Effects of Biochar and Compost on Growth and Yield of Sweet Pepper under a Partial Root-Zone Drying Irrigation System

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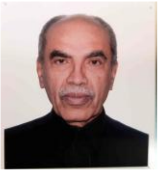

(Corresponding Author)

Abdulrasoul Al-Omran[1]
Alaa Ibrahim[2]
Abdulaziz Alharbi[3]

[1,2]*Soil Science Department, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia.*
[1]*Email: rasoul@ksu.edu.sa Tel: 966114678444*
[2]*Email: iamm_hishesh@yahoo.com Tel: 966114678441*
[3]*Plant Production Department, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia.*
[3]*Email: arharbi@hotmail.com Tel: 966114678347*

ABSTRACT

This study was carried out to assess the effects of compost (CO2 and CO4), biochar (B2 and B4), and biochar–compost mixture (Mix2 and Mix4), at rates of 2% and 4%, on the yield and water use efficiency (WUE) of sweet pepper under greenhouse conditions. Pepper plants were irrigated by partial root-zone drying (PRD) using two levels of water irrigation, 75% from evapotranspiration (ETc) ($PRD_{75\%ETc}$) and 50% from ETc ($PRD_{50\%ETc}$). The objectives of this study were to evaluate the distribution of soil water, salinity, and root system of bell pepper and changes in the WUE of bell pepper due to the PRD technique. The contour lines showed that the salinity was improved by adding biochar, compost, and their combination because the moisture content of the amended soil was the highest compared to that of the control (untreated soil). The WUE of pepper under $PRD_{75\%ETc}$ was 7.5, 6.1, 8.7, 6.69, 9.5, and 7.7 kg m^{-3} for B4, B2, CO4, CO2, Mix4, and Mix2, respectively. The WUE under $PRD_{50\%ETc}$ was 9.8, 8.2, 10.2, 8.5, 11.7, and 10.1 kg m^{-3} for B4, B2, CO4, CO2, Mix4, and Mix2, respectively. The irrigation water saved was 35% and 57% under $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$, respectively.

Keywords: *Biochar, Compost, Partial root-zone drying, Penetrability, Soil moisture distribution, Salt distribution.*

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Highlights of this paper

- The date palm biochar–compost mixture had a higher impact than did both the compost and biochar on yield.
- A rate of 4% of the combination of biochar and compost gave a better results.
- The pepper WUE and crop yield can be maintained under reduced irrigation volume, especially during periods of water shortage.
- The PRD technique combined with a biochar–compost amendment material has the potential to improve sustainable agriculture under arid.
- The impact of biochar and compost treatment was more evidence to improve soil physical properties.

1. INTRODUCTION

Sandy soil management requires agricultural practices that enhance the physico-chemical properties of soil to improve crop production sustainability over time [1]. Favorable soil physical conditions are beneficial for soil fertility, plant growth, and root distribution, which provide the plant with oxygen, nutrients, and water, and are thus related to efficient crop/vegetable production and soil sustainability [2, 3]. Good soil management is an important practice for improving the soil structure, aggregate stability, porosity, and soil organic matter/carbon content. Moreover, agricultural soil management practices, such as the application of organic amendments (compost, manure, sawdust, and rice straw) positively affect water movement, soil water, and crop productivity under arid and semi-arid area conditions [4].

Many experimental studies have reported that using biochar as an organic amendment material could potentially modify the hydro-physical properties of soil, especially the pore size, distribution, and porosity; therefore, the use of biochar could improve the soil available water for plant growth [5-8]. Many scientific studies have focused on elucidating the behavior of the soil hydro-physical attributes affected by irrigation management techniques. Mishra and Kushwaha [9] conducted a study investigating the effects of irrigation management on the physical properties of sandy loam soils. They found that the bulk density and saturated hydraulic conductivity were not altered under varied irrigation treatments. Moreover, Alrajhi, et al. [10] reported that there were no significant changes in saturated hydraulic conductivity under different scenarios of partial root-zone drying (PRD) irrigation. Sepaskhah and Ahmadi [11] proved that PRD is a good technique for deficit irrigation on agronomic and horticultural farms. In PRD, the irrigation water can be conserved and saved till 50% evapotranspiration without significant reductions in yield. Dorji, et al. [12] in a study on pepper irrigation, reported that the water use efficiency (WUE) was 12%, 20.1%, and 17.1% for conventional irrigation, regulated deficit irrigation, and PRD, respectively. They reported that PRD saved irrigation water by 50%. Qin, et al. [13]; Lepaja, et al. [14]; Chandra, et al. [15] and summarized the advantages of PRD as follows: 1) improved WUE and nutrient use efficiency, 2) reduction irrigation water use, and 3) improved fruit quality.

In other study, using full irrigation (FI), deficit irrigation (DI), and PRD irrigation for tomato under greenhouse conditions, Akhtar, et al. [16] reported that biochar applied to soil at rates of 0% and 5% by weight resulted in an increased soil moisture content and yield production. The results showed a significant increase in the WUE by 35% and 15% for PRD and DI, respectively, compared to that for FI, and an increase in the fruit yield of tomato with biochar addition by 20% and 13% for FI and PRD, respectively, compared to that in untreated soil. Aladenola and Madramootoo [17] conducted a study on the effects of various levels of water application on the WUE of bell pepper: they reported that the WUE was 39.2, 30.7, 6.31 and 1.45 kg m^{-3} for 120%, 100%, 80%, and 40% ETc, respectively. The total yield was 26,953, 26,880, 13,605, and 5107 kg ha^{-1} for 120%, 100%, 80%, and 40% ETc, respectively. The results showed that the volume of irrigation water and yield had a linear relationship, and there were no significant differences between 120% and 100% ETc. Sezen, et al. [18] investigated the effects of three irrigation intervals based on cumulative pan evaporation (18–22, 38–42, and 58-62 mm) on the WUE and yield of bell pepper. They reported that when the plant-pan coefficient = 0.5, the WUEs were 7.6, 6.1, and 5.7 kg m^{-3} for 18–22, 38–42, and 58–62 mm, respectively. The yield values were 28.1, 22.3, and 21.6 kg ha^{-1} for 18–22, 38–42, and 58–62 mm, respectively. Therefore, in this study, we will investigate the synergetic effects of PRD irrigation and biochar, compost, and their combination on the soil water distribution, salinity, and root system of bell pepper, and study changes in the WUE of bell pepper.

2. MATERIALS AND METHODS

2.1 Preparation of Biochar and Compost

Biochar production was performed in a greenhouse complex of Almohous Farm, 120 km northwest of Riyadh, Kingdom of Saudi Arabia (altitude: 722 m above mean sea level, latitude: 25° 17′ 40″ N longitude: 45° 52′ 55″ E). Leaves of the date palm were used, without leaflets, as the source material for biochar production. The leaves were collected from different locations, exposed to direct sunlight to dry out, and then the petiole bases (fronds) were cut down to small pieces (20–30 cm). The pieces were packed in the biochar kiln. The kiln was designed as a stainless-steel cylinder container covered tightly to minimize the air volume and provide almost oxygen-free conditions. The kiln was subjected to pyrolysis at a temperature of 400–450 ± 10 °C. The biochar pieces were crushed manually by a 12 kg hammer, ground using an electrical grinder, and screened through a 2 mm sieve. Commercial compost was purchased from a production facility in Riyadh. The products were screened through a 2 mm sieve before mixing with the soil. The moisture content, mobile materials, ash, and fixed carbon (resident materials), as a proximate analysis of biochar and compost, were determined according to ASTM D1762-84 [19]. The specific surface area was estimated by the Brunauer–Emmett–Teller (BET) method using the adsorption of pure nitrogen by Micromeritics ASAP 2020 BET Surface Area and Porosity Analyzer (Micromeritics Instrument Co., USA). An aqueous extract 1:25 (w/v) from biochar and compost was used for determining the EC and pH using a conductivity meter and pH meter, respectively. The C, H, and N contents were measured using a CHN analyzer (Series II; PerkinElmer, USA) Table 1. Selected properties of the soil were determined by standard procedures [20] and are presented in Table 2. The soil salinity was determined in the saturated paste extract. The soil texture was determined using a hydrometer after organic matter and lime removal, according to Hillel [21].

Table-1. Physico-chemical characteristics and proximate composition analysis of compost and biochar.

Parameter	Unit	Biochar	Compost
Specific surface area	$m^2\ g^{-1}$	237.8	1.01
pH (H_2O)	-	8.92	7.84
EC (1:10)	dS m^{-1}	7.78	7.43
OM	%	30.32	40.71
C	%	60.00	26.15
H	%	3.44	4.21
N	%	0.24	1.30
P	%	0.22	1.00
K	%	0.87	1.20
Ca	%	5.63	0.92
C/N ratio	-	250:1	20:1
Moisture	%	3.53	3.64
Mobile material	%	22.82	17.19
Ash	%	25.70	71.23
Resident material (Fixed carbon)	%	47.95	7.94

Table-2. Physico-chemical characteristics of soil properties.

Sand, %	Silt, %	Clay, %	Texture	pH	EC dS m^{-1}	OM %	Bulk density kg m^{-3}
82.88	8.21	8.91	Loamy sand	7.9	1.28	0.63	1400
Soil soluble cations and anions, meq L^{-1}							
Na^{+1}	K^{+1}	Ca^{+2}	Mg^{+2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-2}	$CaCO_3$, %
3.03	1.04	7.88	2.22	1.11	4.02	11.01	33.3

Chemical characteristics of irrigation water

EC dS m^{-1}	pH	Cations (meq L-1)				Anions (meq L^{-1})			
		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	SO_4^{-2}
0.35	6.93	0.26	0.08	2.68	0.06	-	0.12	2.02	1.2

2.2. Experiment Layout

Seven treatments were used in the greenhouse experiment to investigate the effect of date palm biochar, compost, and their combination on the WUE, selected physical properties, and moisture and salt distribution of sandy soils under PRD irrigation techniques Table 3. The seven treatments that were included are as follows: control (unamended soil), date palm biochar treatments (B4 and B2), and compost treatment (CO4 and CO2) at rates of 4% and 2%, and two mixture treatments of biochar and compost (Mix4 and Mix2) at rates of 4% (2% biochar + 2% compost) and 2% (1% biochar + 1% compost).

Table-3. Rates of amendment materials and irrigation levels in a greenhouse experiment.

Treatment	No	Description
Irrigation level	2	- $PRD_{75\%ETc}$ (75% ETc)
		- $PRD_{50\%ETc}$ (50% ETc)
		- Control (Unamended soil)
		- Biochar rate 4% (B4)
		- Biochar rate 2% (B2)
Treatment	7	- Compost rate 4% (CO4)
		- Compost rate 2% (CO2)
		- Biochar rate 2% + Compost rate 2% (Mix4)
		- Biochar rate 1% + Compost rate 1% (Mix2)
Replicates	3	- Rep1, Rep2, and Rep3

* Notes:
a- Total number of experimental units = 2 × 7 × 3 = 42 plots.
b- Experimental unit area = 2 m × 3.25 m = 6.5 m2.

The greenhouse experiment was carried out at Dirab Agricultural Research Station. A drip irrigation system was designed inside the greenhouse using double lines (16 mm diameter) of inline emitters per each plant row with a discharge rate of 6 L h^{-1}. Manual valve-controlled dual emitter lines were designed for irrigating the plant row for PRD (two emitters per plant). PRD was carried out using an on/off technique [22, 23] at irrigation levels of 75% and 50% ETc ($PRD_{75\%ETc}$ and $PRD_{50\%ETc}$). PRD was managed by turning off the emitter line and opening the next adjacent line during the first irrigation. During the second irrigation, the emitter line that was closed in the first irrigation was turned on and the opened one was turned off. Thereby, one portion of the root zone was irrigated, and the other portion was dried, alternately, during the same irrigation period, according to dry/wet cycle shifts. A rectangular ditch (25 cm wide × 25 cm depth) was manually dug in the soil. A plastic membrane was buried vertically inside the ditch to reduce the soil moisture flow from one part of the root system to the other. After that, the ditch was refilled with soil to firmly fix the plastic membrane in place [24, 25]. Thereby, the pepper root system was divided into two equal parts.

Bell pepper seeds (*Sonar F1*) were sown in 40 mm Jiffy-7 peat pellets under controlled nursery conditions on Sep. 19, 2016. After one month, the bell pepper seedlings were transported to the greenhouse for transplanting at a density of 2 plant m^{-2} on Oct. 20, 2016. The bell pepper plant rows were spaced 1 m apart, and the distance between each plant was 0.5 m. Two emitters irrigated one plant by the PRD technique. This irrigation system was applied to all treatments for three weeks to establish the pepper plants, after which $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$ were applied.

2.3. Bulk Density and Porosity

The bulk density was determined using the collected soil cores (5.5 cm in diameter and 6.6 cm in height) by drying the cores in an oven at 105 °C for 24 h and calculating the mass of the dry soil sample (g) and volume of the soil core (cm^3). Then, the bulk density (ρ) was calculated. In addition, the total porosity (Ø) was calculated from the interrelation between the particle density (ρs) and bulk density, according to McKenzie, et al. [26] and Huang, et al. [27].

2.4. Penetrability Test

A cone penetrometer (The Investigator™ Soil Compaction Meter; Spectrum Technologies Inc., Aurora, IL, USA) was used to determine the penetration resistance (PR) of soil by inserting it into the layers of soil at a steady rate and recording the required force. The resistance to penetration was measured at three randomly selected locations in each experimental unit [26].

2.5. Soil Water Content and Salt Distribution

The soil water and salt distribution patterns were described by contour line graphs. The location of soil core samples was taken according to the concept of *Cartesian coordinates*, with the pepper plant taken as the origin point of (0, 0, %). The coordinates of sampling were taken as (X, Y, Z), where X and Y represent the horizontal directions and Z represents the vertical or the salinity/moisture of the soil sample. In each experimental plot, soil samples were collected from the soil profile. The moisture content was determined using the gravimetric method after oven-drying at 105 °C. The distribution of salt was estimated by measuring the EC of the saturation extract (ECe) for each sample. Surfer [28] was used to produce contour maps for the distribution of salinity and soil moisture [29, 30]. This analysis was carried out at the end of the growing season.

2.6. Root Distribution

The distribution of the fine, medium, and coarse roots was graphically mapped. Photographs were taken using a digital camera from the soil profile at the root zone with dimensions of 30 cm from the plant in two directions (left and right) and at a 40 cm depth. The photographs were then transferred as a background for the dimensions of the Surfer software program and the X and Y dimensions of the fine, medium, and coarse roots were digitized as described by FAO [31] and reported by Al-Omran, et al. [32]; Al-Omran, et al. [33] and Al-Omran, et al. [34]. Moreover, the percentage of the root dry weight (%) was estimated. The root system was removed from the soil profile and cleaned with water to remove all soil particles. The root system was divided into four layers; the thickness of each layer was 10 cm and the roots of each layer were oven-dried at 70 °C and weighed (g). The percentage of root dry weight of each layer was calculated corresponding to total weight (g), and presented graphically for each 10 cm layer.

2.7. Gross Water Requirement

At the end of the growth season, the total yield and irrigation water applied were determined. The WUE was calculated for the irrigated bell pepper crop using the PRD irrigation technique under greenhouse conditions in detailed steps, as follows:

Leaching requirements:

$$LR = (EC_{iw})/(2 \times \text{Max } EC_e) \times (1/LE) \quad , \qquad (1)$$

where LR is the leaching requirements, ECiw is the salinity of irrigation water (dS m^{-1}), max ECe is the maximum tolerable salinity of soil for pepper crops (dS m^{-1}) (max ECe = 8.6), and LE is the leaching efficiency (LE = 90%) [35].

Uniformity distribution:

$$UD = (Q_{1/4})/(Q_{mean}) \times 100, \qquad (2)$$

where UD is the uniformity distribution, $Q_{1/4}$ is the mean of the lowest quarter of the observed emitter discharge values, and Q_{mean} is the average discharge of all of the emitters [36].

Storage efficiency (Ks):

The storage efficiency was estimated as Ks = 0.91 according to Karmeli and Keller [36]. Then, the irrigation efficiency was calculated by the following equation:

$$Eff_{irr} = EU \times Ks, \qquad (3)$$

Crop evapotranspiration (ETc): The calculation of evapotranspiration was based on the pan evaporation (class A pan) method, according to Allen, et al. [37] as follows:

$$ET_c = E_o \times K_p \times K_c, \qquad (4)$$

where ET_c is the maximum daily ET in (mm), E_o is the evaporation from the class A pan (mm), K_p is the pan coefficient, and K_c is the crop coefficient of pepper.

The K_c of bell pepper crop was recorded as K_c-ini = 0.6, K_c-mid = 1.15, and K_c-end = 0.9 from FAO standard tables [37]. The levels of 75% ET_c and 50% ET_c were used to calculated applied irrigation water for PRD, as $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$.

The daily crop water requirements (mm day^{-1}) were estimated by the following equation:

$$GWR = (ET_c)/[(1 - LR) \times (Eff_{irr})]. \qquad (5)$$

Water use efficiency:The WUE and irrigation water productivity (IWP) were calculated by the following equations:

$$WUE = \text{Yield (kg)/water consumption}, \qquad (6)$$

$$IWP = \text{Yield (kg)/applied water}, \qquad (7)$$

where yield is the crop production (kg) and applied water is in m^3 [38, 39].

2.8. Statistical Procedure Approach

The experimental design was laid out as a split-plot design in a randomized complete block design (RCBD) with triplicate experimental plots. Statistical analysis was applied for processing the statistical evaluation for all findings and measured data to test for variance and differences in the soil physical properties among investigated treatments. The significant differences between means and the interactions among measured parameters were analyzed by least significant difference (LSD), analysis of variance (ANOVA), correlation, and regression in the RCBD. All statistical analysis was carried out using SPSS v.23 software [40].

3. RESULTS AND DISCUSSION

3.1. Bulk Density and Porosity

The effects of amendment and application rate (2% and 4%) on the bulk density and porosity compared to those in un-amended soil are presented in Table 4. Accordingly, the application of biochar, compost, and biochar–compost mixture had an effect on the bulk density. The result of the bulk density analysis indicated that the irrigation level did not have a significant effect on the porosity (Ø) and bulk density of sandy soil. Table 4 shows the impact of the application rate of biochar, compost, and biochar–compost combination on both the bulk density and porosity (Ø). For instance, at the $PRD_{75\%ETc}$ irrigation level, the bulk density was decreased significantly by 13.2%, 9.2%, 3.9%, 2%, 13.8%, and 10.5% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. Thus, the porosity was increased by 17.7%, 12.4%, 5.3%, 2.7%, 18.6%, and 14.2% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. At the end of season under the $PRD_{50\%ETc}$ irrigation level, the bulk density was decreased by 11.9%, 9.9%, 4.6%, 3.3%, 11.3%, and 7.9% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments; and the porosity was significantly increased by 15.8%, 13.2%, 6.1%, 4.4%, 14.9%, and 10.5% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively.

Other studies suggest that the bulk density of compost is low because of its low organic matter content [41] and biochar is a porous material with high levels of porosity, pore volume, and specific surface area [42-44]. Inferentially, the bulk density and porosity of sandy soil in the present study was decreased because of the physical properties of biochar and compost. Therefore, the results displayed in Table 4 are in accordance with those of Suzuki, et al. [45]; Daniel and Bruno [46] and Githinji [47].

Table-4. Impact of biochar, compost, and biochar–compost mix on soil density and porosity under greenhouse.

Irrigation	Treatments	Density (g cm^{-3})	Ø (%)
	Control	1.52 a	0.426 g
	B4	1.32 d	0.502 b
	B2	1.38 c	0.479 d
$PRD_{75\%ETc}$			
	CO4	1.46 b	0.449 e
	CO2	1.49 ab	0.438 f
	Mix4	1.31 d	0.506 a
	Mix2	1.36 cd	0.487 c
	LSD(0.05)	0.521	0.004
	Control	1.51 a	0.430 f
	B4	1.33 d	0.498 a
	B2	1.36 cd	0.487 b
$PRD_{50\%ETc}$			
	CO4	1.44 b	0.457 d
	CO2	1.46 b	0.449 e
	Mix4	1.34 d	0.494 a
	Mix2	1.39 c	0.475 c
	LSD (0.05)	0.037	0.005

Control: unamended soil; B4 and B2, biochar amended soil with rates of 4% and 2%; CO4 and CO2, compost amended soil with rates of 4% and 2%; Mix4 and Mix2, biochar–compost amended soil with rates of 4% and 2%; Ø: porosity; $PRD_{75\%ETc}$: partial root-zone drying irrigation at a rate of 75% of reference evapotranspiration; $PRD_{50\%ETc}$: partial root-zone drying irrigation at a rate of 50% of reference evapotranspiration; and LSD (0.05): least significant difference at level of $p < 0.05$.

3.2. Soil Penetrability

Table 5 displays the findings of PR within the 0–5, 5–10, 10–15, and 15–20 cm soil layers for all treatments under the $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$ irrigation techniques. Moreover, adding the biochar, compost, and their mixture significantly affected the PR. Amendment with compost had the lowest effect on the PR of soil compared to that in unamended treatments (control). For instance, the PR in the control treatment was 689, 660, 571, and 580 KPa for 0–5, 5–10, 10–15, and 15–20 cm soil layers under $PRD_{75\%ETc}$, respectively. Under the $PRD_{50\%ETc}$ treatment, the PR in the control treatment was 870, 743, 660, and 665 KPa in the 0–5, 5–10, 10–15, and 15–20 cm soil layers, respectively. The PRs in the amended treatments in the 0–5 cm layer were 930, 911, 722, 711, 1022, and 1010 KPa in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments under $PRD_{75\%ETc}$. Therefore, the PRs in the 0–5 cm layer were 1022, 1009, 812, 805, 1118, and 1109 KPa in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments under $PRD_{50\%ETc}$. The results revealed that the PR significantly increased with the application of amendments materials, as well as with increased application rate (%) and reduced soil moisture content. These results are in accordance with those of Vaz, et al. [48] and Silva, et al. [49]. Some studies explained that that the PR was related to the distribution of particle size and soil pores, organic matter, structure and texture of soil, moisture content, and bulk density [50]. Generally, the PR was reduced in $PRD_{75\%ETc}$ due to the increasing soil moisture content.

Table-5. Impact of biochar, compost, and biochar–compost mix on penetration resistance (KPa) under $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$.

Irrigation level	Treatments	Soil depth, cm			
		0–5	5–10	10–15	15–20
$PRD_{75\%ETc}$	Control	689	660	571	580
	B4	930	998	568	572
	B2	911	927	565	575
	CO4	722	745	580	574
	CO2	710	731	577	577
	Mix4	1022	1039	581	580
	Mix2	1010	1029	582	574
$PRD_{50\%ETc}$	Control	870	743	660	665
	B4	1022	1056	672	612
	B2	1009	1032	670	616
	CO4	812	841	659	662
	CO2	805	827	661	663
	Mix4	1118	1126	665	670
	Mix2	1109	1114	662	662

3.3. Soil Water and Salt Distribution

Recorded data of soil water distribution in the pepper root zone are illustrated graphically with contour lines in the vertical section, which is presented in Figure 1 and 2. The figures illustrate the pattern of soil water content (%) for amended treatments compared to that in untreated soil (control) at irrigation levels of $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$. The pattern of soil water around the emitter line was the wettest under the emitter and was dry at the periphery of the wetting pattern [51]. The uniformity of moisture distribution was estimated by using parallel contours lines produced by Surfer software. Generally, the pattern of the soil water contours lines shows that the moisture level was higher inside the amended 0–10 cm surface layer than in the control. Thus, the moisture content in the amended layer was higher than that at other depths. Therefore, the moisture content ranged from 8.9% to 9.1%, 11.3% to 11.5%, 11.1% to 11.4%, 10% to 10.2%, 9.3% to 9.6%, 13.7% to 14.5%, and 12.3% to 12.6% in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively, at the 0–10 cm depth under $PRD_{75\%ETc}$. Under $PRD_{50\%ETc}$, the moisture content ranged from 6.3% to 7.6%; 10% to 10.6%; 9.1% to 9.7%; 8.3% to 8.7%; 7.9% to 8.2%; 11.8% to 12.4% and 11% to 11.5% for control, B4, B2, CO4, CO2, Mix4, and Mix2 in the amended 0–10 cm layer. The Mix4 treatments recorded the highest values of moisture content (θ m) in both irrigation scenarios and showed significant difference from those of other treatments. At both irrigation levels, the moisture content was decreased in the surface and gradually increased with depth in all treatments. The results represented in the graphical contour lines revealed that the soil water was stored in the amended 10-cm layer in the biochar, compost, and biochar–compost mixture treatments. These findings are agreed with Al-Omran, et al. [32]; Al-Omran, et al.

[33]. The highest values of soil water content were higher in $PRD_{75\%ETc}$ than $PRD_{50\%ETc}$ using a 6 L h^{-1} emitter discharge [52].

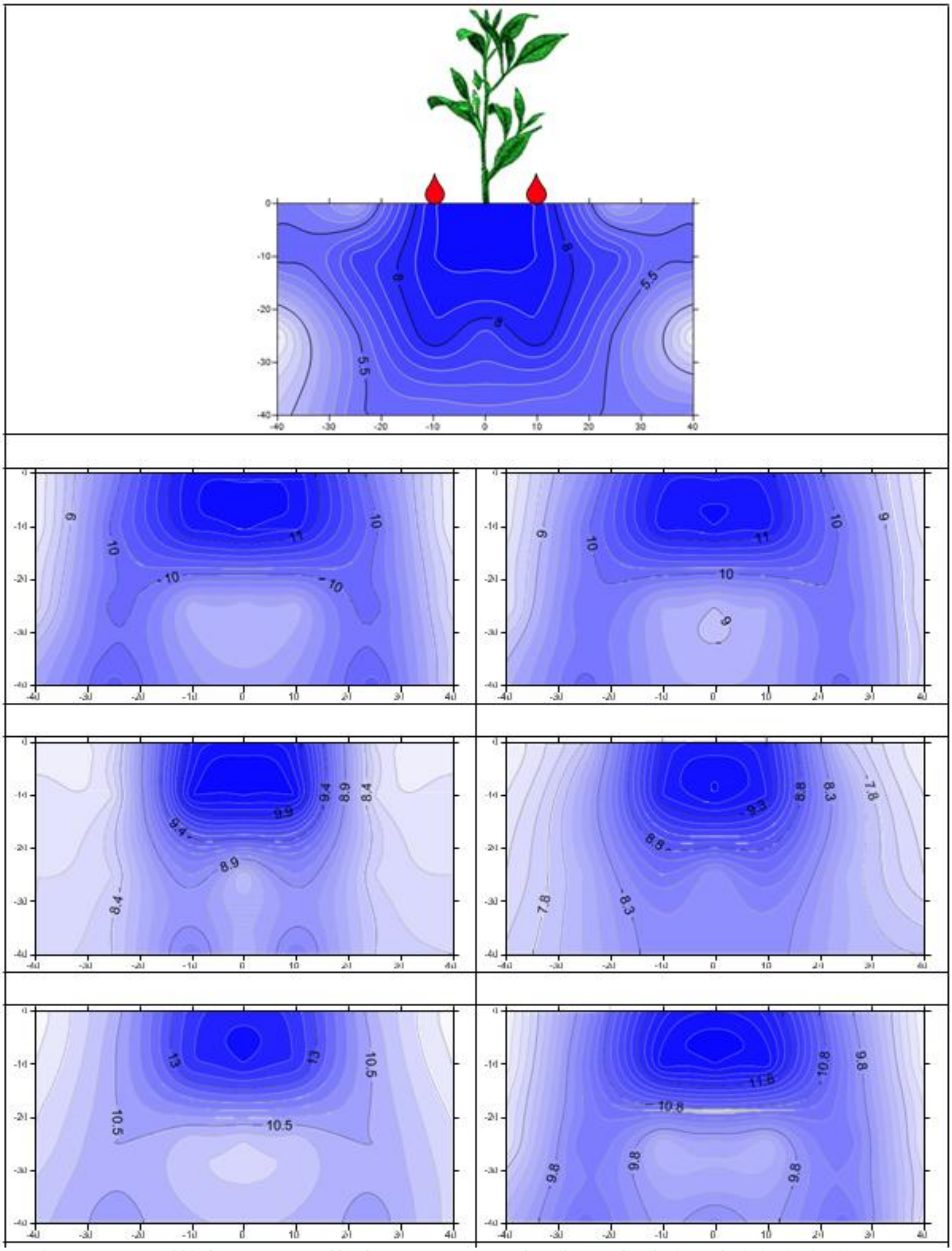


Figure-1. Impact of biochar, compost, and biochar–compost mix on the soil water distribution under irrigation level $PRD_{75\%ETc}$.

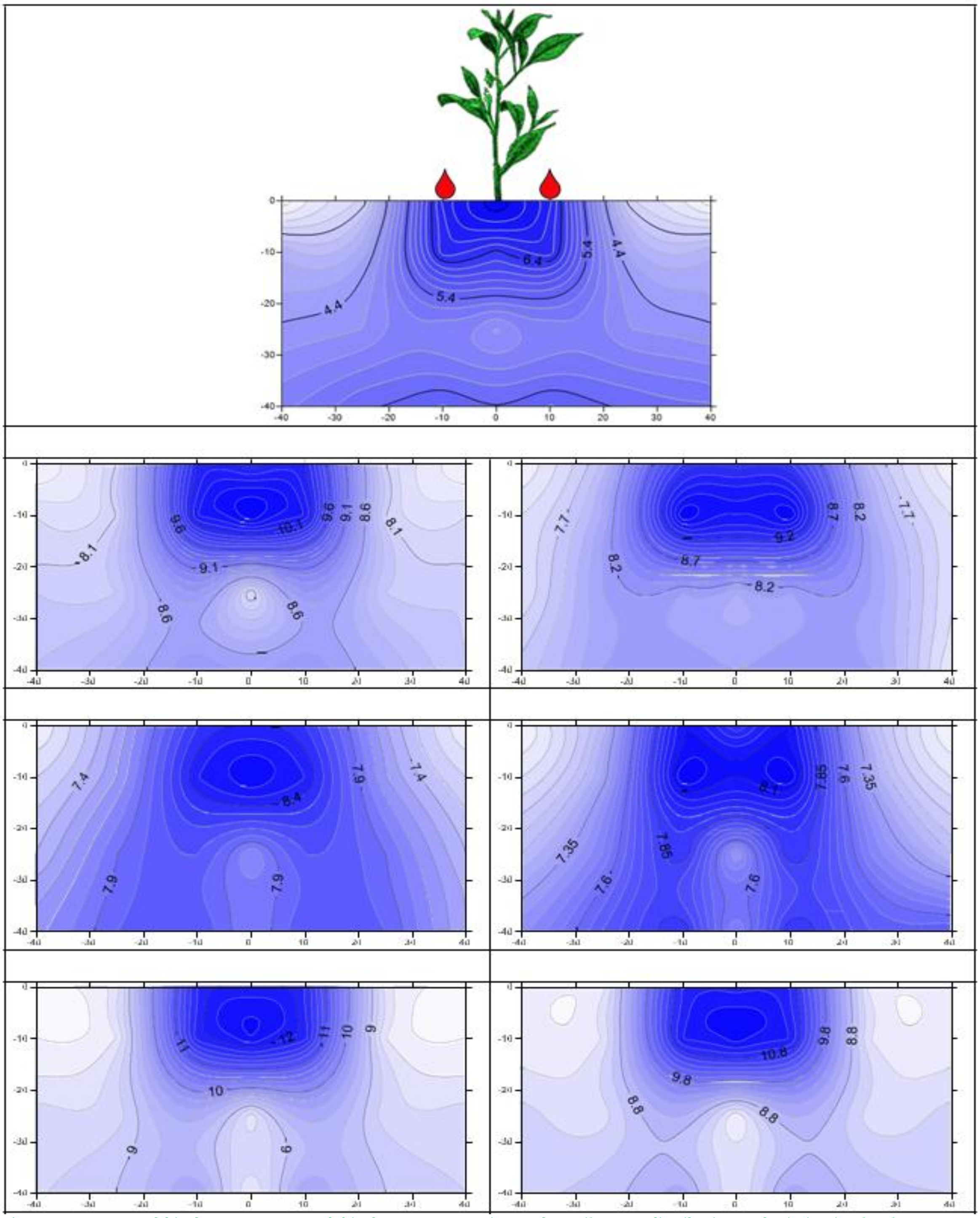


Figure-2. Impact of biochar, compost, and biochar–compost mix on the soil water distribution under irrigation level $PRD_{50\%ETc}$.

Figure 3 and 4 display the distribution of soil salts (ECe, dS m^{-1}) around the pepper plant for all treatments under $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$ using graphical contour lines. After measuring the moisture content for soil water distribution, the salinity was measured in the same soil samples. Repeating the processes of irrigation, evaporation, and wetting/drying cycles may produce a higher soil salinity than can be tolerated by plants [53]. Therefore, it is important to examine and understand the salt accumulation and migration inside the root zone.

Under $PRD_{75\%ETc}$, the ECe values beside the pepper plant were 2, 1.3, 1.7, 1.9, 2, 0.5, and 1.3 dS m^{-1} in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. Under $PRD_{50\%ETc}$, the ECe values were 2.1, 1.5, 1.6, 1.9, 2, 0.7, and 1.3 dS m^{-1} in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. The salinity of the root zone was significantly affected by the amount of irrigation water, distance between the plant and emitter, soil moisture, and hydraulic properties of the soil; therefore, the salinity was increased with increased distance from the emitter. The salt level was high at the periphery of the wetted area Hanson and May [51]. Generally, the soluble salt distribution was higher at the surface and decreased with depth. This is in accordance with the report of Al-Omran, et al. [33] which showed that the graphical contour maps of salinity illustrate that salt distribution showed adverse trends when compared with the moisture distribution.

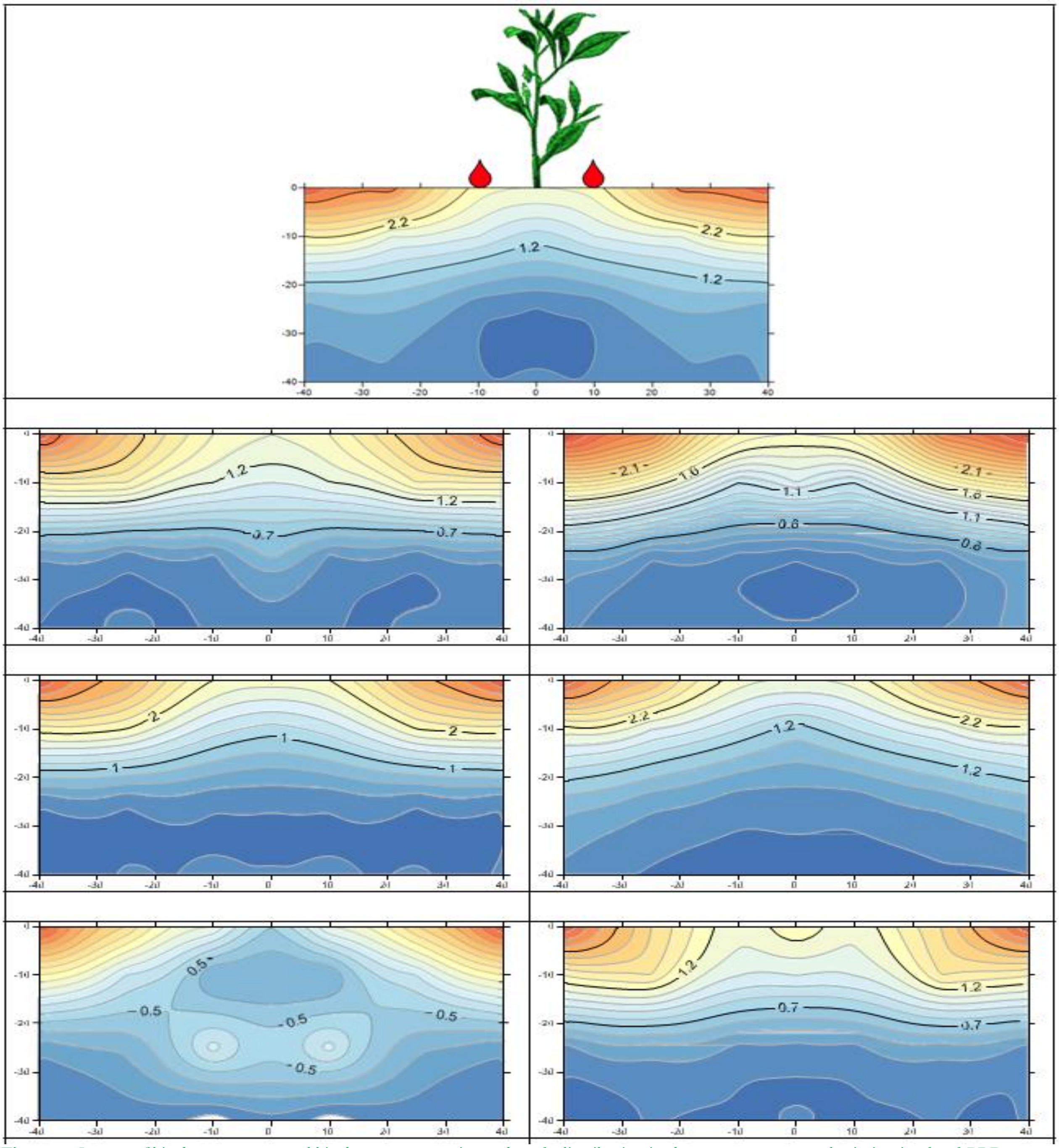


Figure-3. Impact of biochar, compost, and biochar–compost mix on the salt distribution in the root-zone area under irrigation level $PRD_{75\%ETc.}$

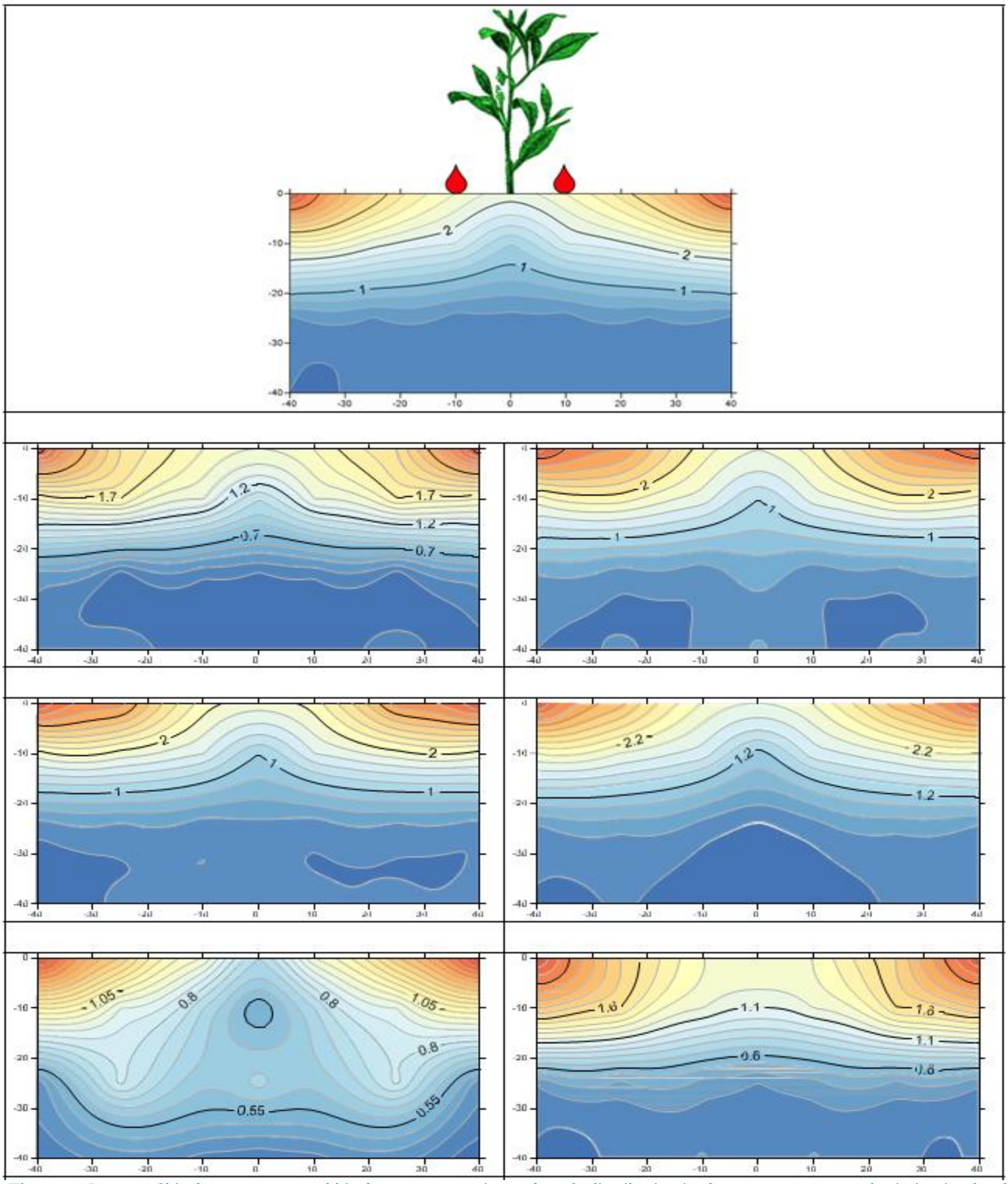


Figure-4. Impact of biochar, compost, and biochar–compost mix on the salt distribution in the root-zone area under irrigation level $PRD_{50\%ETc}$.

3.4. Root Distribution

At the end of the growth season, the data of the pepper root system was recorded and estimated by weighing the root in each 10 cm layer after drying at 70 °C. Figure 5 and 6 illustrate the impact of biochar, compost, and biochar–compost mixture amended layers on the behavior of pepper root system distribution. The amended layer has a positive effect on the dry weight of the root system. At the $PRD_{75\%ETc}$ irrigation level, the dry weight of the root was increased by 41.2%, 30%, 15.2%, 12.3%, 57.4%, and 35.1% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively, compared to that in the control. Under the $PRD_{50\%ETc}$ irrigation level, the dry weight of the root was increased by 37.7%, 31.1%, 17.5%, 10.9%, 60.9%, and 47.2% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively, compared to that in un-amended soil.

Moreover, Figure 5 and 6 highlight the distribution of fine, medium, and coarse roots for all treatments, graphically. The graphical results show that the amended layers produced the highest root density compared to that in untreated soils. The $PRD_{75\%ETc}$ technique improved the root density and distribution more in the 0–10 cm amended layer than did the $PRD_{50\%ETc}$ technique. The root density was the highest in treatments amended with the biochar–compost mixture. The density of the pepper root systems varied according to the amendment materials, application rates, and irrigation levels compared to that in the control units. Generally, the distribution of the root system reflects the behavior of the soil water pattern around the emitter position Figure 5 and 6. These findings are in accordance with those of Al-Omran, et al. [33]; Al-Omran, et al. [34]; Kemer and Coskan [54] and Zainul, et al. [55].

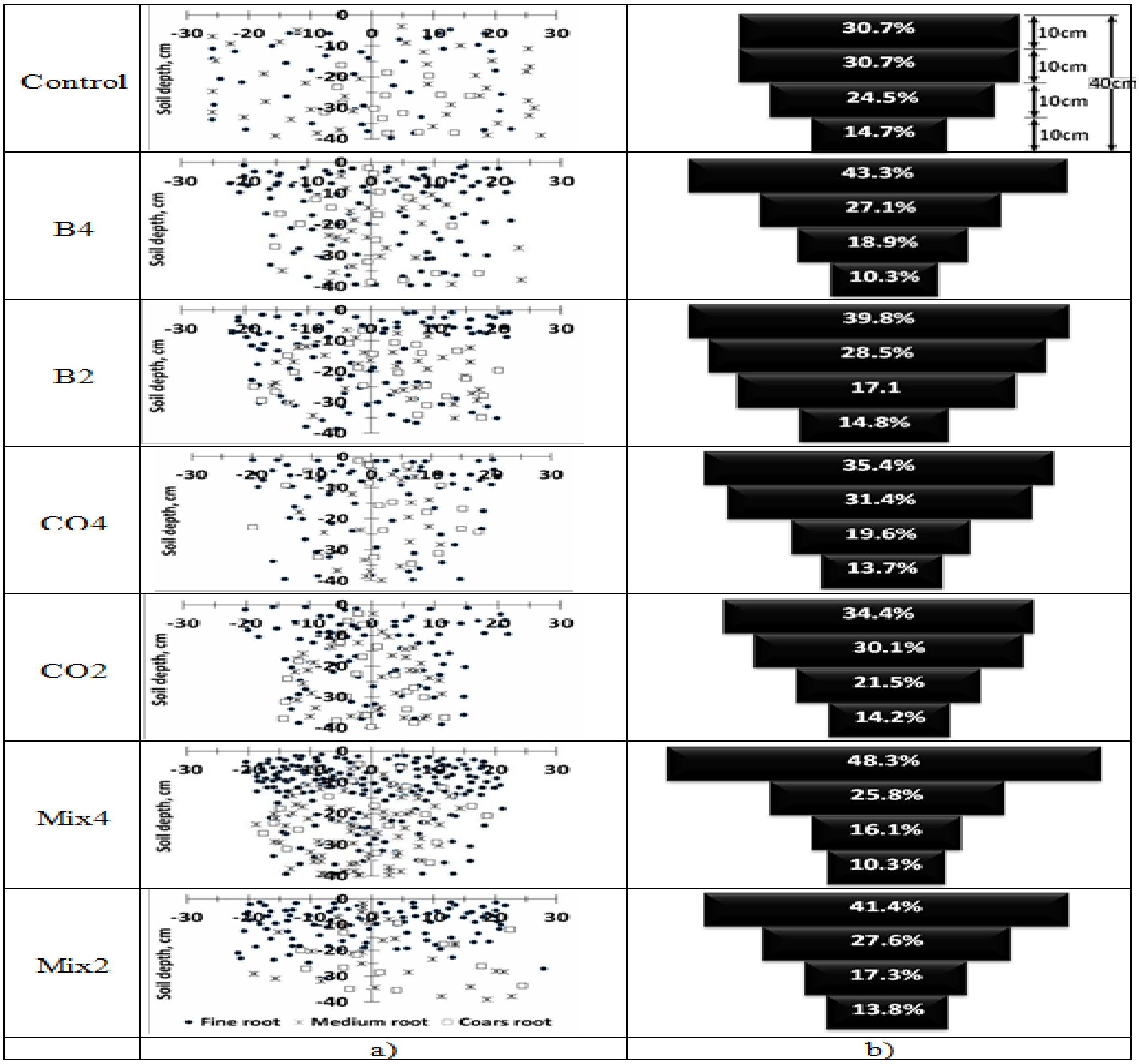


Figure-5. Impact of biochar, compost, and biochar–compost mix on root system distribution under irrigation level $PRD_{75\%ETc}$. a) Graphical distribution of fine, medium, and coarse roots and b) percentage of root dry weight for each layer.

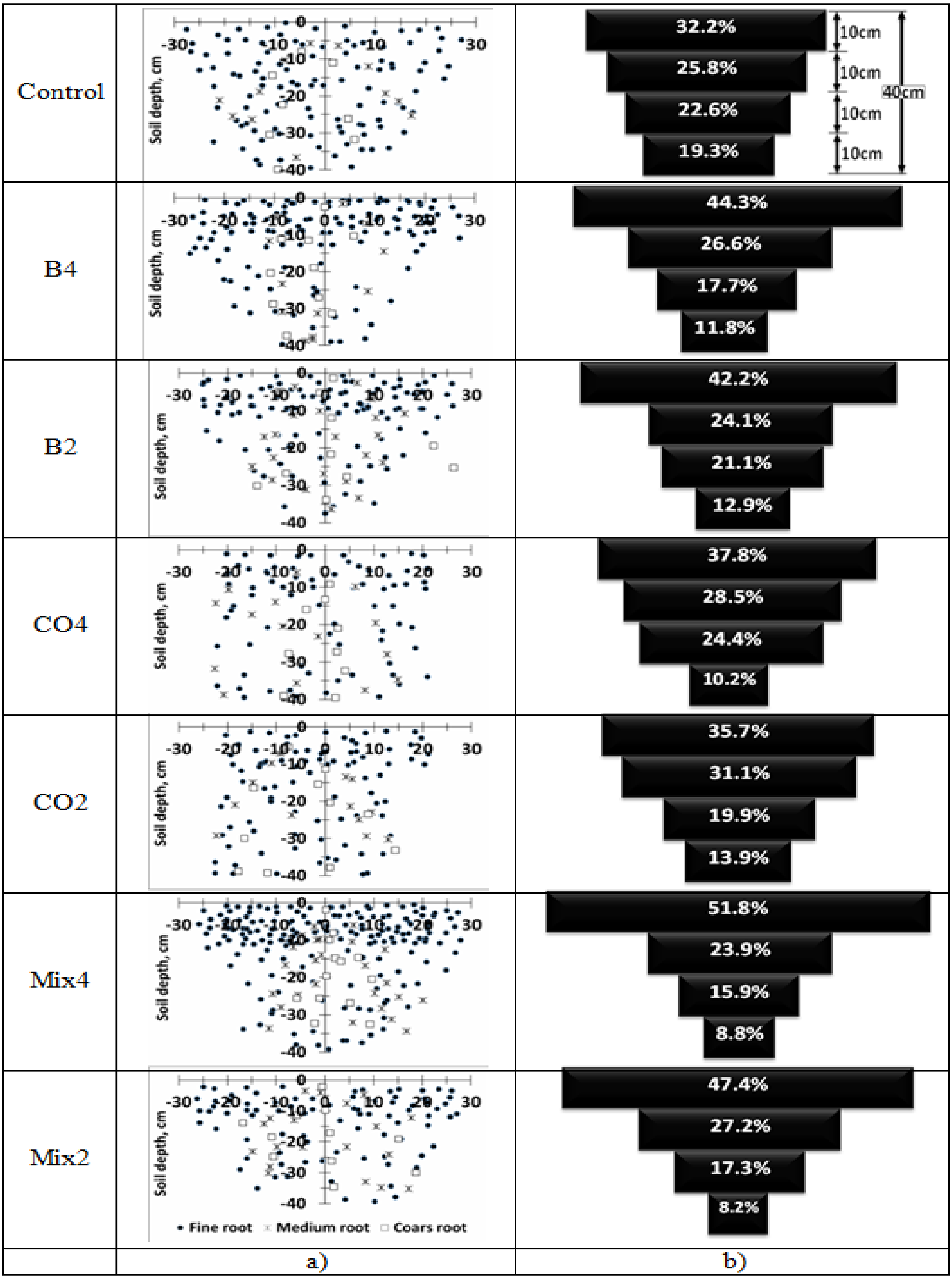


Figure-6. Impact of biochar, compost, and biochar–compost mix on the root system distribution under irrigation level $PRD_{50\%ETc}$. a) the graphical distribution of the fine, medium, and coarse roots, and b) the percentage of root dry weight for each layer.

3.5. Water Requirement

Agrometeorological conditions, air temperate, humidity, and wind speed affect evaporation and applied water during the four growth stages (initial, crop development, mid-season and late stage). The total evaporation amount was 87.1, 113.9, 486.2, and 176.9 mm for first, second, third and fourth growth stages, respectively. The irrigation water requirement was calculated according to the two irrigations levels of 75% ETc and 50% ETc ($PRD_{75\%ETc}$ and $PRD_{50\%ETc}$). The applied water at the $PRD_{75\%ETc}$ irrigation level was 30.4, 55.9, 298.3 and 103.6 mm in the four respective growth stages. While the applied water for $PRD_{50\%ETc}$ level was 20.2, 37.3, 198.9, and 69.1 mm. Doorenbos and Kassam [56] reported that the total irrigation water requirements were 600–900 mm per season for pepper. Consequently, our findings explain that the irrigation water amounts were improved by 35% and 57% for $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$, respectively. These findings are in accordance with the concept of PRD, in which plants can maintain their yield using half of the amount of water normally [57].

3.6. Yield Of Sweet Pepper

Table 6 represents the marketable yield, non-marketable yield, and total yield (kg m^{-2}) of the pepper crop. The lowest pepper yield was recorded in the un-amended treatments (control). The yields of the control plots were 2.64 and 2.50 kg m^{-2} at the $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$ irrigation levels, respectively. The marketable yields were 2.3, 3.2, 2.5, 3.8, 2.8, 4.3, and 3.4 kg m^{-2} under $PRD_{75\%ETc}$ and 2.1, 2.7, 2.1, 2.9, 2.3, 3.4, and 2.8 kg m^{-2} under the $PRD_{75\%ETc}$ irrigation level in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. The soil amended with biochar–compost produced the highest pepper yield compared to that of other treatments, significantly. The total pepper yield was increased by 34.9%, 9.9%, 56.8%, 17.6%, 70.3%, and 37.6% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments under $PRD_{75\%ETc}$ and by 23.3%, 3.6%, 29.4%, 80.0%, 47.7%, and 28.1% for B4, B2, CO4, CO2, Mix4, and Mix2 treatments under $PRD_{50\%ETc}$ compared to that in the control, respectively. It was reported that amending sandy soils by adding materials and conditioners can significantly change the yield and WUE because it improves the sandy soil attributes [33].

Table-6. Combined effects of irrigation level and biochar, compost, and biochar–compost mixture amendment materials on pepper yield.

Irrigation level	Soil amendment	Marketable yield (kg m^{-2})	Non-marketable yield (kg m^{-2})	Total yield (kg m^{-2})
$PRD_{75\%ETc}$	Control	2.335	0.304	2.638 f
	B4	3.204	0.358	3.562 c
	B2	2.54	0.361	2.901 e
	CO4	3.769	0.369	4.138 b
	CO2	2.769	0.335	3.103 d
	Mix4	4.261	0.233	4.494 a
	Mix2	3.384	0.246	3.630 c
	LSD (0.05)	0.107	0.003	0.14
$PRD_{50\%ETc}$	Control	2.117	0.381	2.498 de
	B4	2.729	0.351	3.08 c
	B2	2.084	0.503	2.587 e
	CO4	2.861	0.371	3.231 b
	CO2	2.308	0.39	2.698 d
	Mix4	3.415	0.274	3.689 a
	Mix2	2.801	0.4	3.2 b
	LSD (0.05)	0.074	0.067	0.115

3.7. WUE of Bell Pepper

Figure 7 illustrates the findings of WUE and IWP for all treatments under $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$. The addition rate of 4% of biochar, compost, and their mixture improved the WUE and IWP for all treatments compared to that of both the control and rate 2% under both irrigation levels ($PRD_{75\%ETc}$ and $PRD_{50\%ETc}$). Even the lowest rate of addition increased the WUE and WP for all treatments compared to those in the un-amended treatments. Under the $PRD_{75\%ETc}$ irrigation, the WUE was 5.6, 7.5, 6.1, 8.7, 6.6, 9.5 and 7.7 kg m^{-3} in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. Under the $PRD_{50\%ETc}$ irrigation, the WUE was 8.5, 11.7, and 10.1 kg m^{-3} in the control, B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively. Moreover, IWP was increased by 23.3%, 3.6%, 29.4%, 8%, 47.7%, and 28.1% in the B4, B2, CO4, CO2, Mix4, and Mix2 treatments, respectively, compared to that in the control Figure 7. Previous studies reported that the IWP was increased by 34.9%, 9.9%, 56.8%, 17.6%, 70.3%, and 37.6% for B4, B2, CO4, CO2, Mix4, and Mix2 compared with control Figure 7. The notable improvement of WUE was recorded in irrigation level of $PRD_{50\%ETc}$ and IWP showed the same increasing trend. WUE was 7.9, 9.8, 8.2, 10.2, pepper was increased with reducing the applied irrigation water, in particularly under PRD techniques [17, 58, 59].

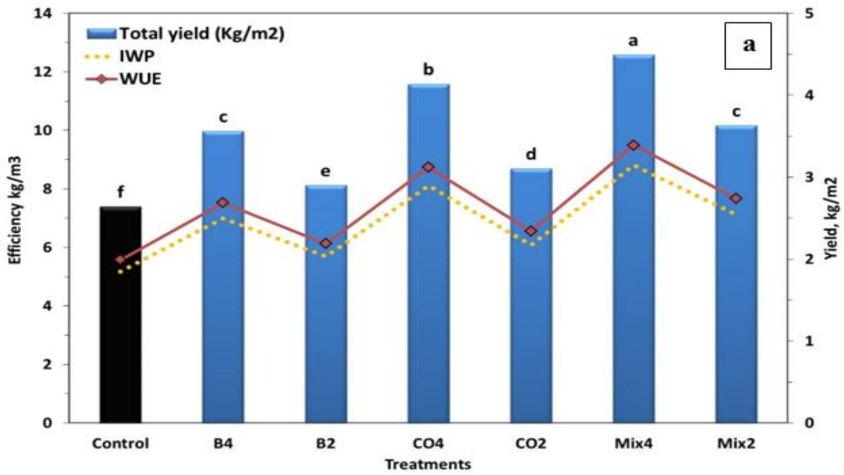
Figure 8 illustrates how WUE changed due to amendment materials and the application rates under two irrigation levels, $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$. As reported by Al-Omran, et al. [33] the WUE was significantly increased with reduced amounts of irrigation water in a contrasting trend to pepper yield. The average WUE between the two irrigation techniques, $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$, was 6.74, 8.64, 7.16, 9.49, 7.55, 10.59, and 8.9 kg m^{-3} by LSD0.05=0.085. Consequently, from this figure, the average of WUE was increased by 28.1, 6.2, 40.7, 12, 57 and 32% for B4, B2, CO4, CO2, Mix4, and Mix2 compared with untreated soils (control). As explained in Figure 7 and 8, adding biochar and compost to arable sandy soils can improve the pepper yield and its WUE. These results agree with Fiasconaro, et al. [60]; Yao, et al. [61]. Biochar as a porous material has high porosity and large surface area may be able to improve water and nutrients retention, hydraulic conductivity, infiltration and water-holding capacity (WHC) of sandy soil [62-64]. Thus, compost is a high organic matter content that can improve physical, chemical, and biological properties of sandy soil [44, 46, 60]. The desired attributes of biochar and compost could be modified positively the soil structure, CEC, texture, water retention and soil water content which affect yield and WUE of pepper. Thus, the results illustrated in Figure 8, explains that the combined adding of biochar–compost mixture made highest values of WUE, IWP and yield of pepper crop using rate of 4%, significantly. These findings are in accordance with those of Daniel and Bruno [46]; Kammann, et al. [65]. On other hand, applying the mixture of biochar and compost to sandy soils achieves a positive synergic impact on the WHC, nutrient content, and infiltration. Moreover, mixing biochar with compost may be able to improve properties and functions of compost materials due to the stability of biochar [55, 66, 67]. Thus, WUE was improved significantly with higher level than convention DI and/or FI [10, 16].

4. CONCLUSION

In this investigation, a greenhouse trial was conducted to study the WUE, IWP, pore size distribution, porosity, penetrability, saturated hydraulic conductivity, WHC, and root distribution of bell pepper, as well as the soil salinity and soil moisture, under date palm biochar, compost, and their combined treatments at application rates of 2% and 4% (w/w, dry weight). The bell pepper was irrigated with the PRD technique, using two levels of irrigation, $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$.

The $PRD_{50\%ETc}$ level had the most significant potential to increase the IWP, WUE, and WHC of bell pepper under greenhouse conditions compared to that of the $PRD_{75\%ETc}$ level. The date palm biochar–compost mixture had a higher impact than did both the compost and biochar, particularly at a rate of 4%. Based on the obtained results, it can be concluded that the pepper WUE and crop yield can be maintained under reduced irrigation volume, especially during periods of water shortage. Therefore, the PRD technique combined with a biochar–

compost amendment material has the potential to improve sustainable agriculture under arid and semi-arid conditions, especially in periods of water scarcity.



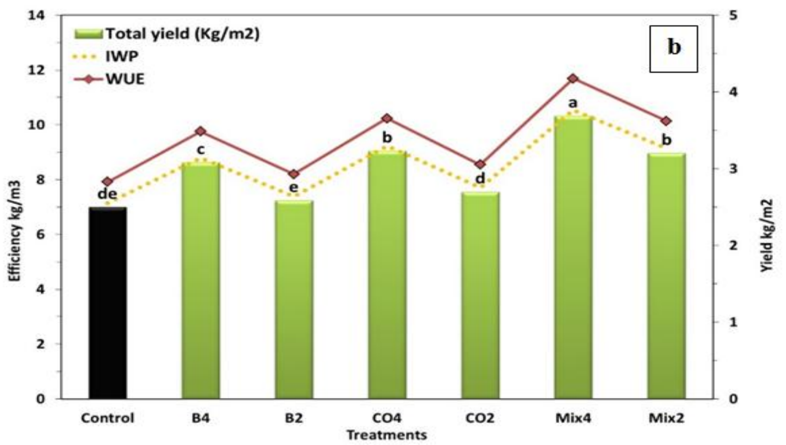


Figure-7. Impact of application rate of biochar, compost, and biochar–compost mix on the IWP, WUE, and yield of pepper under irrigation levels PRD75%ETc (a) and $PRD_{50\%ETc}$ (b).

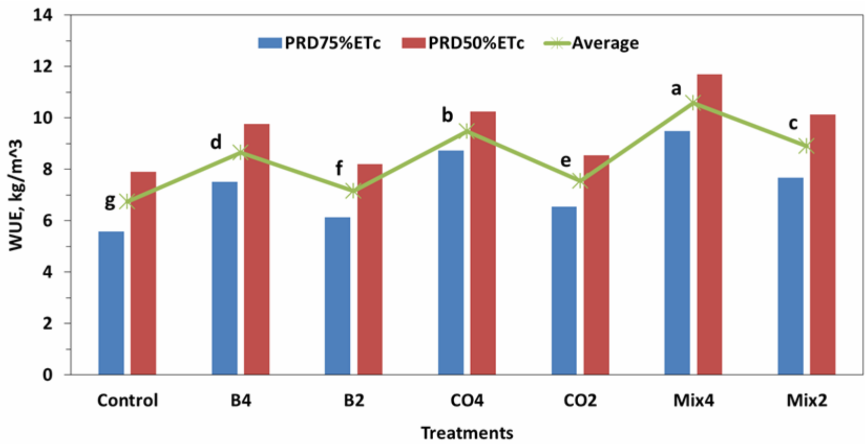


Figure-8. Impact of the application rate of biochar, compost, and biochar–compost mixture on the WUE under the $PRD_{75\%ETc}$ and $PRD_{50\%ETc}$ irrigation levels.

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