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Using Deficit Irrigation Strategies and Organic Mulches for Improving Yield and Water Productivity of Mango under Dry Environment Conditions

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Abstract: Many techniques have been and are being made to find alternatives to water-saving practices. Among them, Partial root drying (PRD), one effective approach, plays a major role in reducing the harmful effects of water deficit stress. Field experiments were carried out on mango trees for a private farm in Egypt over the course of two years, 2020/2021 to 2021/2022, in an area with sandy soil, hot summer conditions, and cold and rainy winter conditions. In the experiment that was carried out, the experimental design included using different irrigation strategies (I1, 100% full irrigation "FI"; I2, 75% FI; I3, 50% FI; and I4 (PRD), 50% FI) in the main plot and different amounts of organic mulch in the soil (L0, no layers of organic soil mulch, used as a control; L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; and L3, three layers of organic soil mulch) in subplots of the main plot in order to inspect the impact of the treatments on yield, water productivity, and energy usage under arid conditions. To meet the study's objective, two field experiments were carried out at a private farm. Our results demonstrate a general decrease in water stress and salt accumulation inside the root-zone area with PRD and L3. During the 2020/2021 and 2021/2022 seasons the PRD strategy increased fruit yields by 3.7 and 7.3% and water productivity by 51.9 and 53.1%, respectively, compared with the control treatment (I1) while reducing the amount of applied irrigation water by 50%. The PRD strategy along with organic mulching showed superior results with respect to increasing mango yields and water productivity. In general, PRD can be used as a good technique to save water and energy by up to 50% while enhancing productivity, ultimately improving mango yields under arid climatic conditions. Thus, it may prove a good adaptation strategy for current and future water shortage scenarios involving climate change.

Keywords: water saving; partial root drying; organic mulch; water productivity; water stress

1. Introduction

The global water resource limitation crisis has attracted interest in increasing the efficiency of using and rationalizing these limited water resources, especially the water used in agricultural irrigation, in order to increase production of crops in drought-prone and densely populated areas. Agricultural sectors are under intense pressure to rationalize and reduce the use of fresh water intended for irrigation in order to use it for farming in other areas [1,2]. Water scarcity is a very serious problem that is considered a challenge to food production in dry areas. It is crucial to cut back on water use and conserve irrigation water by modernizing and developing sustainable and innovative technologies [3]. Increasing crop productivity per unit of irrigation water is a major and necessary objective to increase the demand and the increasing need for food at a rate parallel to the turbulent rise in the population growth rate [4,5]. The adoption and application of modern irrigation techniques are very in order to supply a sufficient irrigation water in arid and semi-arid areas in order to open up the cultivation of new areas and to obtain additional agricultural production to participate in closing the nutritional gap [1].

The issue of drought is one of the most important and dangerous climatic issues, and is sure to have a negative impact on agricultural production. For successful production in dry climates, many agricultural crops need additional irrigation and huge amounts of irrigation water [6]. Therefore, adapting, developing, and optimizing new irrigation technologies is absolutely necessary for the accurate and efficient use of irrigation water in light of combating water scarcity scenarios related to current and future climate change [7].

As a cutting-edge technique for trace irrigation, partial root-zone drying (PRD) divides the crop's root zone into two sections. Essentially, this method entails irrigating about half of the plant or tree's root zone while leaving the other half dry. Then, after a set amount of time, the dry half of the root zone is watered and the previously irrigated half is allowed to dry [8]. In order to prevent scarcity of water and preserve the state of the plant water in the plant buds, the irrigated half distributes water to the buds [9]. This irrigation technique involves periodically moistening and drying plant roots or trees in order to maintain increased plant growth naturally and with less water [8]. Through osmotic modulation, inadequate irrigation techniques and methods such as PRD, promote plant drought tolerance. Previous studies have demonstrated that PRD is superior to standard insufficient irrigation when the same amount of water is used in both treatments. It has been shown that the production of antioxidants and osmotic modification within the framework of PRD increases crops' drought tolerance and yield [10]. To increase water productivity (WP), irrigation technologies that utilise less water are used. Important irrigation water-saving techniques such as DI and PRD lower crops' irrigation needs without dramatically lowering yield.

In order to simultaneously maintain the plant's water condition with maximum water potential and to manage the vegetative growth of certain areas of the seasonal cycle of plant development, the PRD technique is used to alternately irrigate two parts of the plant's root system [11]. In addition, PRD is one of the most important environmentally friendly irrigation strategies through which the leakage of pollutants into the environment can be reduced in the future [12]. Plants and crops that use half-root drying systems typically interchange portions of the plant root system that are permitted to dry out in response to biochemical signals and physiological reactions. In this method, the dry half emits hormones, which are then carried to the plant's buds through the xylem arteries and cause the stomata to close partially, reducing the transpiration rate [13]. Higher CO_2 concentrations in combination with water scarcity represent an additional challenge for PRD in practice; PRD can be used in different ways depending on the crops grown and/or soil and environmental conditions, irrigation method, and future predictions in climate change scenarios that include an increase in greenhouse gas volume.

Recent testing of the precision of PRD irrigation with numerous agricultural crops worldwide has revealed savings of 30–50% of irrigation water with the application of PRD technique without a significant decrease in crop yield compared to the traditional full irrigation method (FI). In addition, many studies have been conducted which indicate and confirm the benefits of PRD technology for fruit trees such as orange [2,14], pear [15], apple [16], olive [17], citrus [18,19], and pomegranate [20–22]. However, there is a dearth of studies examining the impact of PRD on mango productivity and quality [23]. Agriculture water supplies are being depleted due to global climate change and pollution. Yet, cultivated plants have developed specialised defence mechanisms that boost their tolerance to harsh environments [24]. The best and easiest way to manage water use is the combination of two economical techniques (coverage and PRD) that can provide a better way to combat drought stress [25].

Mulch is a versatile application material that serves a variety of purposes for soil and plants, including increasing soil infiltration, lowering water runoff, lowering evaporation losses, and inhibiting weed growth [25]. This organic cover is more beneficial compared to black plastic cover [26]. Mulching enhances plant growth when water is lacking by preserving the leaf water balance and activating antioxidant enzymes [27]. By minimising evaporation and transpiration through controlling weeds and covering increased water intrusion while decreasing water loss, the selection and use of appropriate mulch is a good method for soil moisture conservation and sustainable crop production that should be further investigated in order to determine the impacts of mulch on cultivated land over both the short and long term [28].

Due to its vibrant colour, distinct flavour, and nutritional content, mango is a highly prized fruit worldwide. The fruiting characteristics (number of fruits, weight of fruits, etc.), which are considerably impacted by irrigation levels, and it has been shown that mango yields are higher when utilising the drip irrigation technique [29].

Few researchers have examined the use of organic mulches (OM) and PRD irrigation technology together for mango production in arid environments. In this approach, any organic soil covers, which frequently include crop waste from fields, are positioned above the soil's surface and on drip hoses in an effort to limit evaporation and preserve the soil's ground moisture for as long as feasible. Salt reduction and weed growth reduction are other advantages. This research investigates the combined effects of PRD and the use of organic mulching in mango production in order to provide farmers and agricultural stakeholders with the knowledge needed to adapt effective strategies for water productivity. Consequently, this study aims to pinpoint the most effective irrigation techniques using sustainable materials (organic mulch) to increase yield and water productivity of mango while increasing soil organic matter content in arid environmental conditions.

2. Materials and Methods

2.1. Location and Climate of the Experimental Site

Field experiments were carried out on mango trees for a private farm in Egypt's Al-Nubariya Region, Al-Beheira Governorate (latitude 30°26′28″ N, longitude 30°18′0″ E, and mean altitude above sea level 21 m) for two years, 2020/2021 and 2021/2022, in an area with sandy soils and with hot summers and cold and rainy winters. Regarding the central areas, the winters are cold and dry and their summers are torrid. The chosen area experiences these conditions due to its dry climate; the average air temperatures were 22.74 and 23.8, respectively, for 2020/2021 and 2021/2022, with average air relative humidity of 65.3 and 67.9%.

2.2. Aspects of the Soil's Physical and Chemical Makeup and Irrigation Water

The water source for irrigation was a groundwater well that passed across the experimental area, which had an average pH of 7.6 and an electrical conductivity (EC) of 2.55 dS m^{-1}. At the start of the experiment, the soil's significant physical and chemical characteristics were identified on-site and in the lab, and are provided in Table 1. Soil samples were taken from depths of 0–40, 40–80 and 80–120 cm at the start of the experiment and analyzed for their physical and chemical properties.

Table 1. The soil's physical and chemical characteristics in the testing area.

Soil Properties	Soil Depths (cm)		
	0–40	**40–80**	**80–120**
Soil texture	Sandy	Sandy	Sandy
Course sand (%)	48.00	55.22	44.72
Fine sand (%)	49.43	41.60	51.54
Silt + clay (%)	2.57	3.18	3.74
Bulk density (g cm^{-3})	1.68	1.69	1.71
Organic matter (%)	0.45	0.32	0.23
EC (dS m^{-1})	0.67	0.55	0.51
pH (1:2.5)	8.6	8.3	8.4
Total $CaCO_3$ (%)	7.25	2.43	4.66

2.3. Experimental Design

Three replicates were used in a split-plot design for the experimental setup. Four irrigation strategies (I1, 100% of full irrigation (FI); I2, 75% FI; I3, 50% FI; and I4 (PRD), 50% FI) were assigned as main plots. Each main plot was then divided into subplots subjected to four cases for soil organic mulch as a sustainable material (L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; and L3, three layers of organic soil mulch). One layer of shredded agricultural waste, which was equivalent to 6.7 t ha^{-1}, was used. The means of these two trees were employed for statistical analysis, and each treatment was reproduced three times with two trees per replicate, as shown in Figure 1.

2.4. Irrigation System Description

A pump, filtration unit, and control head made up the irrigation system. It was made up of an electrically powered submersible pump with a 45 m^3/h discharge, control valves, a screen filter, a flow meter, pressure gauges, a pressure regulator, and a backflow prevention system. Through a 2″ control valve and discharge gauge, manifold lines with a diameter of 63 mm were formed of polyethylene pipes and connected to the laterals. Emitters were constructed in the laterals and had a diameter of 16 mm and a length of 60 m. The emitter discharge was 6 L per hour at an operating pressure of 1.0 bar.

2.5. Irrigation Requirements for Mango

Equation (1) was used to measure daily irrigation water. For 100% full irrigation (FI) during both 2020–2021 and 2021–2022, the seasonal irrigation water was 10,080 and 10,000 m^3/ha/season, respectively, using the drip irrigation system. Because the volume of rainfall was very small and only a few minutes in duration, there was no rainfall included across the two seasons. For the irrigation period, FI meant the necessary irrigation volume to satisfy the crops' evapotranspiration needs:

$$\mathrm{IRg} = \left[\frac{\mathrm{ETO} \times \mathrm{Kc} \times \mathrm{Kr}}{\mathrm{Ei}}\right] - \mathrm{R} + \mathrm{LR} \quad (1)$$

where IRg represents the daily gross irrigation needs (mm); ETO is the evapotranspiration reference (mm/day); Kc is the FAO-56 crop factor, Kr is the ground cover reduction factor, Ei is the irrigation efficiency (%), R is the quantity of water a plant receives from sources other than irrigation, such as rainfall (in millimetres), and LR (leaching requirements) is the amount of water required for salt leaching (in millimetres).

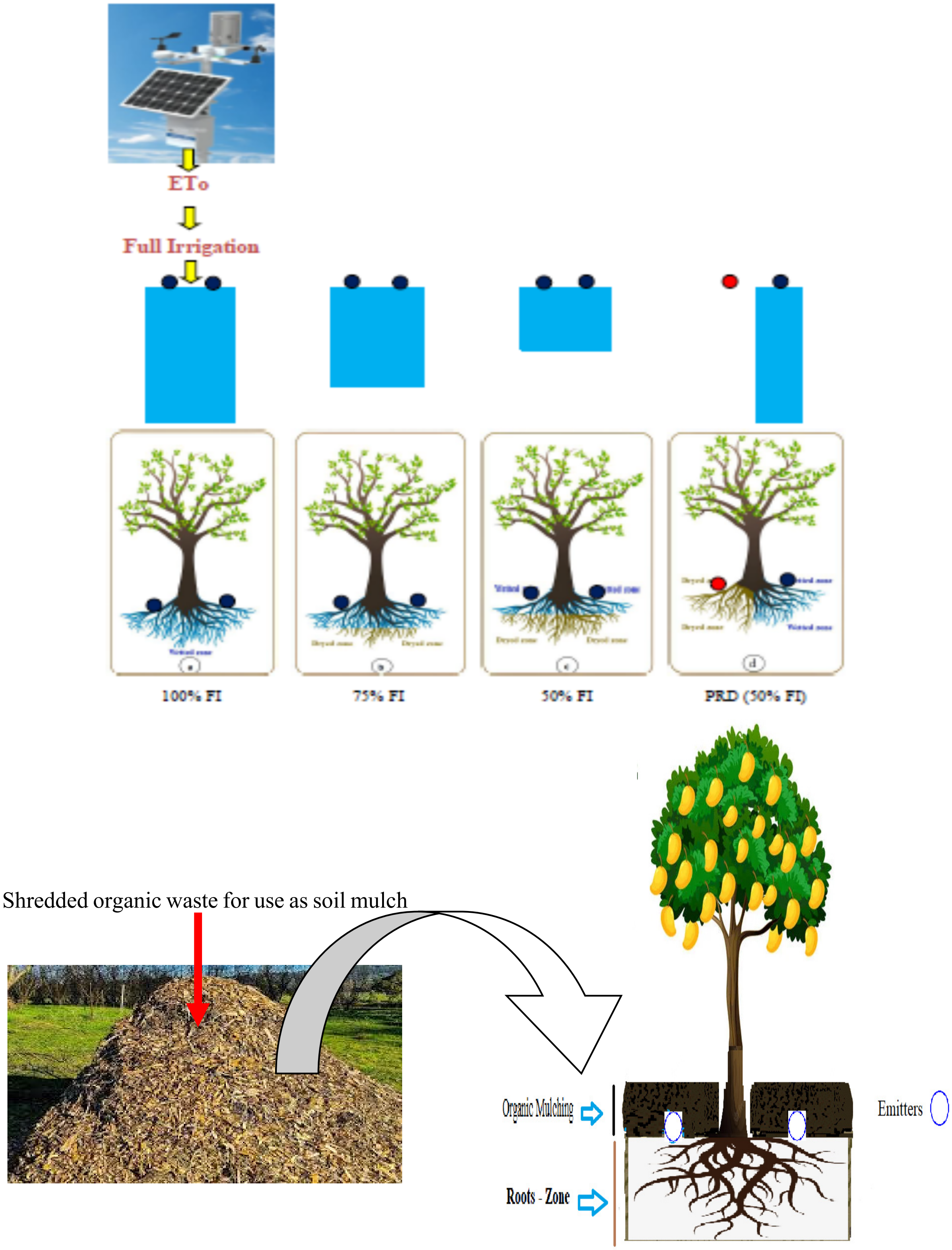


Figure 1. Distribution of main and sub-main factors according to experimental design. Main factor: Schematic of the irrigation pattern in 100% FI (**a**), 75% FI (**b**), 50% FI (**c**) and PRD (50%) (**d**). Sub-main factor: Organic mulching.

2.6. Mango Trees

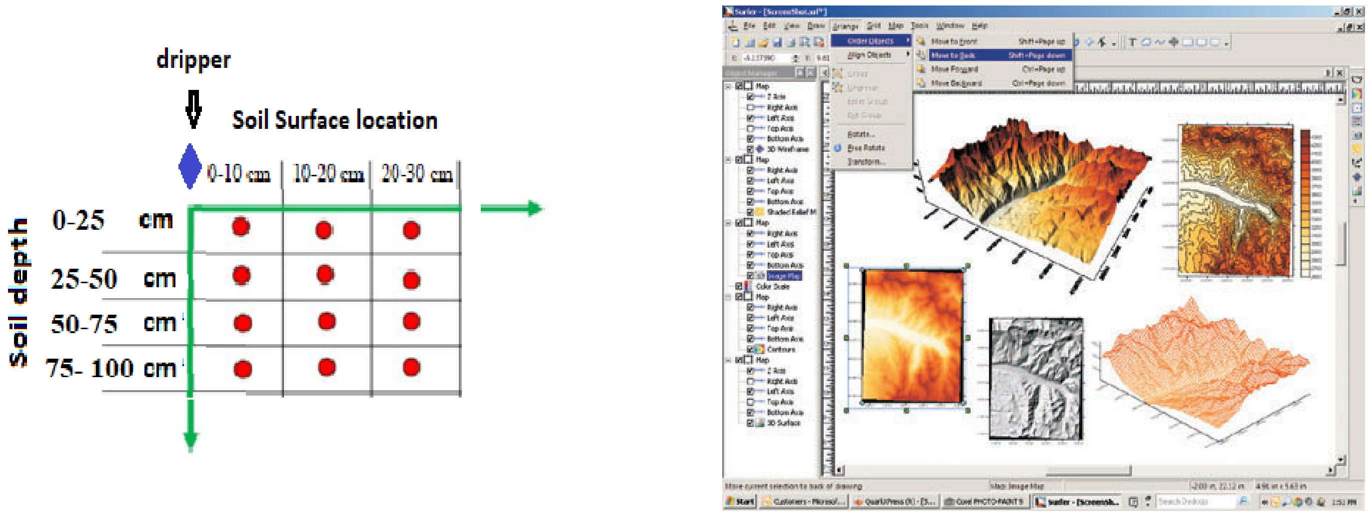
Regardless of the experimental treatments, all experimental plots were treated by the normal and recommended mango growing requirements as recommended by the instructions of the official agricultural bulletins. Mango trees that were 10 years old and spaced at 3 × 5 m were used in the study, with an average of 600 trees per hectare. All fieldwork was completed per local recommendations using the same fertilisation (240 kg N, 71 kg P_2O_5, and 212 kg K_2O) and standard cultivation methods for disease and pest management. Fertigation was attributed to the application of nutrient solution via irrigation water. All field practices were as usually recommended for mango cultivation in sandy soils.

2.7. Water Stress inside the Root Zone

Prior to watering, the effective root zone's soil moisture content was measured. According to Abdelraouf et al., field capacity and wilting point were taken into account as evaluation metrics for the exposure range of plants to water stress [2]. Soil moisture content measurements were determined using a profile probe. Field capacity (FC) water contents were 15% and permanent wilting point (PWP) water contents were 4%.

2.8. Soil Moisture Distribution

The distribution of soil moisture was identified by monitoring soil moisture content using a profile probe device at maximum actual water demand two hours after irrigation and at various sites. Locations were obtained at 0, 10, 20, and 30 cm on the X-axis and at 0, 25, 50, 75, and 100 cm on the Z-axis in the direction of the depth of the dirt. The contouring maps for various soil moisture levels with the depths for all treatments were obtained using the Surfer 13 Golden software programme, as illustrated in Figure 2.



Soil moisture content measurement sites

Surfer 13 Golden software program

Figure 2. Contouring map for different moisture levels with depths for all treatments under study.

2.9. Salt Accumulation in the Root Zone

In the effective root zone, the concentration of soil salts was determined both at the start and after the end of the season.

2.10. Soil Organic Matter Content

The most common method used to estimate the amount of organic matter present in a soil sample is by measuring the weight lost by an oven-dried (105 °C) soil sample when it is heated to 400 °C; this is known as 'loss on ignition', in which the organic matter is essentially burnt off. The average organic matter content of the root spreading area in the laboratory was measured for all treatments before the study and after chopping and cutting the organic cover at the end of each season and mixing it with the root spreading area during the two years of growth of the mango trees. Measuring the soil organic matter content in the root zone in response to the various sustainable materials (organic mulch) under irrigation strategies was investigated as an indicator of nutritional status for mango trees.

2.11. Mango Yield

At harvest time in August, the fruit yield in terms of the number of fruits per tree (tree load) was determined as kg per tree for each treatment after the samples were gathered, weighed, and counted. After conversion, the total yield in tonnes per hectare was calculated.

2.12. Water Productivity of Mango (WP_{mango})

Following James (1988), WP_{mango} was determined by Equation (2) as follows:

$$WP_{mango} = \frac{Ey}{Ir} \tag{2}$$

where, WP_{mango} is the water productivity of the mango crop ($kg_{mango}/m^3{}_{water}$), Ey is the economical yield (kg/ha), and Ir is the applied volume of irrigation water ($m^3{}_{water}$ /ha/season).

2.13. Mango Fruit Quality

In order to measure quality parameters of the mango fruits, such as the total soluble solids, (TSS), a Carl Zeiss hand refractometer was used in accordance with Singh (1988). The total acidity of the fruit juice was estimated as g citric acid/100 mL juice, and vitamin C (mg/100 mL juice) was determined in accordance with AOAC. Representative samples of mango were randomly selected from each treatment [30].

2.14. Energy Consumption

Energy consumption was determined for the tested variables using the following equation:

$$\text{Energy consumed (kW h)} = BP * \text{operating hours of irrigation} \tag{3}$$

$$BP = (Q * TDH * Y_W)/(E_i * E_P * 1000) \tag{4}$$

Here, BP stands for brake power (kW), Q for pump discharge (m^3/s), TDH for total dynamic head (m), E_P for pump effectiveness (%), Y_W for the specific weight of water (9.81 kN/m^3), and Ei for the efficiency of the electric engine (%).

2.15. Statistical Analysis

Following Snedecor and Cochran, all the data collected during the two research seasons were statistically analysed using the conventional analysis of variance procedure (ANOVA) for a split plot design with three replications [31]. The statistical programme CoStat (Version 6.303, CoHort, USA, 1998–2004) was used to process all of the data. When using least significant difference (LSD) tests to compare treatment means of the measured parameters, differences were deemed significant at p 0.05.

3. Results and Discussion

3.1. Water Stress in the Root Zone

Data related to water stress in the root zone for both treatments of irrigation strategies and sustainable materials (organic mulch) for the two seasons presented in Figure 3. The figure shows a general reduction in water stress within the root zone area when using organic mulch under all irrigation strategies treatments, as inferred from the approximate moisture content of field capacity and spacing from the permanent wilt point. The lowest water stress value was reported in the I1 and PRD (I4) strategy using OM (L3), while the highest value was at I3 + L0. Mulches reflect sunlight, reduce evaporation losses, and improve soil moisture content compared to bare soil, reducing water stress reactions [13].

Water stress typically lowers a plant's ability for photosynthesis, which affects the rate of photosynthesis and stomatal conductance as well as the creation of matter and plant yield [32]. These findings concur with those of Abdelraouf et al. [2,4].

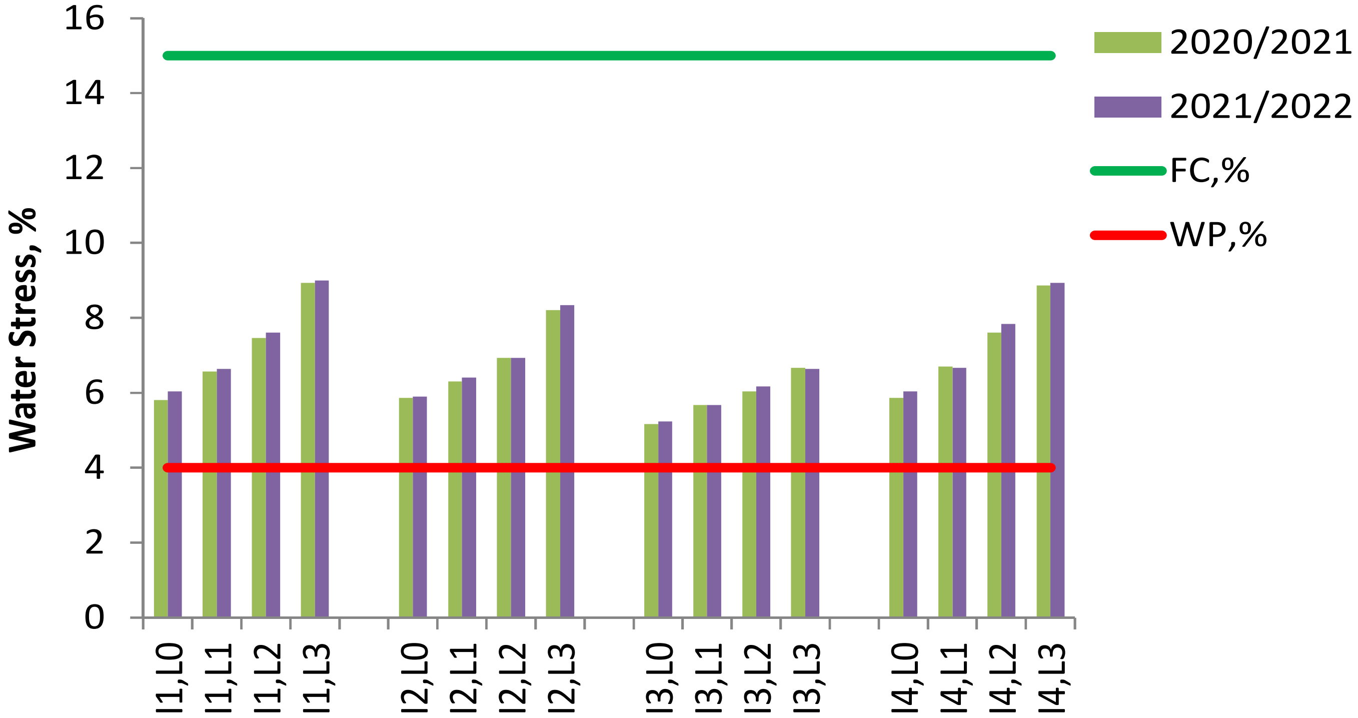


Figure 3. The performance of the partial root-zone drying technique and soil organic mulch with regard to water stress in the root zone. (I1, 100% of full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50% FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity).

3.2. Soil Moisture Distribution

The measurement of soil moisture distribution under the drip system on both sides of the mango tree is one of the most important measurements that can highlight and clarify the importance of using organic mulching with the partial root–zone drying technique as a technique for sustainable management of irrigation deficit and shortage of water resources.

Figure 4 indicates the soil moisture distribution under 100% full irrigation with different layers of organic soil mulch. It can be observed that by increasing the number of layers of soil organic mulch the horizontal movement of water increases compared to the vertical movement, leading to an increase in the volume of water stored in the root-zone spread and a decrease in water stress in the area of root spreading. This might be due to the slower rate of water evaporation from the wet soil's surface caused by adding more layers of organic mulch. Figures 5–7 confirm that there is a noticeable effect of the organic mulch and that its increase relieves soil moisture stress within the root spread area of the mango trees; the soil moisture distribution improves with an increase in the number of organic mulch layers compared to with no mulch.

3.3. Salt Accumulation

Figure 3 illustrates how organic mulching and watering techniques affect salt buildup in the root zone. Figure 8 illustrates how covering the soil's surface with organic mulch can help to reduce the accumulation of salt in the area of root spreading under all irrigation strategies for the two seasons. The largest amount of soil salt accumulation was in the soil at L0 and when adding I1, while the lowest amount of soil salt accumulation was when using L3 under PRD technique for the two seasons. This might be as a result of the organic mulch layers' ability to slow the rate of evaporation, which in turn could have prevented salt from building up in the root zone. The fundamental reason for higher salt concentrations in stressful situations is the breakdown of bigger molecules into smaller ones, which causes the osmotic potential to reach its maximum value [10].

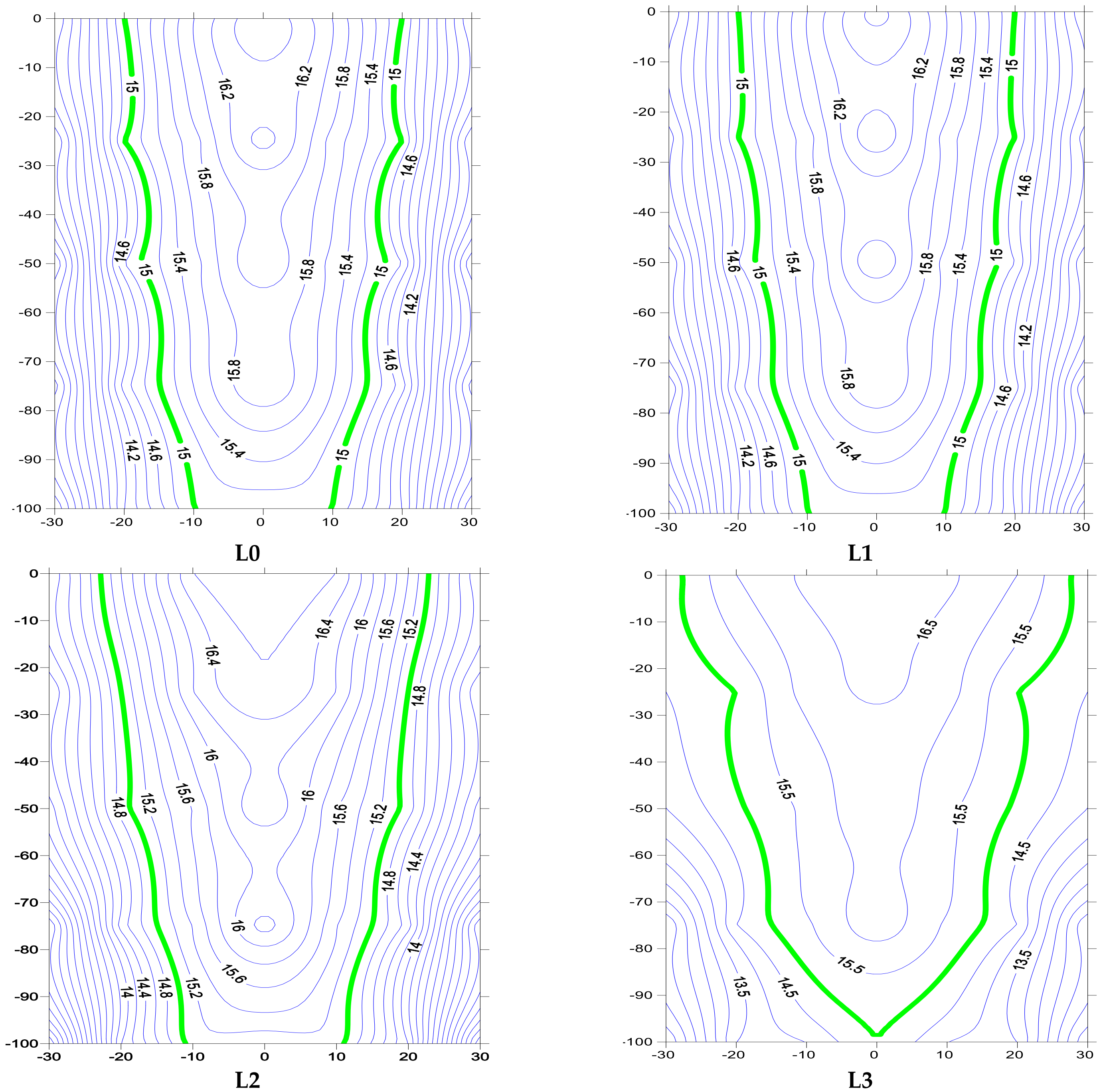


Figure 4. Soil moisture distribution under 100% full irrigation and soil organic mulch in the root zone. ((**L0**), zero organic soil mulch (control); (**L1**), a single layer of organic soil mulch; (**L2**), two layers of organic soil mulch; (**L3**), three layers of organic soil mulch; the green line represents field capacity, the vertical coordinate represents the depth of the rooting zone (0 to 100 cm), and the horizontal coordinate represents the width of the rooting zone (0 to 60 cm)).

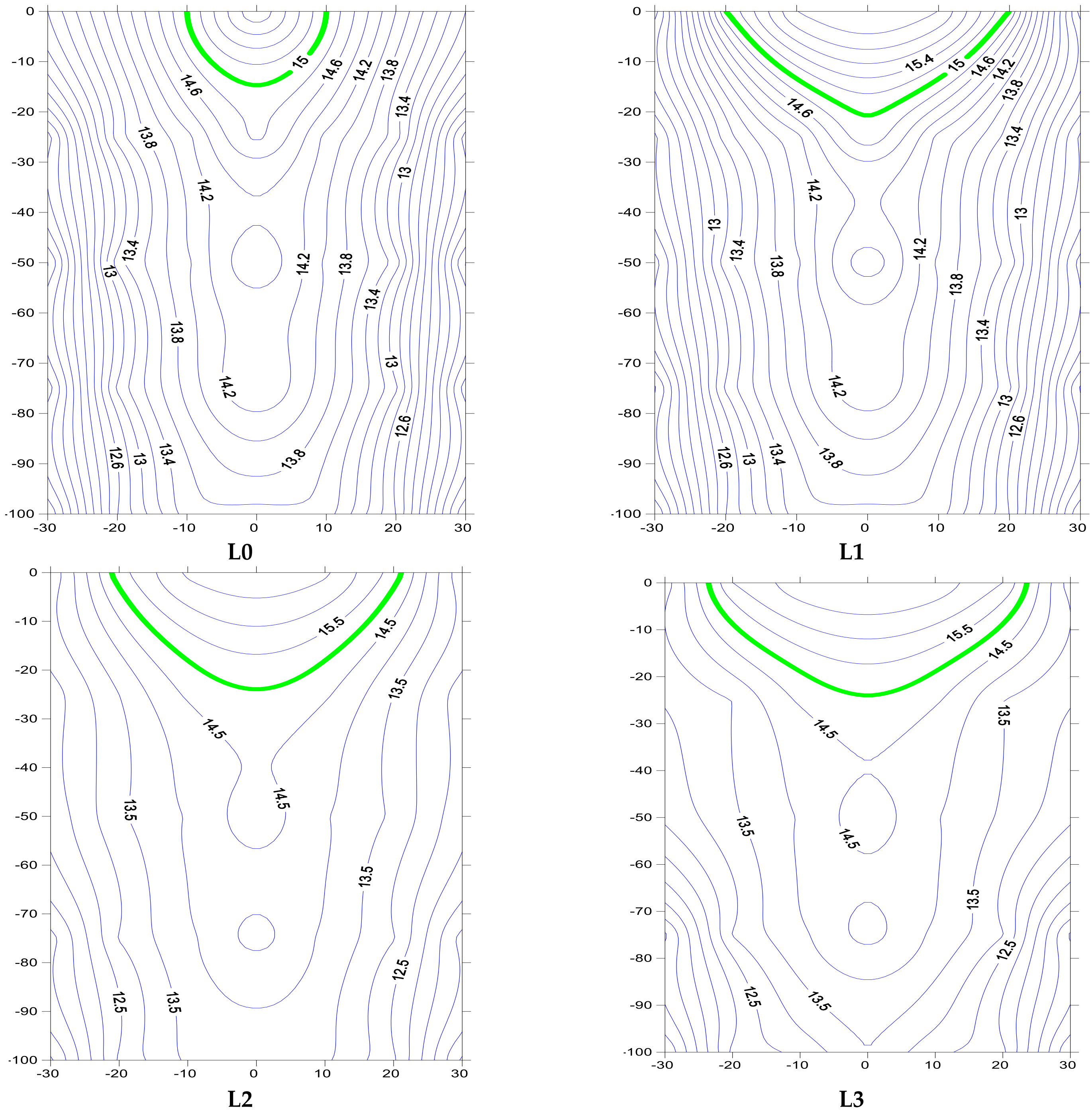


Figure 5. Soil moisture distribution under 75% full irrigation and soil organic mulch in the root zone. ((**L0**), zero organic soil mulch (control); (**L1**), a single layer of organic soil mulch; (**L2**), two layers of organic soil mulch; (**L3**), three layers of organic soil mulch; the green line represents field capacity, the vertical coordinate represents the depth of the rooting zone (0 to 100 cm), and the horizontal coordinate represents the width of the rooting zone (0 to 60 cm)).

These observations support those made by Abdelraouf and Ragab [4], who demonstrated through field and modelling results that salinity was lower for 100% FI, 75% IF, and 50% IF treatments than when applying PRD. However, under the same treatments with mulch the observed and simulated soil salinity was lower than without mulch. To save fresh water and lower salt concentration in the root zone of plants, they suggested employing PRD under a localised drip system while applying organic mulch as a smart irrigation management practise. The same conclusions were presented by [33], who reported that salt concentration was higher under conditions of extreme water stress than during full irrigation.

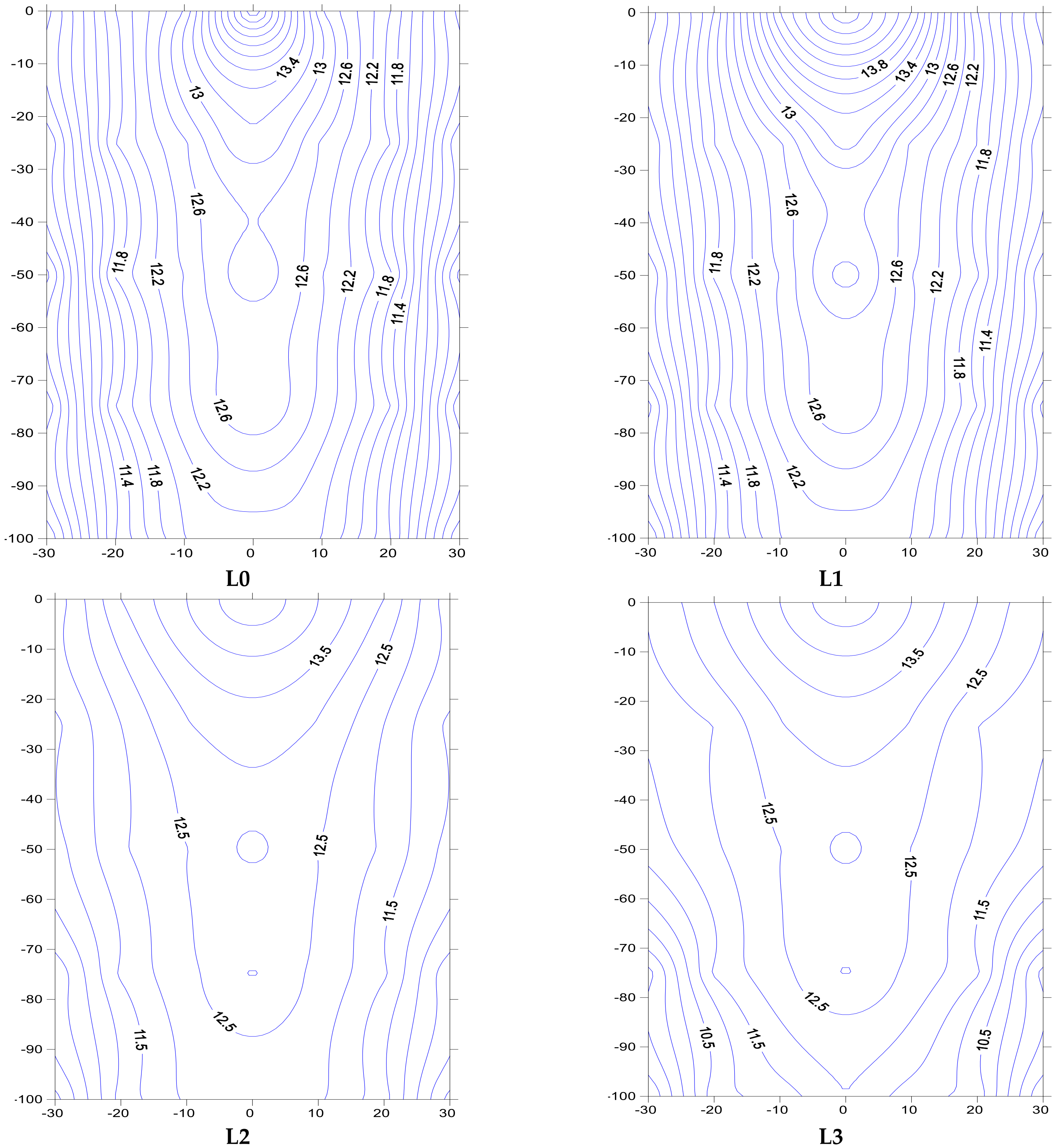


Figure 6. Soil moisture distribution under 50% full irrigation and soil organic mulch in the root-zone. ((**L0**), zero organic soil mulch (control); (**L1**), a single layer of organic soil mulch; (**L2**), two layers of organic soil mulch; (**L3**), three layers of organic soil mulch; the green line represents field capacity, the vertical coordinate represents the depth of the rooting zone (0 to 100 cm), and the horizontal coordinate represents the width of the rooting zone (0 to 60 cm)).

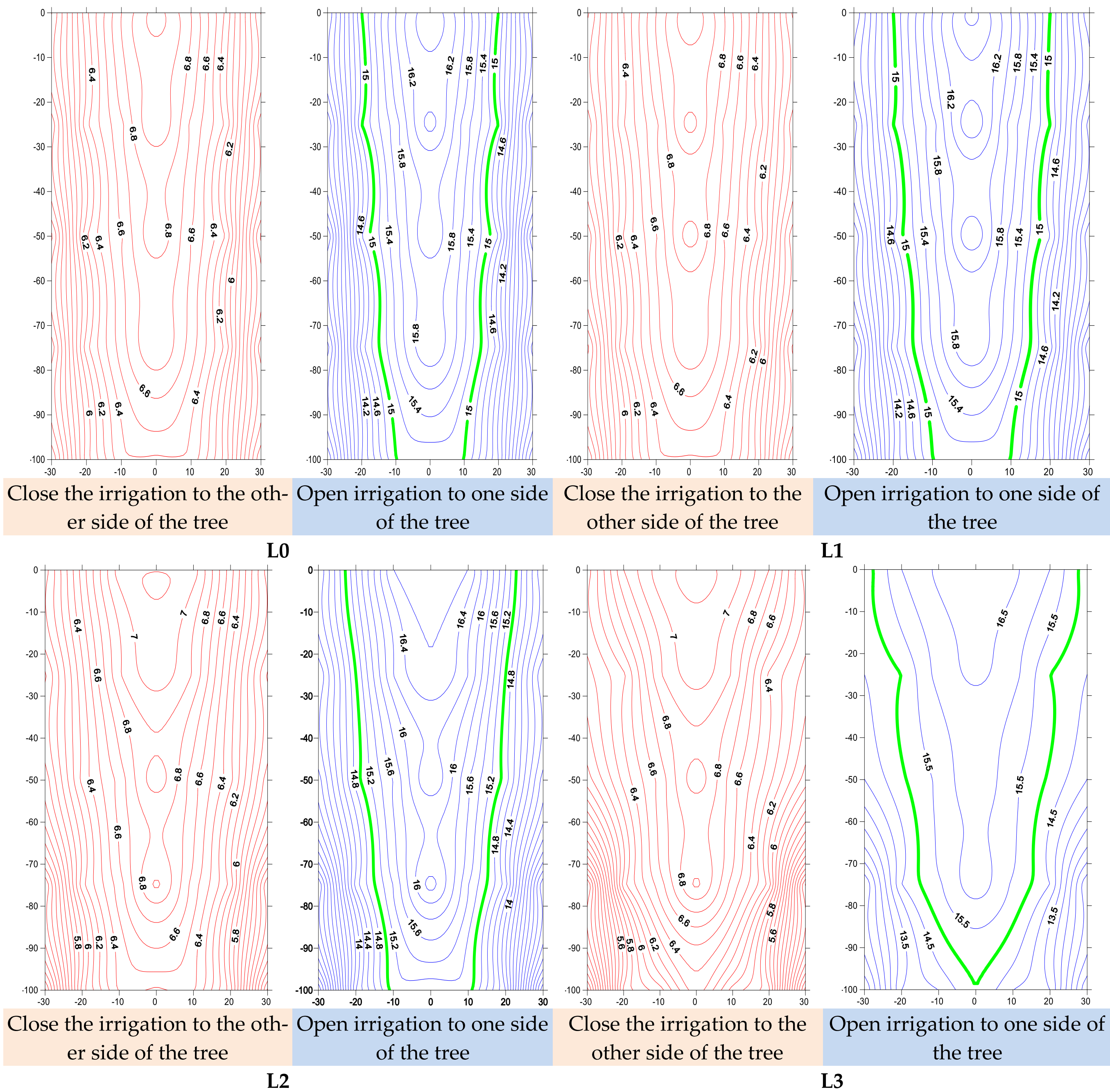


Figure 7. Soil moisture distribution under partial root-zone drying (PRD) (50% full irrigation) and soil organic mulch in the root zone. ((**L0**), zero organic soil mulch (control); (**L1**), a single layer of organic soil mulch; (**L2**), two layers of organic soil mulch; (**L3**), three layers of organic soil mulch; the green line represents field capacity, the vertical coordinate represents the depth of the rooting zone (0 to 100 cm), and the horizontal coordinate represents the width of the rooting zone (0 to 60 cm)).

3.4. Soil Organic Matter Content

The nutritional status of the soil was tested by measuring the soil organic matter content for all treatments under study during the two seasons. Figure 9 illustrates the importance of organic mulching for increasing soil organic matter content under all irrigation strategies. Organic matter content was increased by increasing the number of organic mulch layers. This may be due to two reasons. The first is because of the organic coverage and with the increase in the number of its layers, where the rate of decomposition of the organic matter in the area of root spread decreased as a result of the decrease in soil temperatures with the increase in the moisture content. The second is that chopping the organic cover and mixing it with sandy soil after the end of the harvest season may have led to an increase in the organic content within the sandy soil. According to an investigation carried out on roselle plants (*Hibiscus sabdariffa* L.) at the Experimental Farm of the Faculty of Agriculture in May during the two seasons of 2008 and 2009, mulch improves soil organic matter and moisture levels for healthy root development, increasing the soil's capacity to store water [34]. The goal was to determine how the application of amino acids, humic acids, and microelements affected the vegetative growth, yield characteristics, and antioxidant activity of plants grown in various organic and inorganic media conditions. The findings revealed a high degree of resemblance, which had been observed with the bulk of the characters studied in both seasons. It may be concluded that the values of the previous characters were higher with the first treatment than with the second in both seasons when compost plus humic acid was applied compared to magnetic iron plus humic acid. Although these values were greater than those of compost or single magnetic iron as well as those of the control treatments in both seasons, the lowest character values were consistently seen with the mixture of compost or magnetic iron with amino acids or with microelements. Plants treated with compost and humic acid showed the best DPPH radical scavenging activity, which was associated with the overall anthocyanin content [30]. The highest soil organic matter content was indicated in PRD + L3, while the lowest content was under I3 + L0 for the two seasons.

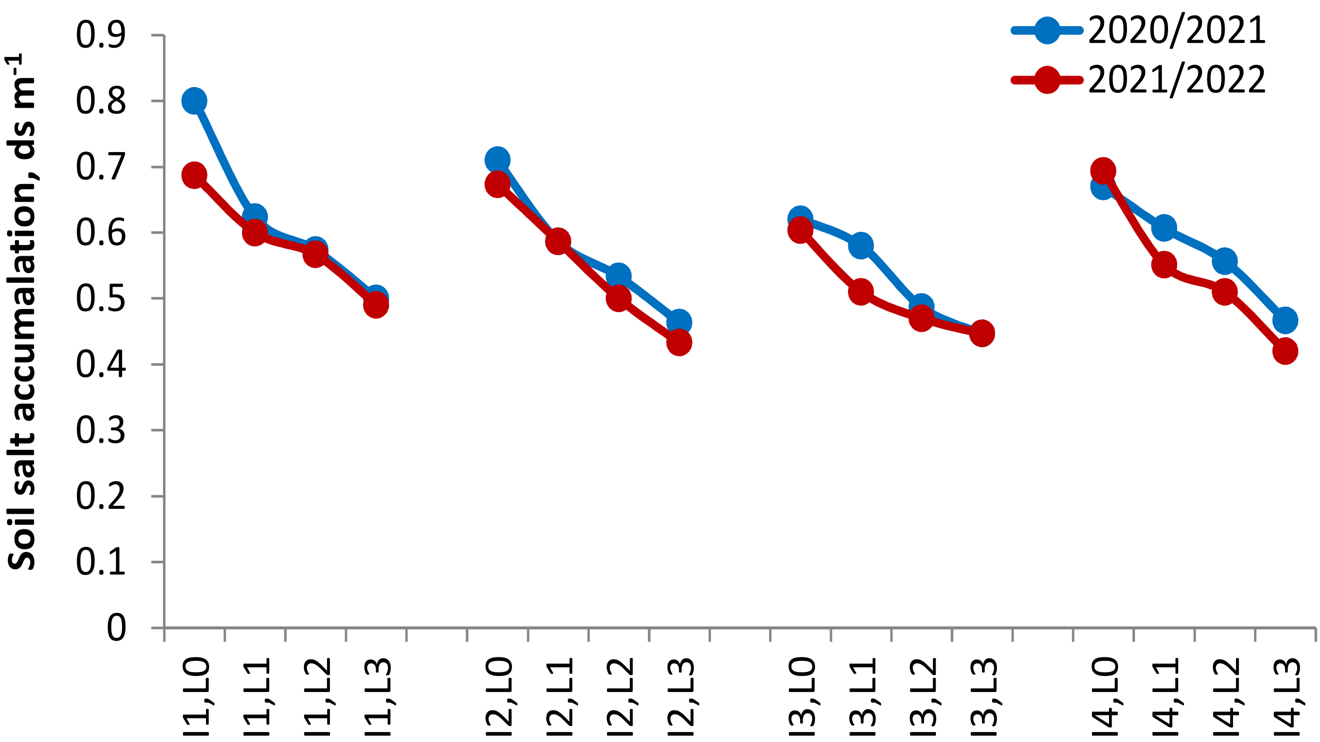


Figure 8. The performance of partial root-zone drying technique and soil organic mulch on salt accumulation in the root zone. I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50% FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity.

3.5. Mango Yield

When analyzing the factors separately, the first factor (irrigation strategies) had a positive and significant effect on mango yield, which was also significantly affected by the second factor (sustainable materials "organic mulch t") for the two seasons, as represented in Table 2.

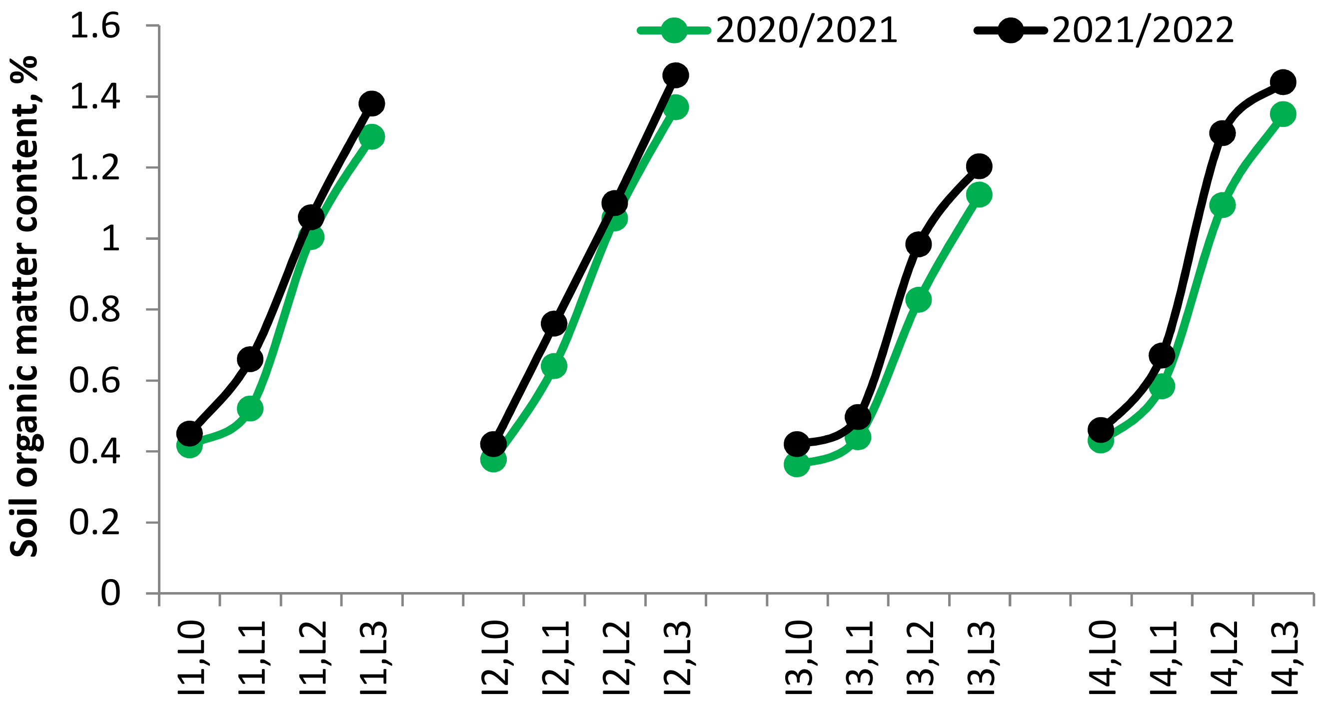


Figure 9. The performance of partial root-zone drying technique and soil organic mulch on the soil organic matter content. I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50 % FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity.

The highest yield values for the irrigation strategies treatments were under I4 (PRD), followed by I2 and then I1, while the lowest yield values for the two seasons were under I3. Using I4 (PRD), the greatest mango yields for 2020–2021 and 2021–2022, were respectively 10.080 and 10.466 ton ha^{-1}, and there were no-significant differences between using I4 (PRD), I2, and I1 on mango yield. There were significant difference between I3 and the other treatments, while the lowest values of mango yield, 9.705 and 9.706 ton ha^{-1} for 2020/2021 and 2021/2022, respectively, occurred when using I3. The rationale behind this is that under PRD the soil water in the root system's moist portion evaporates earlier due to increasing atmospheric demand. With the same amount of water applied, field experiments contrasting PRD and DI have found that PRD can significantly increase crop production. According to Shahabian et al. (2012), DI treatment decreased fruit yields for orange trees by 30% compared to I1. However, PRD treatments had no effect on fruit yield. Furthermore, Hutton and Loveys [19] demonstrated that PRD had no impact on citrus plants' fruit yields.

For sustainable materials (organic mulch) treatments, more mango yield was recorded when increasing the number of organic mulch layers, and there were significant differences between using OM and other treatments. The minimum yield (7.369 and 7.577 ton ha^{-1}) were recorded with L0 for 2020/2021 and 2021/2022, respectively. Due to increased growth, faster photosynthetic rates, improved soil moisture retention, and overall higher yield characteristics compared to other treatments, the OM treatment produced a higher mango yield. Raza et al. [10] made similar observations and discovered that mulching improved stomatal conductance in plants as a result of increased soil moisture availability and preservation of leaf turgor, which keeps the stomata open.

As shown in Figure 10 and Table 2, the interaction between the two parameters had a statistically significant impact on mango yield for the two seasons. The highest values of mango yield were 13.103 and 13.612 ton ha^{-1} during 2020/2021 and 2021/2022, respectively, when applying PRD with L3. There were no-significant differences between applying PRD + L3 and I3 + L3, while there were significant differences between using these conditions and other treatments. The lowest values of mango yield were 5.9 and

6.3 ton ha^{-1}, respectively, when applying I3 under L0. Observing a good effect of PRD with OM while observing a negative impact on the yield when irrigation water is reduced under deficit irrigation may be attributable to three factors. First, the positive effects of the PRD strategy. PRD involves alternately watering both sides of a plant's root system, and this strategy causes mild water stress in the plant, which causes stomata to partially close and reduce transpiration losses without significantly affecting photosynthesis or yield. Additionally, organic mulching is crucial in lowering the rate of evaporation, which increases the amount of water available to roots and decreases salt content. These observations are in keeping with the findings of Ahmad et al. [35] and Abdelraouf et al. [2], who indicated that a combination of these two techniques (mulching and PRD) could be a better way to combat drought stress and increase yield.

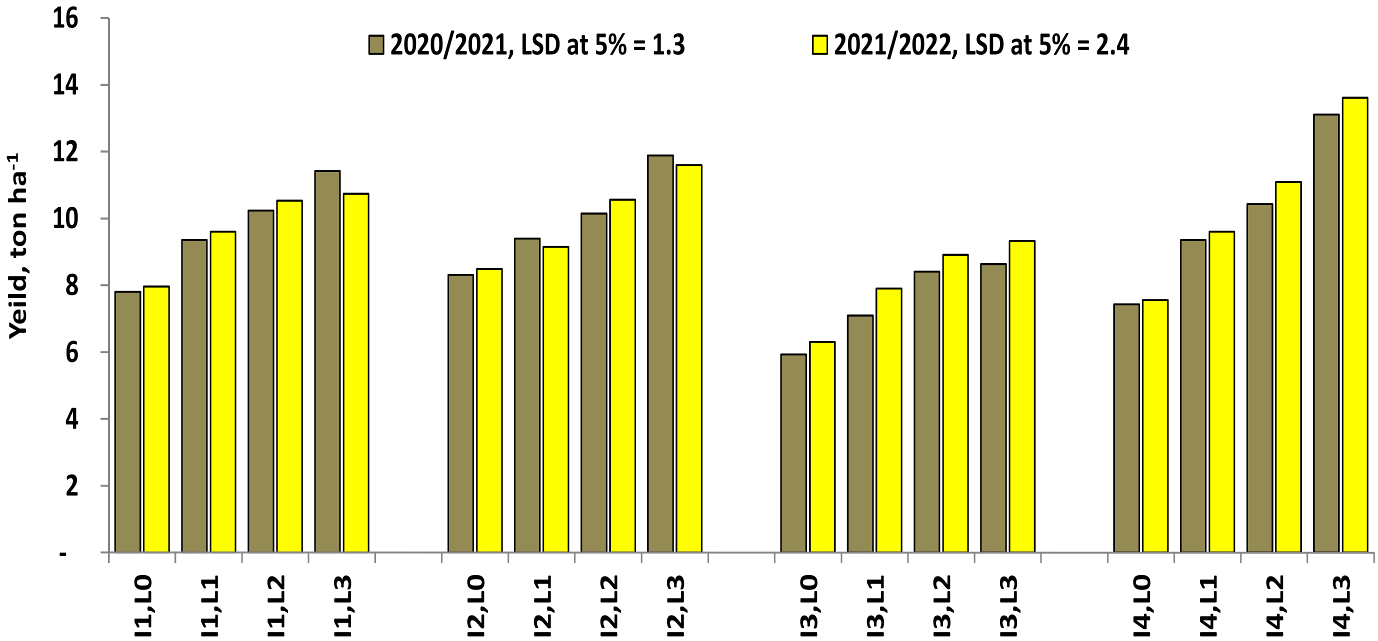


Figure 10. Performance of the partial root-zone drying technique and soil organic mulch with regard to the yield of mango. I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50 % FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity.

3.6. Water Productivity

Both irrigation strategies and organic mulching had a statistically significant effect on water productivity (WP) for the two seasons, as indicated in Table 2. The first factor (irrigation strategies) positively and significantly affected WP. The highest WP values were under PRD followed by I3 and then I2, while the lowest values were under I1 for the two seasons. The highest values of WP were 2 and 2.093 kg m^{-3} for 2020/2021 and 2021/2022, respectively, when using I4 (PRD), while PRD and other treatments differed significantly.

The second factor (organic mulch) significantly affected WP. More WP was recorded in OM, while the lowest values of WP were under L0 for the two seasons. The highest values of WP were 1.754 and 1.801 kg m^{-3} when using L3, and there were significant difference between using L3 and other treatments, while the lowest values of water productivity were 1.131 and 1.175 kg m^{-3} for L0. Fewer evaporation losses and more water conservation in the L3 treatment as compared to other treatments led to a higher value of WP. Due to its influence on soil conditioning, L3 may help improve the soil's ability to retain water and raise the WP. The effect of L3 on increasing the quantity of fruits, and as a result the yield and WP, is probably connected to the maximum WP. Abdelraouf et al. (2021) proposed the same. In a similar investigation in orange trees, the findings of Shahabian et al. [14] were in agreement with our findings in the present study. According to Figure 11 and Table 2, the interaction between the two parameters had a statistically significant impact on WP for the two seasons. The highest values of WP were 5.6 and 5.4 kg m^{-3} when using I4, PRD + L3, and there were significant differences between these conditions and other treatments. The lowest values of WP were 2.8 and 2.7 kg m^{-3} under I1 + L0. It has been noted that using L3 in conjunction with PRD irrigation can improve WP without much of an effect on crop production. Abdelraouf et al. noted comparable results [2,4].

Table 2. The performance of the partial root-zone drying technique and soil organic mulch with regard to the yield and water productivity of mango.

Deficit Irrigation Strategies	Soil Organic Mulch	Yield of Fruits, (Ton ha^{-1})		Water Productivity, (kg_{mango} $m^{-3}{}_{water}$)	
		2020/2021	2021/2022	2020/2021	2021/2022
I1		9.7	9.7	1.0	1.0
I2		9.9	10.0	1.3	1.3
I3		7.5	8.1	1.5	1.6
I4		10.1	10.5	2.0	2.1
LSD at 5%		0.7	0.7	0.1	0.1
	L0	7.4	7.6	1.1	1.2
	L1	8.8	9.1	1.4	1.4
	L2	9.8	10.3	1.5	1.6
	L3	11.3	11.3	1.8	1.8
LSD at 5%		0.7	1.2	0.1	0.2
I1	L0	7.8	8.0	0.8	0.8
	L1	9.4	9.6	0.9	1.0
	L2	10.2	10.5	1.0	1.1
	L3	11.4	10.7	1.1	1.1
I2	L0	8.3	8.5	1.1	1.1
	L1	9.4	9.1	1.2	1.2
	L2	10.2	10.6	1.3	1.4
	L3	11.9	11.6	1.6	1.5
I3	L0	5.9	6.3	1.2	1.3
	L1	7.1	7.9	1.4	1.6
	L2	8.4	8.9	1.7	1.8
	L3	8.6	9.3	1.7	1.9
I4	L0	7.4	7.6	1.5	1.5
	L1	9.4	9.6	1.9	1.9
	L2	10.4	11.1	2.1	2.2
	L3	13.1	13.6	2.6	2.7
LSD at 5%		1.3	2.4	0.2	0.3

I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50% FI; L0, zero layers of organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch.

3.7. Quality of Mango Fruit

Among the different irrigation strategies, the highest total soluble solids (TSS), total acidity, and vitamin C content of mango fruits values were reached under I4 (PRD), followed by I2 and then I1, while the lowest values were under I3 for both seasons. The highest values of total soluble solids (TS.S), total acidity, and vitamin C content of mango fruits occurred when using I4 (PRD), and there were no significant differences between using I4 (PRD), I2, and I1, although there were significant differences between using I3 and other treatments. More total soluble solids (TSS), total acidity, and vitamin C content of mango fruits were recorded when increasing the number of organic mulching layers, and there were significant difference between using OM and other treatments, while the minimum values were recorded under L0 for both 2020/2021 and 2021/2022. Improved mango quality occurred with OM treatments due to more moisture retention in the soil, improved growth, and a higher photosynthetic rate. Similar findings were noted by Raza et al. [10], who found that mulching increased stomatal conductance in plants due to higher availability of soil moisture and maintenance of leaf turgor, which keeps the stomata open. All of the above helped to increase the absorption of water and nutrients and decrease the water and nutritional stress while increasing the layers of organic mulches as indicated in Table 3.

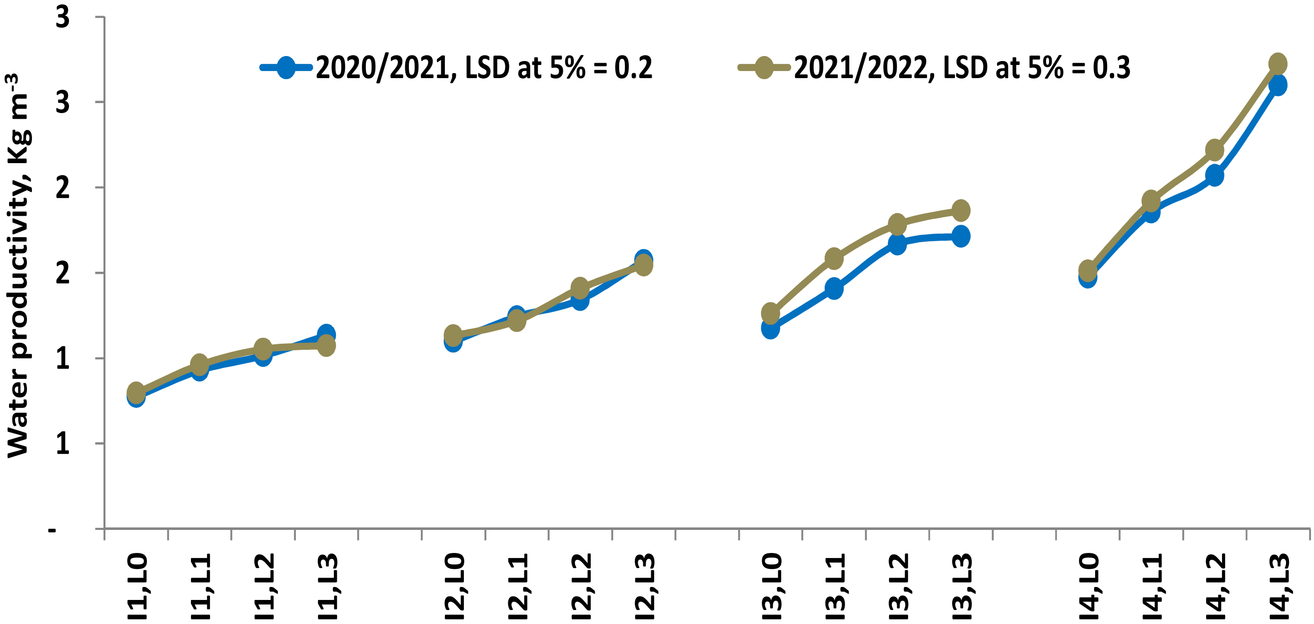


Figure 11. The performance of the partial root-zone drying technique and soil organic mulch with regard to the water productivity of mango. I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50 % FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity.

Table 3. Effect of deficit irrigation strategies and soil organic mulch on quality traits of mango.

Deficit Irrigation Strategies	Soil Organic Mulch	T.S.S., (%)		Total Acidity, (%)		Vitamin C, (mg/100 mL Juice)	
		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
I1		10.0	10.8	0.84	0.86	34.7	37.0
I2		10.4	11.0	0.86	0.89	36.2	38.6
I3		8.2	8.73	0.85	0.88	33.5	36.4
I4		10.7	11.3	0.84	0.91	35.3	38.0
	L0	8.5	9.3	0.74	0.79	28.6	31.3
	L1	9.2	9.7	0.81	0.84	31.3	33.9
	L2	9.9	10.6	0.88	0.90	36.8	39.0
	L3	11.7	12.3	0.97	1.02	43.0	46.0
I1	L0	8.4	10.2	0.70	0.76	26.6	29.0
	L1	9.6	10.1	0.77	0.83	28.8	31.4
	L2	9.9	10.8	0.85	0.85	38.0	40.1
	L3	11.9	12.1	1.02	1.03	45.2	47.5

Table 3. *Cont.*

Deficit Irrigation Strategies	Soil Organic Mulch	T.S.S., (%)		Total Acidity, (%)		Vitamin C, (mg/100 mL Juice)	
		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
I2	L0	9.2	9.6	0.81	0.84	31.7	33.8
	L1	9.7	10.4	0.83	0.85	34.2	36.4
	L2	10.8	11.3	0.85	0.88	36.5	38.9
	L3	11.8	12.7	0.97	1.01	42.7	45.4
I3	L0	6.9	7.4	0.77	0.79	29.4	32.4
	L1	7.6	8.0	0.81	0.83	32.4	35.2
	L2	8.8	9.3	0.90	0.93	34.1	36.2
	L3	9.7	10.4	0.93	0.99	38.1	41.7
I4	L0	9.6	10.1	0.68	0.78	26.9	29.8
	L1	9.9	10.4	0.83	0.88	29.8	32.4
	L2	9.9	11.1	0.90	0.93	39.0	40.8
	L3	13.1	14.1	0.98	1.06	45.7	49.3

I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50% FI; L0, zero layers of organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch.

3.8. Energy Savings

Figure 12 and Table 4 show the amount of energy savings consumed with the different strategies for scheduling under-irrigation; it was confirmed that the least energy consumption was achieved with the root drying technique, with which the highest values of crop productivity were achieved, especially when the soil was covered with three layers of organic covering. Energy savings of 50% were achieved with the root drying technique.

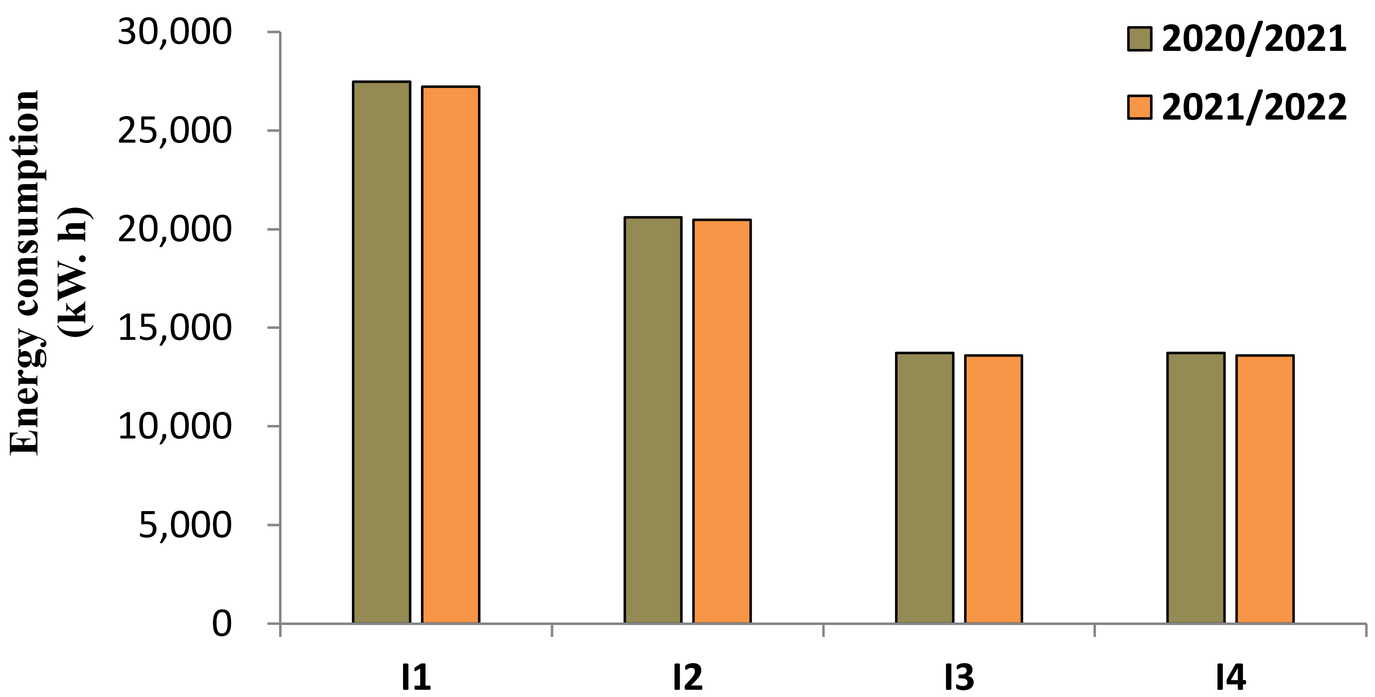


Figure 12. Energy consumed with scheduled deficit of irrigation. I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50% FI.

Table 4. Energy consumed with scheduling deficit of irrigation.

	BP: Brake Power (kW)					Operating Hours of Irrigation, (h)		Energy Consumption (kW. h)		%, Saving Energy	
	Q, m^3/s	TDH, (m)	Y_W, kN/m^3	E_i, %	E_P, %	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
I1	45	200	9.81	90	80	224	222	27,468	27,223	0	0
I2						168	167	20,601	20,478	25	24.8
I3						112	111	13,734	13,611	50	50
I4						112	111	13,734	13,611	50	50

I1, 100% full irrigation (FI); I2, 75% FI; I3, 50% FI; I4 (PRD), 50 % FI; L0, zero organic soil mulch (control); L1, a single layer of organic soil mulch; L2, two layers of organic soil mulch; L3, three layers of organic soil mulch; PWP, permanent wilt point; FC, field capacity.

4. Conclusions

The introduction of water-saving techniques and drought-tolerant varieties are vital for better crop production. The PRD irrigation technique is a new strategy that has been adapted during the last decade to a wide range of agronomic and horticultural crops, allowing increased water productivity and the possibility of increasing the efficiency of water and energy use and the improvement of the nutritional and health attributes of different agricultural species. This study has revealed that PRD along with application of organic mulch as a sustainable material is the best approach under conditions of limited water supply, resulting in improved mango yield, water productivity, and quality traits under in an arid climatic region. PRD + organic mulching (OM) may prove a good adaptation for better WP of mango under limited water conditions, as the region is currently facing a water shortage. As PRD + OM improves yield and water productivity while providing energy savings of up to 50%, it can be recommended for mango growers as a potential adaptation strategy under current climate scenarios in the region to achieve high mango production while saving both water and energy consumption.

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References

1. Hozayn, M.; El Monem, A.A.A.; Abdelraouf, R.E.; Abdalla, M.M. Do Magnetic Water Affect Water Use Efficiency, Quality and Yield of Sugar Beet (*Beta vulgaris* L.) Plant under Arid Regions Conditions? *J. Agron.* **2012**, *12*, 1–10. [CrossRef]
2. Abdelraouf, R.E.; El-Sayed, A.; Alaraidh, I.A.; Alsahli, A.; El-Zaidy, M. Field and Modeling Study on Saving Mineral Fertilizers, Increasing Farm Income and Improving Soil Fertility Using Bio-Irrigation with Drainage Water from Fish Farms. *Water* **2020**, *12*, 2998. [CrossRef]
3. El-Metwally, I.M.; Abdelraouf, R.E.; Ahmed, M.A.; Mounzer, O.; Alarcón, J.J.; Abdelhamid, M.T. Response Of Wheat (*Triticum aestivum* L.) Crop And Broad-Leaved Weeds To Different Water Requirements And Weed Management In Sandy Soils. *Agric. Polnohospodárstvo* **2015**, *61*, 22–32. [CrossRef]
4. Abdelraouf, R.E.; Ragab, R. Effect of Fertigation Frequency and Duration on Yield and Water Productivity of Wheat: Field and Modelling Study Using the Saltmed Model: Fertigation Frequency, Water Productivity, Wheat, SALTMED Model. *Irrig. Drain.* **2018**, *67*, 414–428. [CrossRef]
5. Eid, A.R.; Negm, A. Improving Agricultural Crop Yield and Water Productivity via Sustainable and Engineering Techniques. In *Conventional Water Resources and Agriculture in Egypt*; Negm, A.M., Ed.; The Handbook of Environmental Chemistry; Springer International Publishing: Cham, Switzerland, 2018; Volume 74, pp. 561–591, ISBN 978-3-319-95064-8.
6. Anjum, M.A.; Hussain, S.; Arshad, P.; Hassan, A. Irrigation Water of Different Sources Affects Fruit Quality Attributes and Heavy Metals Contents of Un-Grafted and Commercial Mango Cultivars. *J. Environ. Manag.* **2021**, *281*, 111895. [CrossRef] [PubMed]
7. Saddique, Q.; Liu, D.L.; Wang, B.; Feng, P.; He, J.; Ajaz, A.; Ji, J.; Xu, J.; Zhang, C.; Cai, H. Modelling Future Climate Change Impacts on Winter Wheat Yield and Water Use: A Case Study in Guanzhong Plain, Northwestern China. *Eur. J. Agron.* **2020**, *119*, 126113. [CrossRef]
8. Iqbal, R.; Raza, M.A.S.; Toleikiene, M.; Ayaz, M.; Hashemi, F.; Habib-ur-Rahman, M.; Zaheer, M.S.; Ahmad, S.; Riaz, U.; Ali, M.; et al. Partial Root-Zone Drying (PRD), Its Effects and Agricultural Significance: A Review. *Bull. Natl. Res. Cent.* **2020**, *44*, 159. [CrossRef]
9. Adu, M.O.; Yawson, D.O.; Armah, F.A.; Asare, P.A.; Frimpong, K.A. Meta-Analysis of Crop Yields of Full, Deficit, and Partial Root-Zone Drying Irrigation. *Agric. Water Manag.* **2018**, *197*, 79–90. [CrossRef]
10. Raza, M.A.S.; Ahmad, S.; Saleem, M.F.; Khan, I.H.; Iqbal, R.; Zaheer, M.S.; Haider, I.; Ali, M. Physiological and Biochemical Assisted Screening of Wheat Varieties under Partial Rhizosphere Drying. *Plant Physiol. Biochem.* **2017**, *116*, 150–166. [CrossRef]
11. Shahnazari, A.; Liu, F.; Andersen, M.N.; Jacobsen, S.-E.; Jensen, C.R. Effects of Partial Root-Zone Drying on Yield, Tuber Size and Water Use Efficiency in Potato under Field Conditions. *Field Crops Res.* **2007**, *100*, 117–124. [CrossRef]
12. Zuazo, V.H.D.; García-Tejero, I.F.; Rodríguez, B.C.; Tarifa, D.F.; Ruiz, B.G.; Sacristán, P.C. Deficit Irrigation Strategies for Subtropical Mango Farming. A Review. *Agron. Sustain. Dev.* **2021**, *41*, 13. [CrossRef]
13. Iqbal, R.; Raza, M.A.S.; Valipour, M.; Saleem, M.F.; Zaheer, M.S.; Ahmad, S.; Toleikiene, M.; Haider, I.; Aslam, M.U.; Nazar, M.A. Potential Agricultural and Environmental Benefits of Mulches—A Review. *Bull. Natl. Res. Cent.* **2020**, *44*, 75. [CrossRef]
14. Shahabian, M.; Samar, S.M.; Talaie, A.; Emdad, M.R. Response of Orange Trees to Deficit Irrigation Strategies in the North of Iran. *Arch. Agron. Soil Sci.* **2012**, *58*, 267–276. [CrossRef]
15. Kang, S.; Hu, X.; Jerie, P.; Zhang, J. The Effects of Partial Rootzone Drying on Root, Trunk Sap Flow and Water Balance in an Irrigated Pear (*Pyrus communis* L.) Orchard. *J. Hydrol.* **2003**, *280*, 192–206. [CrossRef]
16. Zegbe, J.A.; Behboudian, M.H.; Clothier, B.E.; Lang, A. Postharvest Performance of 'Pacific Rose™' Apple Grown Under Partial Rootzone Drying. *HortScience* **2008**, *43*, 952–954. [CrossRef]
17. Ghrab, M.; Gargouri, K.; Bentaher, H.; Chartzoulakis, K.; Ayadi, M.; Ben Mimoun, M.; Masmoudi, M.M.; Ben Mechlia, N.; Psarras, G. Water Relations and Yield of Olive Tree (Cv. Chemlali) in Response to Partial Root-Zone Drying (PRD) Irrigation Technique and Salinity under Arid Climate. *Agric. Water Manag.* **2013**, *123*, 1–11. [CrossRef]
18. Pérez-Pérez, J.G.; Dodd, I.C.; Botía, P. Partial Rootzone Drying Increases Water-Use Efficiency of Lemon Fino 49 Trees Independently of Root-to-Shoot ABA Signalling. *Funct. Plant Biol.* **2012**, *39*, 366. [CrossRef]
19. Hutton, R.J.; Loveys, B.R. A Partial Root Zone Drying Irrigation Strategy for Citrus—Effects on Water Use Efficiency and Fruit Characteristics. *Agric. Water Manag.* **2011**, *98*, 1485–1496. [CrossRef]
20. Parvizi, H.; Sepaskhah, A.R.; Ahmadi, S.H. Effect of Drip Irrigation and Fertilizer Regimes on Fruit Yields and Water Productivity of a Pomegranate (*Punica granatum* (L.) Cv. Rabab) Orchard. *Agric. Water Manag.* **2014**, *146*, 45–56. [CrossRef]
21. Galindo, A.; Rodríguez, P.; Mellisho, C.D.; Torrecillas, E.; Moriana, A.; Cruz, Z.N.; Conejero, W.; Moreno, F.; Torrecillas, A. Assessment of Discretely Measured Indicators and Maximum Daily Trunk Shrinkage for Detecting Water Stress in Pomegranate Trees. *Agric. For. Meteorol.* **2013**, *180*, 58–65. [CrossRef]
22. Mena, P.; Galindo, A.; Collado-González, J.; Ondoño, S.; García-Viguera, C.; Ferreres, F.; Torrecillas, A.; Gil-Izquierdo, A. Sustained Deficit Irrigation Affects the Colour and Phytochemical Characteristics of Pomegranate Juice: Sustained Deficit Irrigation Affects Phenolics and Colour of Pomegranate Juice. *J. Sci. Food Agric.* **2013**, *93*, 1922–1927. [CrossRef] [PubMed]
23. Spreer, W.; Nagle, M.; Neidhart, S.; Carle, R.; Ongprasert, S.; Müller, J. Effect of Regulated Deficit Irrigation and Partial Rootzone Drying on the Quality of Mango Fruits (*Mangifera indica* L., Cv. 'Chok Anan'). *Agric. Water Manag.* **2007**, *88*, 173–180. [CrossRef]
24. Shahzaman, M.; Zhu, W.; Bilal, M.; Habtemicheal, B.A.; Mustafa, F.; Arshad, M.; Ullah, I.; Ishfaq, S.; Iqbal, R. Remote Sensing Indices for Spatial Monitoring of Agricultural Drought in South Asian Countries. *Remote Sens.* **2021**, *13*, 2059. [CrossRef]

25. Ahmad, I.; Bibi, F.; Ullah, H.; Munir, T. Mango Fruit Yield and Critical Quality Parameters Respond to Foliar and Soil Applications of Zinc and Boron. *Plants* **2018**, *7*, 97. [CrossRef]
26. Ghosh, P.K.; Dayal, D.; Bandyopadhyay, K.K.; Mohanty, M. Evaluation of Straw and Polythene Mulch for Enhancing Productivity of Irrigated Summer Groundnut. *Field Crops Res.* **2006**, *99*, 76–86. [CrossRef]
27. Ullah, A.; Sun, H.; Yang, X.; Zhang, X. Drought Coping Strategies in Cotton: Increased Crop per Drop. *Plant Biotechnol. J.* **2017**, *15*, 271–284. [CrossRef] [PubMed]
28. Steinmetz, Z.; Wollmann, C.; Schaefer, M.; Buchmann, C.; David, J.; Tröger, J.; Muñoz, K.; Frör, O.; Schaumann, G.E. Plastic Mulching in Agriculture. Trading Short-Term Agronomic Benefits for Long-Term Soil Degradation? *Sci. Total Environ.* **2016**, *550*, 690–705. [CrossRef] [PubMed]
29. Levin, A.G.; Peres, M.; Noy, M.; Love, C.; Gal, Y.; Naor, A. The Response of Field-Grown Mango (Cv. Keitt) Trees to Regulated Deficit Irrigation at Three Phenological Stages. *Irrig. Sci.* **2018**, *36*, 25–35. [CrossRef]
30. Horwitz, W.; Association of Official Analytical Chemists (Eds.) *Official Methods of Analysis of the Association of Official Analytical Chemists*, 13th ed.; Association of Official Analytical Chemists: Washington, DC, USA, 1980; ISBN 978-0-935584-14-1.
31. Snedecor, G.W.; Cochran, W.G. *Statistical Methods*, 7th ed.; The Iowa State University Press: Ames, IA, USA, 1990.
32. Shen, D.; Zhang, G.; Xie, R.; Ming, B.; Hou, P.; Xue, J.; Li, S.; Wang, K. Improvement in Photosynthetic Rate and Grain Yield in Super-High-Yield Maize (*Zea mays* L.) by Optimizing Irrigation Interval under Mulch Drip Irrigation. *Agronomy* **2020**, *10*, 1778. [CrossRef]
33. Zhang, S.; Yang, W.; Muneer, M.A.; Ji, Z.; Tong, L.; Zhang, X.; Li, X.; Wang, W.; Zhang, F.; Wu, L. Integrated Use of Lime with Mg Fertilizer Significantly Improves the Pomelo Yield, Quality, Economic Returns and Soil Physicochemical Properties under Acidic Soil of Southern China. *Sci. Hortic.* **2021**, *290*, 110502. [CrossRef]
34. AbdAllah, A. Impacts of Kaolin and Pinoline Foliar Application on Growth, Yield and Water Use Efficiency of Tomato (*Solanum lycopersicum* L.) Grown under Water Deficit: A Comparative Study. *J. Saudi Soc. Agric. Sci.* **2019**, *18*, 256–268. [CrossRef]
35. Ahmed, Y.M.; Shalaby, E.A.; Shanan, N.T. The Use of Organic and Inorganic Cultures in Improving Vegetative Growth, Yield Characters and Antioxidant Activity of Roselle Plants (*Hibiscus sabdariffa* L.). *Afr. J. Biotechnol.* **2011**, *10*, 1988–1996.