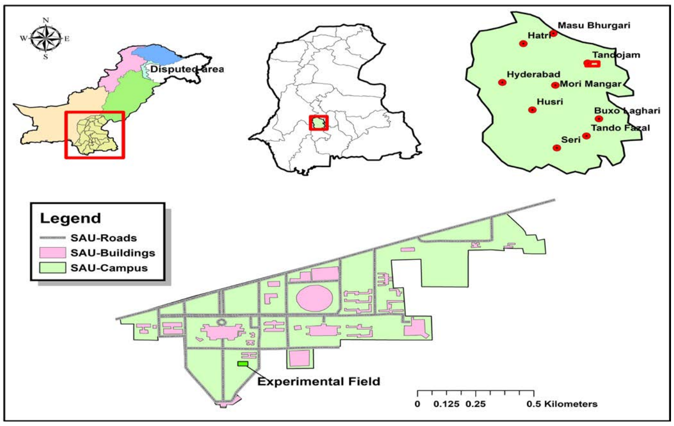

Figure 1: *Location of the experimental field.*

Soil parameters

Soil samples were randomly taken from the bottom of the furrows from each treatment at the center of raised beds from different soil depths viz. 0-20 cm, 20-40 cm, 40-60 cm and 60-80 cm before and after harvesting of the crop. The collected soil samples were analyzed for determination EC_e, and pH through the method provided by (Rowell, 1994) in regards to the size of raised bed. Thus, the effect of the size of raised bed on the salt concentration and distribution was determined. The dry bulk density of soil was measured (Bouyoucos, 1936), only for the upper soil layer of 0-20 cm as this layer is extremely vulnerable to the biological and other natural and human activities.

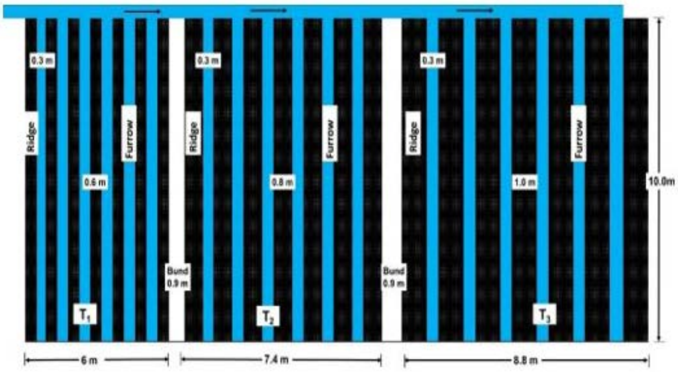

Figure 2: *Experimental design layout for study.*

Preparation of land, furrows and raised bed

The area under study was ploughed using a Moldboard plough implement and the resulting clods were thoroughly pulverized using disk harrow. The plot was then leveled with leveler. Furrows and ridges were constructed manually using spade as per the layout of the plan shown in Figure 1. The width of 6 ridges/ raised bed under treatment T_1 was kept 0.6 m, while the next 6 raised beds were constructed with 0.8 m width. The remaining 6 raised beds under treatment T_3 had a width of 1.0 m. The length of all the ridges/ raised beds and furrows was kept same, *i.e.* 10 m, whereas the width of furrows was kept 0.30 m in all the experimental treatments.

Irrigation

Groundwater was used for irrigation in the study field. For better germination of seed, a soaking dose of 100 mm was applied to furrows as first irrigation. The subsequent or regular irrigations applied at an interval of 6 to 7 days to all treatments (Minfal, 2005). The total requirement of water for ridge gourd is 500 mm, which were divided into 8 irrigation splits with an interval of 6-7 days. Hence, 62 mm of water was applied per irrigation to crop. When furrows were filled about 70% of depth, the water application was cut off. The water infiltrated vertically, through the bottom of the furrow, as well as horizontally into the ridge and provided a require water to the crop roots in the raised bed. The discharge was measured using a cut throat flume of size 0.23 m x 0.457m during each irrigation. The flow rate of applying water was measured by the following Equation 1:

$$Q_s = \frac{[C\,(h_u - h_d)^{nf}\,]cc}{(-log\ S)^{\,n_s}} \quad ....(1)$$

Where;

hd/hu>0.68 and the flow rate of applying water were measured by the following equation; S= represents the submerged flow; C= submerged flow coefficient (1.606); d= denoting downstream; Qs= submerged flow discharge rate; hd= downstream flow depth (ft); nf= is submerged flow exponent (3.999) and ns= submerged flow exponent (1.728).

Water consumption

Various researchers and scientists have reported that raised bed technology is an improved form of furrow irrigation method which not only improves water use efficiency but also increases crop yield (Monayem Miah et al., 2015; Hussain et al., 2018). Hence, in the present study probable effect of different sizes of raised beds on irrigation was determined using the following relationship as shown in Equation 2.

$$WS(\%) = \frac{W_{FL} - W_{RB}}{W_{FL}} \times 100 \quad ....(2)$$

in which WS= represents the water saving in (%); W_{RB}= is the total water consumed and W_{FL}= is the total water used for growing ridge gourd with raised bed-furrow irrigation (mm).

Cropping indicator and fertilizer

The Ridge gourd (Luffa Cylindrical Roxby) is a commonly used vegetable in which is cultivated around the country mostly in the bed-furrow system. Ridge gourd belongs to Cucurbitaceous family. Ridge gourd grows best in well-drained sandy loam soil. Ridge gourd is a vegetable crop which is usually grown in spring (February-March) and summer (June-July) with a plant to plant spacing of 30 cm and row to row spacing of 60 cm. Ridge gourd requires about 400-500 mm of water throughout crop period (Minfal, 2005). The plant seed was sown on both sides of furrows ridge manually. The seed started germination after five days from sowing under bed-furrow irrigation. The plant to plant distance was maintained as 0.3 m. Moreover, the doses of manures and fertilizers depend upon soil type, climate, and variety. The NPK fertilizer was applied 30 days after the first day of sowing. When vegetative growth was accelerating, organic manure was also added to all furrows. Urea and Di-ammonium Phosphate (DAP) were also used as a primary source of nutrients.

Crop yield and crop water productivity (CWP)

The picking of ridge gourd fruit was done on alternate days when the fruit grew to a required size. The first picking was done after 40 days of sowing. The picking process continued throughout the crop period. The picked fruit was then weighed separately for each treatment, which was later converted into kilogram per hectare (kg/ha). The yields of the ridge gourd vegetables from the experimental treatments were compared to assess the effect of the size of raised bed on the yield of ridge gourd. However, Crop water productivity is the ratio between crop yield and the total water applied to the crop (Jacob et al., 2003; Memon et al., 2017). Hence, it merely indicates the crop productivity due to artificially applied water (irrigation) plus water received through precipitation. Thus, it can be defined as total crop yield per unit volume application of irrigation water as Equation 3:

$$CWP=\frac{Y}{WR} \quad ...(3)$$

in which CWP = Crop water productivity/water use efficiency (kg/m^3); Y= Total yield of crop (kg/ha); WR = Total water consumed for crop production (m^3/ha).

Simulations of soil water and movement of salt in the soil profile by HYDRUS (2/3D)

The HYDRUS (2D/3D) software package by (Simunek et al., 2006) was used to simulate soil water and salt movement in the root zone. Three flow domains of sizes 90 cm x 75 cm, 110 cm × 75 cm and 130 cm × 75 cm were used for simulation of soil water and salt movement in treatments T_1, T_2 and T_3 respectively. Flow domains were discretized in nodes and triangular elements for treatment with smaller spacing on the ridge and raised bed (Figure 3). Using of automatic triangulation algorithm which is applied in HYDRUS model and generated finite element mesh (Simunek et al., 2006). Saharawat *et al* (Saharawat et al., 2010) studied the hydraulic parameters (θ_r, θ_s, α, n and ℓ) which are used for soil nodes with the using of Rosetta pedotransfer HYDRUS model. θ_r = 0.065, θ_s = 0.41, K_s = 4. 42 cm/h, α = 0.075 cm^{-1}, n = 1.89 and ℓ= 0.5 are the data of dry bulk density and also percentage data of sand, silt and clay, hydraulic parameters for the sandy loam soil.

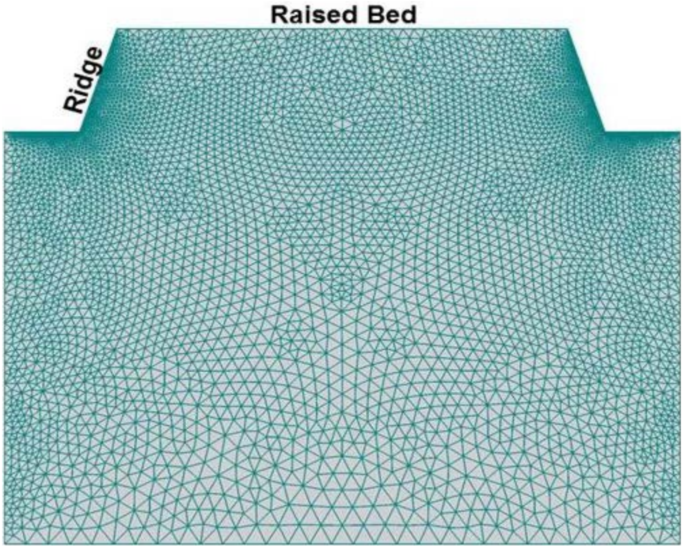

Figure 3: *Finite Element Mesh of flow domain used in simulation.*

The ridge boundary and furrow-bottom nodes were assigned an adjustable head equivalent to pressure head found in the experimental trial (Figure 4). However, the left and right boundaries were set as a zero flux condition. The surface boundary condition of raised bed was specified as atmospheric boundary condition, the constant potential rate is 0.02 cm/h, then water evaporates from the surface, and the soil-water pressure head is above a threshold value -15000 cm. While the constant pressure head condition -15000 cm switches, if the soil dries down the threshold value and the bottom boundary specified with free drainage boundary condition.

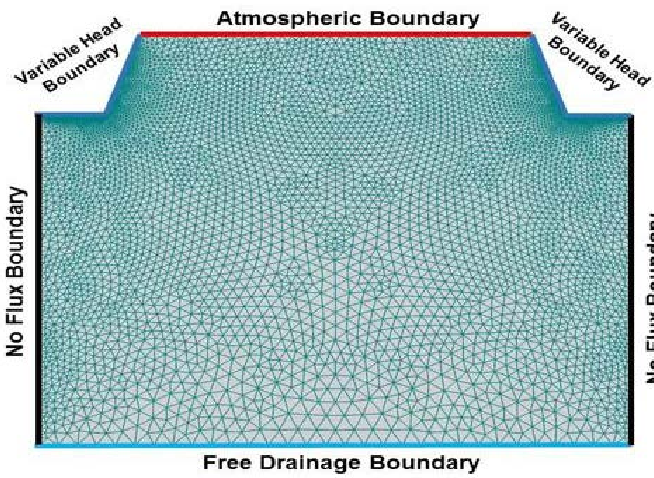

Figure 4: *Boundary conditions used in soil water and solute transport simulations.*

The initial condition of soil profile had specified based on the measured moisture content in the soil samples when the irrigation pipe was buried. These measures of moisture content were transformed into main pressure values through soil-water retention characteristic curve within sandy loam soil parameter. In accordance with these observable values, the initial conditions were determined in such a way that the pressure head increased linearly with the depth of the profile, from -300 cm in the upper part (z = 0) to -200 cm at the bottom (z = 75 cm).

Model description of soil water and solute movement

The HYDRUS-2D (Simunek et al., 2011) was used to simulate two dimensional vertical isothermal variably-saturated flux at the experimental site. Experimental observations were described by the two-dimensional single porosity model (2D-SPM), where unsaturated water flow in a two-dimensional vertical cross section of the soil is described with the following form of Richards' Equation 4:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[K\left(K_{ij}^A \frac{\partial h}{\partial x_j} + K_{iz}^A\right)\right] - WU_{(h,r,z)} \quad ....(4)$$

Where,

θ is the volumetric water content (cm^3 cm^{-3}); t is time (day); xi and xj are the spatial coordinates (cm); K is the unsaturated hydraulic conductivity function (cm day-1); K^A_{ij} are components of a dimensionless anisotropy tensor K^A; h is the pressure head (cm), WU (h, r, z,) is root water uptake.

Root water uptake was determined according to Feddes model, as implemented in the HYDRUS-2D. An accurate soil-water retention curve is required to model the described system. Accordingly, the van Genuchten-Mualem model (Equation 5, 6, 7) for unsaturated hydraulic conductivity was calibrated to the system. The expressions of van Genuchten are given by:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_0 - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \quad ....(5)$$

$$S_e = \frac{\theta - \theta_r}{\theta_0 - \theta_r} = \left(\frac{1}{1+(\alpha|h|)^n}\right)^m \quad ....(6)$$

$$K(h) = K_0 S_e^l [1 - (1 - S_e^{\frac{1}{m}})^m]^2 \quad ....(7)$$

in which the hydraulic characteristics θ(h) and K(h) were described by the analytical functions of (Mualem, 1976) and (Van Genuchten, 1980):

θ_r and θ_s denote the residual (r) and saturated (s) water content [L^3 L^{-3}], respectively; K_s is the saturated hydraulic conductivity [LT^{-1}]; α [L-1] and n [-] are shape parameters, m=1- 5 1/n; S_e is effective saturation [-]; and *l* is a pore-connectivity parameter estimated to be about 0.5 as an average for many soils (Mualem, 1976).

In Hydrus-2D (Simunek et al. 1999), the two dimensional solute transport under transient water flow conditions in a partially saturated porous medium is expressed by the following Equations 8:

$$\frac{\partial \theta c}{\partial t} = \frac{\partial}{\partial x_i}\left(\theta D_{ij}\frac{\partial c}{\partial x_j}\right) - NU(c,r,z,t) \quad ...(8)$$

in which the subscripts *i* and *j* denote either *r* or *z* and *c* denotes the solute concentration in the soil solution (ML–3). The first term on the right side represents the solute flux due to dispersion, the second term is the solute flux due to convection with flowing water, and the third term represents root nutrient uptake. *Dij* is the dispersion coefficient (L_2 T^{-1}), and *NU* defines the local passive solute uptake (ML^{-3} T^{-1}) by plant roots, which is a function of time and the spatial coordinates:

$$NU(r,z,t) = C(r,z,t)S(r,z,t) \quad ....(9)$$

Electrical conductivity of water

Water samples taken during the field experiment were averaged and entered as the solute concentration of water emitted from the time-dependent variable flux source. Mean EC_w values during different seven irrigations were 1.23 ± 0.03, 1.03 ± 0.1, 1.00 ± 0.01, 1.10 ± 0.1, 1.13 ± 0.1, 1.25 ± 0.01, 1.11 ± 0.04 and 1.22 ± 0.05 dS/m. For model simulations, mean EC_w from three repeats was entered for each irrigation applications. The initial value of soil EC_e was 0.79 dS/m.

Results and Discussion

Soil pH and ECe

The soil samples were collected at same depths and same location after harvest for all treatments. The pH at various soil depths ranged from 8.0 to 8.5 in the soil profile before experiment which changed to 7.8 to 8.6 after the experiment. Before experiment, the maximum soil pH was 8.5, 8.5 and 8.4 for furrows under treatment T_1, T_2 and T_3 respectively, while minimum soil pH for all treatments was 8.0. After harvesting of the crop, the maximum soil pH was 8.6, 8.7 and 8.5 for treatments T_1, T_2 and T_3 respectively. Similarly, minimum pH for all treatments was 7.9. The results of soil pH as influenced by the size of raised bed are shown in Table 1 and analysis of variance demonstrated a non-significant ($p>0.05$) effect of the size of raised bed on soil pH.

Moreover, the results of soil analysis in respect of electrical conductivity of soil saturation extract (ECe) as influenced by different treatments (different sizes of the raised bed-furrow) are given in Table 1. It is evident from the analysis of variance that the effect of different sizes of the raised bed-furrow on the ECe of soil profile was non-significant ($p > 0.05$). The maximum value of ECe before the experiment was 1.1 dS/m and the minimum value was noted 1.0 dS/m under the treatment T_1. However, before the trial, the maximum ECe in soil profile was 1.2 dS/m under the treatments T_2 and T_3, while the minimum ECe values were noted as 1.0 dS/m and 0.9 dS/m respectively. The ECe of soil samples taken after experiment was 1.2 dS/m (maximum) and 0.9 dS/m (minimum) under the treatment T_1. Likewise, the maximum value of ECe was noted 1.3 dS/m, and the minimum was recorded 1.0 dS/m under the treatment T_2 while under the treatment T_3 the maximum and minimum values were recorded 1.3 dS/m and 1.0 dS/m respectively.

Soil dry bulk density

The dry bulk density of the soil down to 20 cm depth under the experimental treatments T_1, T_2 and T_3 are presented in Figure 5. The analysis of variance indicates that the dry density of soil profile was non-significantly ($p>0.05$) affected by the different sizes of the raised bed-furrow. The determined data of the dry density of soil profile with treatment T_1, T_2 and T_3 indicated that the data was varied from 1.32 g/cm^3, 1.33 g/cm^3 and 1.38 g/cm^3 before the experiment to 1.34 g/cm^3, 1.34 g/cm^3 and 1.39 g/cm^3 respectively after the experiment. Hence, a negligible increase in dry bulk density of soil was observed in the present study in all the treatments at a depth of 0-20 cm.

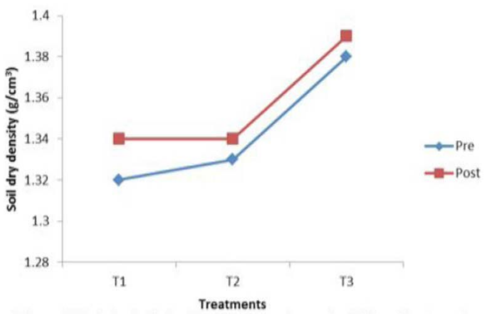

Figure 5: *Soil dry bulk density of soil samples under different treatments.*

Crop yield

The results of bottle gourd yield are presented in Table 2, which show a significant ($P<0.05$) effect of the size of raised bed furrow on crop yield. The total picked yield of ridge gourd was 8500 kg/ha, 8748 kg/ha and 6547 kg/ha from the experimental subplots under treatment T_1, T_2 and T_3 respectively. The average yield of ridge gourd with convention flood irrigation method is reported as 4895 kg/ha (Shreeniwas et al., 2000). Thus, about 42.4%, 44.1%, and 25.2% more crop yield were obtained with T_1, T_2 and T_3 respectively. 3.4 Crop Water Productivity (CWP).

The crop water productivity with different sizes of raised bed furrow irrigation method was determined and are presented in Table 3. The crop water productivity (CWP) for treatment T_1 was 2.95 kg/m^3 while it was 3.74 kg/m^3 and 3.33 kg/m^3 for treatments T_2 and T_3 respectively. Thus, highest CWP was obtained with treatment T_2 followed by treatments T_3 and T_1 respectively.

Simulations of water and solute transport in soil profile with HYDRUS model

Figure 6 shows that the simulated soil is wetting patterns in the profile at different time intervals for all three treatments. It shows that as the size of raised bed increased the central part of the raised remained unsaturated. However, in all treatments sides of raised-bed/furrow received enough water to support the plant growth.

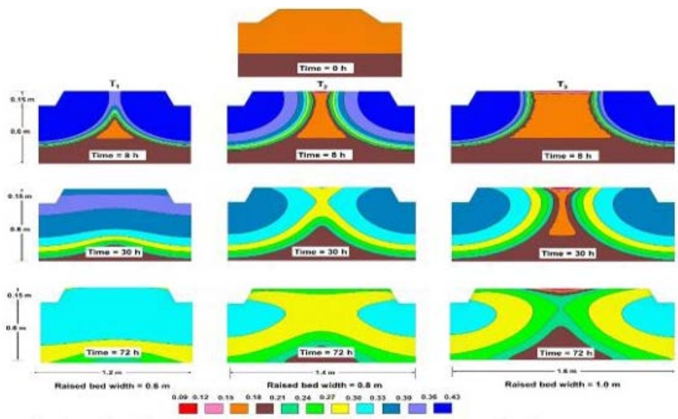

Figure 6: *Simulated soil patterns at different time intervals for treatments T_1, T_2 and T_3.*

Whereas, the salt distribution (ECe) patterns in the soil profile (Figure 7) shows down to 0.75 m for all three treatments at the end of the experiment. It shows an almost similar pattern of salt distribution in

Table 1: *Soil pH and ECe of the 0–80cm soil layer for the salt distribution in soil profile under different treatments.*

Soil depth (cm)	Pre experiment						Post experiment					
	T_1		T_2		T_3		T_1		T_2		T_3	
	Ridge	Furrow	Ridge	Furrow	Ridge	Furrow	Ridge	Furrow	Ridge	Furrow	Ridge	Furrow
0-20	8.4	8.3	8.5	8.1	8.1	8.4	8.6	7.9	8.7	7.9	8.4	8.3
20-40	8.5	8.2	8.3	8.3	8.2	8.2	8.6	8.0	8.5	8.0	8.3	7.9
40-60	8.3	8.0	8.1	8.0	8.3	8.1	8.3	7.9	8.1	8.0	8.3	8.0
60-80	8.2	8.0	8.0	8.0	8.0	8.1	8.2	8.0	8.0	8.0	8.1	8.1
Soil EC_e (dS/m) of the profile under different treatments												
0-20	1.1	1.1	1.2	1.1	1.0	1.1	1.2	1.0	1.3	1.0	1.3	1.0
20-40	1.1	1.0	1.1	1.1	1.1	1.0	1.0	0.9	1.1	1.0	1.2	1.0
40-60	1.0	1.1	1.0	1.0	1.0	1.20	1.0	1.1	1.0	1.1	1.0	1.3
60-80	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.1	1.0	1.1	1.0	1.2

the profile except at the center of the raised bed where slightly more salt was accumulated for treatments T_1 and T_2 as compared to treatment T_3.

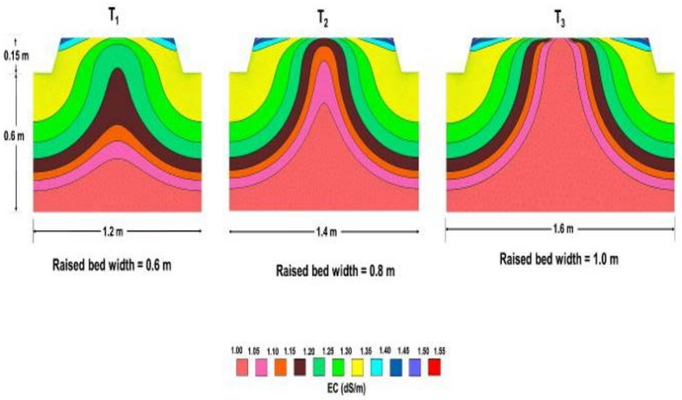

Figure 7: *Simulated salt distribution [EC (dS/m) patterns in soil profile down to 0.75 m under treatments T_1, T_2 and T_3 at the end of the experiment.*

Water conservation methods, such as raised bed-furrow irrigation method, is considerable as an useful technique of irrigation to increase crop water productivity and getting more crop yield as compared to other furrow irrigation method in the limited water supplies. The origins of the furrow raised-bed cultivation have traditionally been related to water management problems, either providing opportunities to reduce the effects of excess moisture on rainwater irrigation or more effectively providing irrigation water in high-yielding irrigation systems (Fahong et al., 2004b). One of the objectives of sustainable agricultural development is to expand the cultivated area by reclaiming and cultivating an additional land and finding alternative renewable water resources in new areas. Whereas, the vertical expansion targets at increasing crop productivity per unit of water use, which improves the on-farm irrigation efficiency. While, it is reported that the water scarcity will affect one-third of the population in developing countries by the year 2025, (Seckler et al., 1999), in this manner there will be insufficient water resources to cover agricultural, domestic, and industrial purpose. However, traditional irrigation methods like flood, basin, border and furrow are widely used for irrigation of the crops, which are considered inefficient irrigation methods. Thus the present study was conducted to determine the effect of the size of raised bed on salt distribution under soil profile.

However, the average EC_e of soil profile increased 0.02 dS/m and 0.13 dS/m under T2 and T3 respectively but there was no change under T1 post-experiment for samples taken from the center of the ridge. Whereas, average EC_e decreased 0.02 dS/m and 0.08 dS/m for samples taken from the furrow bed under T_1 and T_3 respectively but it did not change under T_2. The analysis of variance showed non-significant ($p>0.05$) change in the EC_e of soil profile due to different sizes of the raised bed-furrow. These results were close to (Ma et al., 2008), who determined that the EC_e was increased in upper layers of soil profile due to the accumulation of salts because of small soil particles and leaching of salt from the lower soil layers by deep percolation due to coarse soil particles. Moreover, (Bo et al., 2015), who also concluded that the soil EC_e increased in surface soil layer in ridge due to high evapotranspiration from the soil surface.

Consequently, the soil pH in the soil profile after experiment increased about 0.1 under treatments T_2 and T_3 while it remained unchanged under treatment T_1 at the top center of the ridge while it decreased about 0.1 for samples taken at the bottom of furrow under all three treatments. The analysis of variance demonstrated a non-significant ($p > 0.05$) effect of the size of raised bed on the change in soil pH after experiment for soil samples taken from both ridge and furrow. The experimental results showed that the salt concentration was increased on the ridge while salts leached down from the furrow bottom. These results are in similar trend with those of (Rowell, 1994) (Ouhadi and Goodarzi, 2007), who reported that the decrease in pH of soil at upper layers are due to upward movement of irrigation water, which contain soluble salts on the top of ridge or evaporation from top layer of ridges due to larger width of bed. The salts available in the upper layer may be leached down or stored in the lower layer. These results showed the pH of soil increased in deeper layers of soil profile in furrows after experiment which may be due to leaching of salts from upper layers and their accumulation on lower soil layer.

In addition, the crop yield was 42.4%, 44.1% and 25.2% more with treatments T_1, T_2 and T_3 respectively when compared to yield of ridge gourd with conventional irrigation methods. Whereas, the crop yield was 2.9% more under treatment T_2, while it was 22.9% less under T_3 when compared with treatment T_1. The yield was significantly higher under treatment T_2 compared to treatment T_1 (Table 2). These results are similar to those given by (Khoso, 1994), who reported that crop yield increased under raised bed, due to rich nutritional soil, being loose, had a better environment for aeration, water movement, root development and sufficient moisture content. Raised bed furrow irrigation method has the potential of better utilization of water and produces more yield as compared with conventional irrigation methods.

Table 2: *Crop yield under different treatments.*

Treat-ment	Crop Yield			% increase
	(kg/subplot)	(kg/furrow)	(kg/ha)	
T_1	51.0	8.50	8500	42.4
T_2	65.0	10.8	8748	44.1
T_3	58.0	9.6	6547	25.2

Moreover, the crop water productivity increased by 0.79 kg/m^3 and 0.38 kg/m^3 under T_2 and T_3 respectively compared with T_1. The results were significant under T_2 and T_3 (Table 3). The results are in similarity reported by (Limon-Ortega et al., 2008), they said the permanent raised bed as very suitable, easy and beneficial method to increased crop water productivity as compared to flood method.

Table 3: *Crop water productivity under different treatments.*

Treat-ments	Yield (kg per subplot)	Yield (kg/ha)	Irrigation water (m^3/ha)	CWP (kg/m^3)
T_1	51.0	8500	2880	2.95
T_2	65.0	8748	2333	3.74
T_3	58.0	6547	1964	3.33

Furthermore, the simulations carried out by HYDRUS-2D model showed that with increasing size of raised bed, the center of the raised bed does not get the required quantity of water, hence remains unsaturated. However, sides of raised-bed/furrow, where the ridge gourd was sown, received enough water to support the plant growth in all treatments. The salt distribution [EC_e (dS/m)] the soil profile down to 0.75 m for all three treatments at the end of the experiment demonstrated that there was a uniform distribution of salt EC_e (dS/m) in the profile except at the center of the raised bed where slightly higher salt concentration was observed for treatments T_1 and T_2 compared to treatment T_3.

Conclusions and Recommendations

Based on the analysis and simulation results, it was found that the average soil pH increased under T_2 and T_3, as compared to T_1 treatments at the top center of ridge, while the pH was decreased at the bottom of furrows under all three treatments. However, the EC_e slightly increased by 0.02 dS/m and 0.13 dS/m in T_2 and T_3 treatments respectively after the experiment at the top center of the ridge. Whereas, the average EC_e of soil profile at the furrow bed decreased 0.02 dS/m and 0.08 dS/m under treatments T_1 and T_3 respectively, but it did not change under treatment T_2. The yield and CWP were recorded higher under Raised bed with width of 0.8m (T_2) treatment with compared to other treatments. In addition, the simulation results suggested that salts moved upward to the top (upper layers) and concentrated at the center of ridge for T_2 and T_3 treatments but leached down from the bottom of furrows. Thus, the size of raised bed in bed-furrow irrigation method has a significant effect on crop yield, water productivity, and salt distribution. Through the results of current study, we strongly suggested to the policymakers and stakeholders for understand the responses and adaptations of the raised bed irrigation method with 0.80m bed width for growing of vegetable/row crops under different dry region with limited irrigation sources for the long-term agricultural sustainability. Furthermore, this study will enable us to conduct future research on the appropriate sizes and shape of raised bed furrows under distinct irrigation frequency for the vegetable/row crops in regards to enhance crop water productivity and water saving under different climatic regions.

Acknowledgments

First of all, thanks to the contributors for their support and we wish special thanks to the reviewers for the recommendations, which improved the manuscript. This work was edited for proper English language, grammar and overall style by native English-speaking editors of American Journal Experts.

Author Contributions

Muhammad Sohail Memon and Khadim Ullah designed performed the experiments, Khadim Ullah was also involved in data collection. Altaf Ali Siyal and Ahmed Ali Tagar supported Muhammad Sohail Memon in the writing the manuscript, and substantial contributed to the concept of the manuscript, to the acquisition and interpretation of data. Naimatullah Leghari support Muhammad Sohail Memon in manuscript revisions and resources. Syed Tahir Ata-ul-karim and Muhammad Tahir supported Muhammad Sohail Memon in performing the data analyzing and development of the idea. Noreena Memon contributed to the interpretation of results and editing format. All authors have revised and approved the final manuscript.

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