agronomy

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Impact of Partial Root Drying and Soil Mulching on Squash Yield and Water Use Efficiency in Arid

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Abstract: Practical and sustainable water management systems are needed in arid regions due to water shortages and climate change. Therefore, an experiment was initiated in winter (WS) and spring (SS), to investigate integrating deficit irrigation, associated with partial root drying (PRD) and soil mulching, under subsurface drip irrigation on squash yield, fruit quality, and irrigation water use efficiency (IWUE). Two mulching treatments, transparent plastic mulch (WM) and black plastic mulch (BM), were tested, and a treatment without mulch (NM) was used as a control. Three levels of irrigation were examined in a split-plot design with three replications: 100% of crop evapotranspiration (ETc), representing full irrigation (FI), 70% of ETc (PRD70), and 50% of ETc (PRD50). There was a higher squash yield and lower IWUE in SS than WS. The highest squash yields were recorded for PDR70 (82.53 Mg ha^{-1}) and FI (80.62 Mg ha^{-1}). The highest IWUE was obtained under PRD50. Plastic mulch significantly increased the squash yield (34%) and IWUE (46%) and enhanced stomatal conductance, photosynthesis, transpiration, leaf chlorophyll fluorescence, and leaf chlorophyll contents under PRD plants. These results indicate that in arid and semi-arid regions, soil mulch with deficit PRD could be used as a water-saving strategy without reducing yields.

Keywords: squash; partial root drying; water use efficiency; soil mulch; growing seasons; gas exchange; fruit quality

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Citation: Farah, A.H.; Al-Ghobari, H.M.; Zin El-Abedin, T.K.; Alrasasimah, M.S.; El-Shafei, A.A. Impact of Partial Root Drying and Soil Mulching on Squash Yield and Water Use Efficiency in Arid. *Agronomy* **2021**, *11*, 706. https://doi.org/10.3390/agronomy11040706

Academic Editor: Aliasghar Montazar

Received: 25 February 2021
Accepted: 4 April 2021
Published: 7 April 2021

1. Introduction

Increasing the consumption of water in the agricultural sector, and a lack of preventative measures to permanently conserve water and avoid water shortages, make it vital to manage water resources rather than develop new ways to supply water. Therefore, the need to develop practical and sustainable management systems for water supply has become a subject of intense discussion. Drip irrigation is a promising irrigation strategy that reduces soil evaporation and deep drainage losses, while efficiently delivering water to plant roots [1]. Compared with conventional methods, drip irrigation has shown its utility for water-saving and the efficient use of fertilizers, especially fruit and vegetable crops [2].

Various methods are currently used to increase the efficiency of delivering water to plants. One of these is subsurface drip irrigation (SSDI), which is primarily utilized to decrease water loss during water delivery to plants. Compared with other drip irrigation methods, SSDI has gained more acceptance in the irrigation sector in its ability to increase crop yield and reduce plant diseases and soil erosion [3–5]. Other methods that are used to efficiently managing water irrigation include deficit irrigation (DI) and soil mulching. Ever since the focus of water irrigation shifted from increasing yield per planted area to increasing yield per unit volume of water applied [6], DI has become an important strategy in arid and semi-arid regions where water shortages are a major limitation to farming.

Therefore, the optimal goal of using DI is to save water, either by reducing the number of irrigation cycles or reducing the volume of water applied during each irrigation event [7]. Irrigation water use efficiency (IWUE) has been developed to indicate increasing crop yield while using less water, or maximizing yield in limited water sources [8]. IWUE was defined by the total yield to the total water applied [9,10]. In a physiological perspective, IWUE is used to describe the amount of carbon to the water lost through transpiration [11]. However, agronomists primarily focus on maximizing yield per water applied [12].

Partial root drying (PRD) is an improved form of DI strategy that involves applying water to the sides of a plant root zone, either by irrigating one side of the plant root (fixed PRD) or alternately watering both sides of the root (alternating PRD) [13]. Adequate water and nutrients are delivered to the plant on the wet side of the root, while the dry side is stimulated and releases chemical hormones. These chemical hormones cause stomata to partially close, which increases IWUE [13]. This strategy makes PRD more efficient than DI [13–15]. Barideh et al. [16] reported that alternating PRD saves more water than fixed PRD. Several studies have shown the advantages of DI and PRD over full irrigation (FI), in terms of IWUE without the reduction of yield [17–20]. A number of researchers working on different crops found that the PRD strategy increased IWUE by 38–53% compared with FI without a significant reduction in yield [18,21,22]. Ors et al. [23] reported that deficit irrigation (67%) had significantly reduced chlorophyll index value (7%), leaf water content (42%), stomatal conductance (69%), transpiration (62%), photosynthesis (62%) of squash. Al-Ghobari and Dewidar [24] indicated that deficit irrigation significant affected the fresh leaf, stem weight of tomato, compared with full irrigation. In terms of fruit quality, PRD preserved fruit quality, compared with deficit irrigation. Zhang et al. [25] reported that PRD was not affected by soluble solid contents of strawberry, while deficit irrigation considerably decreased soluble solid contents. Guang-Cheng et al. [26] indicated that both PRD50 and DI50 strategies considerably decreased dry weigh of shoot and root pepper compared with full irrigation. Furthermore, PRD50 reduced photosynthesis 19% while DI50 decreased 22%. In chlorophyll fluorescence (FV/Fm) PRD50 reduced by 9.5% while DI50 decreased 12.0%.

Another method that can increase IWUE is soil mulching, which can be used for many purposes in the agriculture sector. However, preserving soil moisture, improving soil physical properties, and controlling soil erosion are the most significant uses of soil mulching in arid and semi-arid regions [27,28]. Mulching materials positively affect the moisture of the soil by improving soil structure and soil retention, as well as decreasing soil evaporation [27,29–31]. Yaghi et al. [32] reported that combining drip irrigation with plastic mulch increased cucumber yield (45%) and IWUE (72%) compared with the treatment without mulch during two successive growing seasons in the arid region. Abhivyakti et al. [33] found that black plastic mulch increased the tomato yield by 30% compared with bare soil in open field conditions. Abd El-Mageed et al. [34] also reported that soil mulching increased both, the squash yield and IWUE by 26%, compared with the non-mulched treatments. Experimenting on broccoli, Verma et al. [35] observed that mulching increased the photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, and transpiration rate. Additionally, Lira-Saldivar et al. [36] found that plastic mulch significantly increased photosynthetic activity in zucchini plants (17.9%) compared with non-mulched treatments.

In addition to water, growing season also influences both crop yield and IWUE. Numerous studies on zucchini squash have reported that growing season has a significant effect on crop yield and IWUE [9,34,37,38].

Despite numerous studies that have been conducted on SSDI, PRD irrigation and soil mulching, as water management strategies, combined with arid regions with different growing seasons, has not been fully investigated. Therefore, this study aimed to investigate the effect of DI levels, associated with PRD strategy and plastic mulch on squash yield and IWUE in winter and spring. This study also examined the combined effects of PRD, soil mulch, and growing season on gas exchanges, chlorophyll fluorescence, and the chlorophyll content index at different plant growth stages.

2. Materials and Methods

2.1. Experimental Design and Growth Conditions

Two experiments were conducted in two consecutive growing seasons: the winter season (WS) and spring season (SS) of 2018–2019 at the Educational farm, King Saud University, Riyadh, which is in an arid area. A meteorological station was set up to constantly measure weather parameters, namely, air temperature, relative humidity, solar radiation, evapotranspiration, and rainfall throughout the WS and SS (Figures 1 and 2). Field preparations were made, including plowing, grading, and leveling. Then, the irrigation layout was implemented according to the experimental design, as shown in Figure 3.

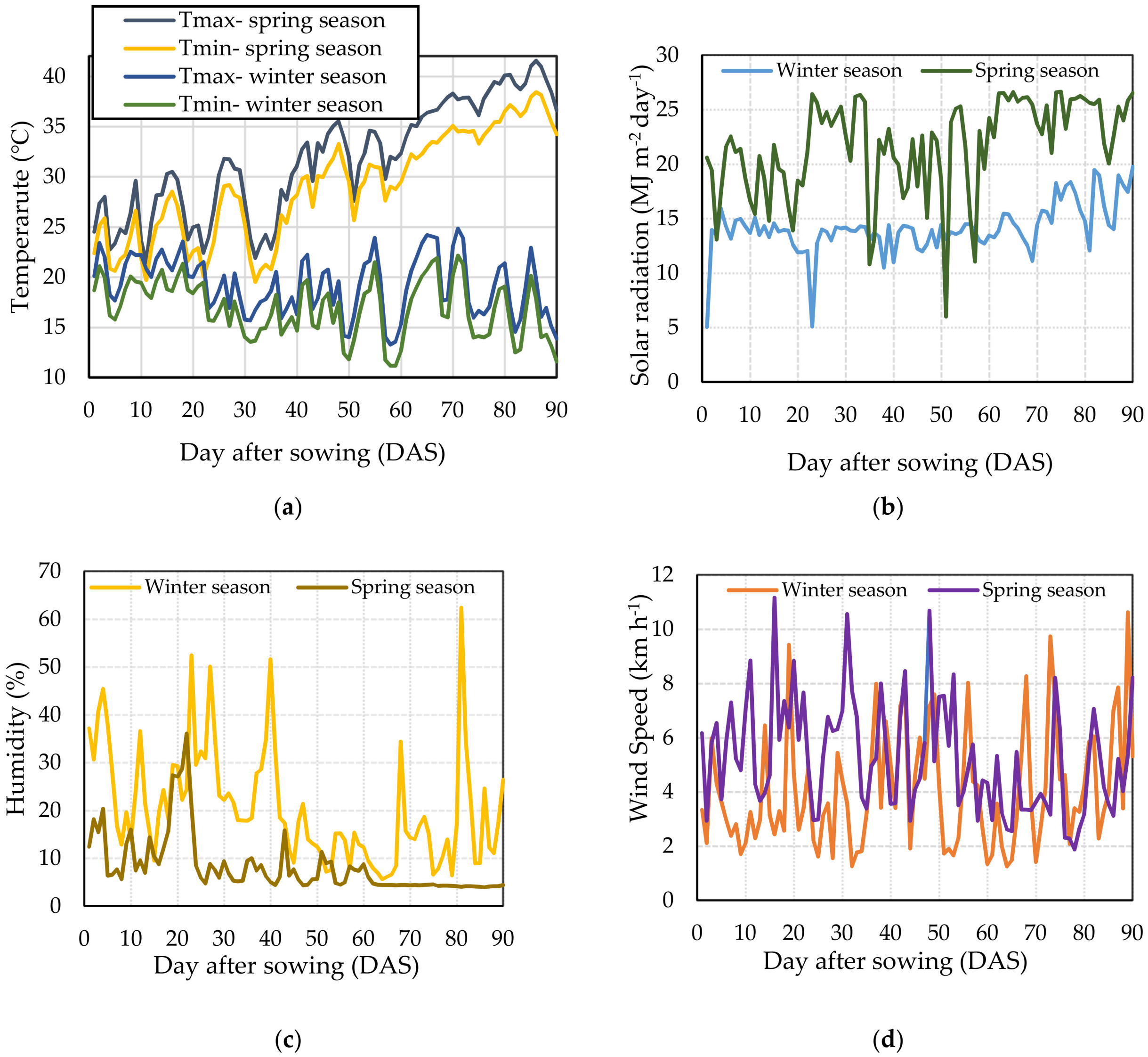


Figure 1. Daily climate parameters in the winter and spring of 2018–2019 during the squash growing seasons: (**a**) Daily maximum and minimum temperature, (**b**) solar radiation, (**c**) relative humidity, and (**d**) wind speed.

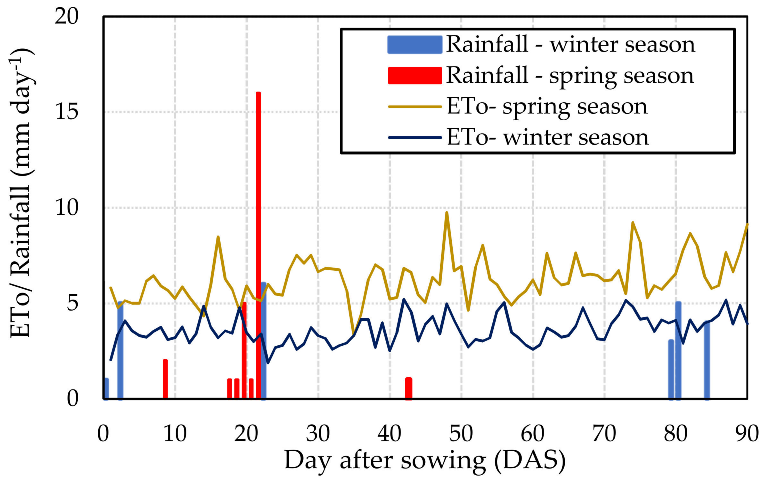


Figure 2. Seasonal reference evapotranspiration (ETo) at the experimental field throughout the winter and spring growing seasons.

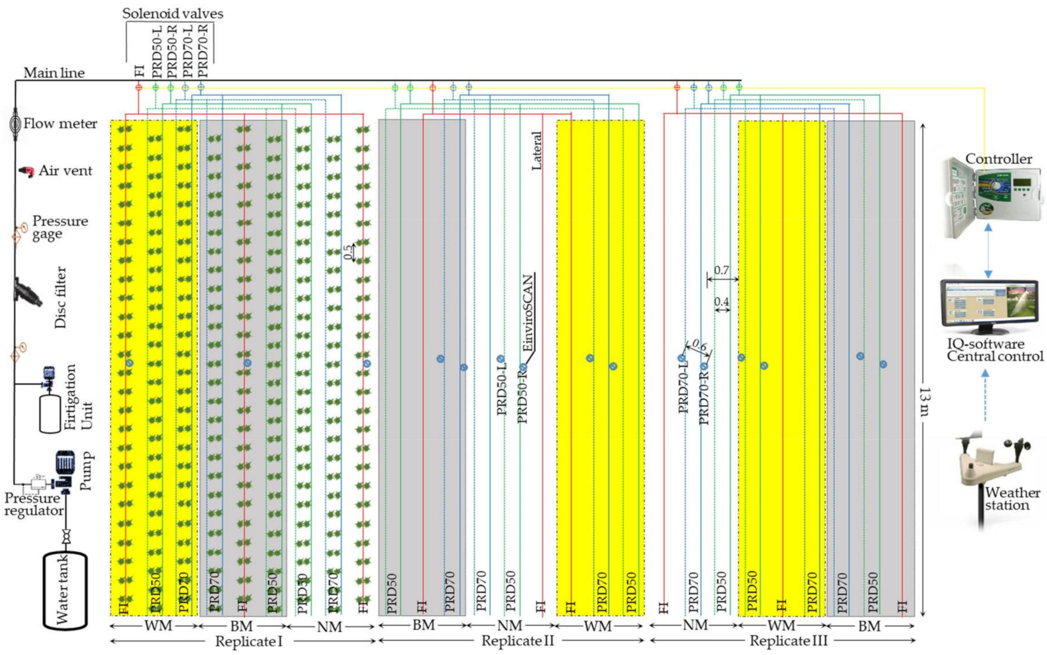


Figure 3. Schematic diagram of the experimental fields under mulch treatments (black mulch-BM, transparent mulch-WM and non-mulch- NM) and irrigation treatments (full irrigation-FI, partial root drying with 50% of evapotranspiration-PRD50, partial root drying with 70% of evapotranspiration-PRD70).

Soil physical and chemical analyses were conducted by taking soil samples every 0.1 m down to a depth of 0.5 m, as shown in Table 1. Soil physical parameters were determined, including the field capacity (FC), wilting point (WP), saturated hydraulic conductivity (ks), bulk density (ρ_b), and soil saturation (S). The experiment was conducted in a split-plot design (Figure 3). Treatments were allocated three levels of irrigation and three mulching treatments. The mulching treatments, transparent mulch (WM), black mulch (BM), and without mulch (NM), were assigned as main plots, and the irrigation treatments, FI with 100% of crop evapotranspiration (ET_c), irrigation with 70% of ET_c (PRD70), and irrigation with 50% of ET_c (PRD50%) were allocated in subplots. The experimental plot area was 13 m in length by 0.70 m in row width (9.1 m^2). A total of 27 plots were made by replicating each treatment three times.

Table 1. Soil physical and chemical properties.

Depth (cm)	Particle Size (%)			Texture	FC %	WP %	k_s (mm/h)	S %	ρ_b (g cm^{-3})
	Sand	Silt	Clay						
0–10	82.90	8.80	8.30	sandy loam	22.11	5.53	48.06	38.15	1.40
10–30	74.35	16.85	8.80	sandy loam	21.30	4.72	18.10	35.00	1.51
30–50	70.32	20.8 8	8.80	sandy loam	22.44	4.46	11.39	33.17	1.57

Depth (cm)	pH	Cation (meq L^{-1})				Anions (meq L^{-1})			
		Ca^{2+}	Mg^{2+}	Na^+	K^+	$HCO_3{}^-$	$CO_3{}^{2-}$	CI^-	$SO_4{}^{2-}$
0–10	7.56	2.95	0.95	1.98	0.39	1.25	0.00	2.45	2.35
10–30	7.47	3.73	0.59	3.85	0.44	1.28	0.00	3.10	3.45
30–50	7.35	4.40	0.98	4.78	0.73	1.78	0.00	4.00	4.48

FC: field capacity; WP: wilting point; k_s: saturated hydraulic conductivity; S: soil saturation; ρ_b: bulk density.

2.2. Applied Irrigation Water

Drip pipes were buried 15 cm below the soil surface and had 26 inline emitters, which were spaced at intervals of 0.5 m, and had a discharge rate of 8 L h^{-1} at an operating pressure of 100 kPa. In the FI experimental plot, one lateral was installed adjacent to the crop rows, while in the PRD treatments, two laterals with two control valves were installed 0.4 m apart in each crop row. Irrigation in the PRD treatment was shifted between the two sides of plants every five days.

A weather station (WS-PRO LT Weather Station, Rain Bird) was launched in the experiment field. Daily reference evapotranspiration (ET_o) was calculated from daily climate data according to Allen et al. [39] using Equation (1),

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2\ (e_S - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

where ET_o is reference crop evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), Δ is the slope of the vapor pressure curve (kPa °C^{-1}), and γ is a psychrometric constant (kPa °C^{-1}).

Irrigation was conducted every day using an automatic controller (ESP-LXME controllers, Rain Bird Corporation, Tucson, AZ, USA), which was connected with a central control (IQ v2.0, Rain Bird Corporation, Azusa, CA, USA). The IQ-software monitored and adjusted watering schedules for the controller and site from a compatible Windows PC, which was connected with the weather station to schedule irrigation automatically based on ET_c. The crop water requirements (ET_c) were estimated using Equation (2),

$$ET_c = ET_o \times K_c \tag{2}$$

where ET_c is the crop water requirement (crop evapotranspiration; mm day^{-1}), and K_c is the crop coefficient. The crop growth stages, initial, development, mid, and late stage, were 20, 30, 25, and 15 days, respectively, and K_c of 0.6, 1.0, and 0.75 were used for the initial, mid, and late stage, respectively [39]. Moreover, the values of K_c were adjusted according to Allen et al. [39] based on the relative humidity, wind speed at 2 m, percentage of wetted soil surface in the experimental field using Equations (3) and (4),

$$K_{c\ ini} = f_w\ K_{c\ ini(Table)} \tag{3}$$

where $K_{c\ ini}$ is the adjusted value of initial K_c, f_w is the fraction of surfaced wetted by irrigation, and $K_{c\ ini(Table)}$ is the value of initial K_c from Allen et al. [39].

$$K_{c\ mid\ OR\ end} = K_{c\ mid\ OR\ end(Table)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (4)$$

where $K_{c\ mid\ OR\ end}$ is the adjusted values of mid K_c or end K_c, $K_{c\ mid\ OR\ end(Table)}$ is the value of of mid K_c or end K_c from Allen et al. [39], RH_{min} is the mean value for daily minimum relative humidity during the mid-season growth stage or the end-season stage [%], and h is mean plant height during the mid-season stage or the end-season stage [m].

At 20 days after sowing (DAS), PRD70 and PRD50 were applied until harvesting.

2.3. Plant Management

Two seeds of zucchini squash, *Cucurbita pepo* L., were hand-sown 10 cm apart on both sides of the central line of the planting rows, and there was 0.5 m between plants within a row. Seeds were planted on November 18, 2018 and terminated on 15 February 2019 in the WS, and in the SS, seeds were planted on 23 March 2019 and terminated on 20 June 2019. Chemical fertilization was applied at the recommended rate for squash production in this area: 5.1 g N/plant, 5.1 g P_2O_5/plant, 16.8 g K_2O/plant, 37.5 g $Ca(NO_3)_2$/plant, 28.5 mL H_3PO_4/plant, 14.52 mL HNO_3/plant, and 1.41 g humic acid/plant. Pest management and disease control were conducted based on local squash protection procedures.

2.4. Soil Moisture Measurements

Capacitance probes (EnviroSCAN®, Sentek Sensor Technologies, Stepney, Australia) were used to measure soil moisture. Enviroscan probes were used to continuously monitor volumetric soil water content (θ_v) down to a depth of 0.5 m in the root zone of each irrigation treatment. Probes were installed vertically at a distance of 0.10 m from laterals and had five sensors at 0.10 m intervals. Soil frequencies (F_s) were converted into scaled frequencies (S_f) according to Equation (5) following Buss [40],

$$S_f = \frac{F_A - F_S}{F_A - F_W} \quad (5)$$

where F_A is the sensor reading in the air, F_S is the sensor reading in the soil, and F_W is the sensor reading in non-saline water. According to Vera et al. [41], θ_v can be calculated using Equation (6),

$$\theta_v = \left(\frac{S_f - C}{A}\right)^{\frac{1}{b}} \quad (6)$$

where A = 0.1957, b = 0.404, and C = 0.02852. The determination coefficient value provided using standard default calibration was 0.97. One EnviroScan device per plot was installed in single lateral treatments (FI), while two EnviroScan devices were installed 0.6 m apart in the diagonal direction in the two lateral treatments: PRD70 and PRD50 (Figure 3).

2.5. Physiological and Agronomic Measurements

Chlorophyll index (soil-plant analysis development (SPAD) value) and gas exchange measurements, including stomatal conductance (g_s), photosynthesis (P_n), and transpiration rate (T_r), were measured at three different growth stages: development (35 DAS), mid (63 DAS), and late stage (83 DAS). One leaf (of the same age) was selected per plant from five plants per plot. A total of 15 measurements per treatment were made at every growth stage.

The chlorophyll index (SPAD value) was measured using a SPAD 502 Plus Chlorophyll Meter (Minolta Co. Ltd., Osaka, Japan). Using a chlorophyll meter is a non-destructive method that quickly and precisely approximates the chlorophyll concentration of leaves by measuring the red (650 nm) and infrared (940 nm) radiation of leaves [42]. The sample readings were made for every plot using the center section of the selected leaf at all measured growth stages.

The gas exchange measurements g_s, P_n, and T_r were measured using an LI-6400XT portable photosynthesis system (LiCor Inc., Lincoln, NE, USA). The samples were measured for each treatment from functional leaves on a cloudless day from 08h00 to 10h00 local time.

Total fresh squash yields (Mg ha^{-1}) were determined by manually collecting and weighing fruits from each line for all harvested squash fruits. The irrigation water use efficiency (IWUE) was calculated by dividing the total weight of harvested squash fresh fruits (kg ha^{-1}) by the volume of water applied to the crop (m^3 ha^{-1}) [9,10].

The fruit quality parameters, total soluble solids (TSS, %), vitamin C (V_C, mg 100 g^{-1} fruit fresh weight-FW), and titratable acidity (TA, % citric acid), were assessed by choosing samples of three mature fruits in the third, fifth, and seventh harvestings per treatment in each growing season. A squash extract was taken by blending and filtering the flesh of each fruit. A digital refractometer (PR-101 model, ATAGO, Tokyo, Japan) was used to determine the TSS using standard methods of analysis [43], while TA was determined using the procedure, described by Caruso et al. [44]. 2,6-dichlorophenol-indophenol-dye was used to measured Vc in the extracted juice [45].

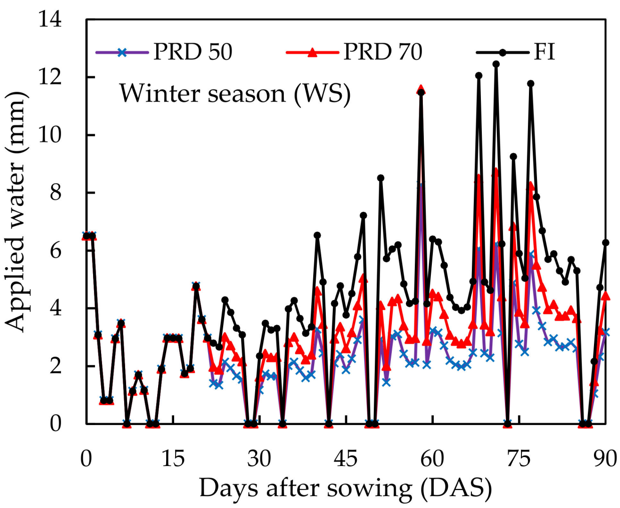
2.6. Statistical Analysis

Statistical analysis was conducted using analysis of variance procedures using CoStat version 6.451 [46]. The difference between means was compared using a least significant difference test (LSD) at the 5% level ($p \leq 0.05$).

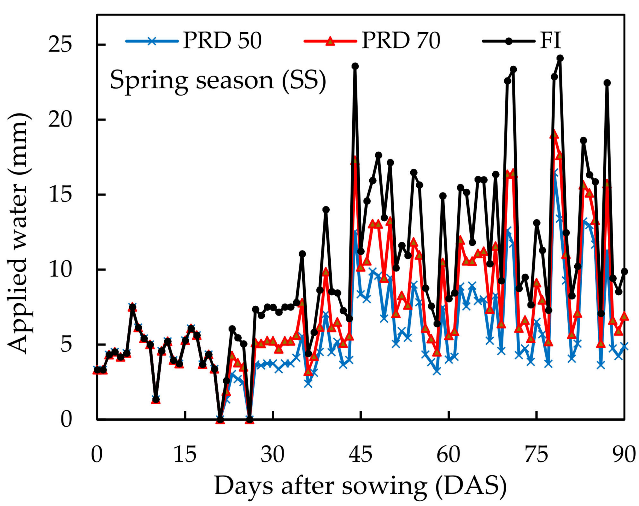
3. Results and Discussion

3.1. Evapotranspiration and Applied Irrigation

There was variation in the weather parameters of the WS and SS (Figure 1). Air temperature, solar radiation intensity, and wind speed were higher in the SS than the WS. However, in the WS, the relative humidity was higher than in the SS. This caused a 73% increase in the seasonal reference evapotranspiration (ET$_o$) in the SS, compared with the WS (Figure 2). As irrigation scheduling was based on ET$_c$, more water was consumed in the SS than the WS (Figure 4).



(**a**)



(**b**)

Figure 4. Seasonal water application to zucchini squash crops for the two growing seasons: (**a**) Winter season, and (**b**) spring season.

3.2. Soil Moisture Content

Figure 5 shows the different patterns of soil moisture distribution in their response to FI, PRD70, and PRD50, combined with WM, BM, and NM during the WS and SS. The values presented for volumetric soil moisture content (θ_v) are an average of 0.1, 0.2, 0.3, 0.4, and 0.5 m soil depths. Before irrigation treatments (20 DAS), the θ_v for all treatments was almost the same for each growing season. Irrigation was scheduled based on ET, and this caused a variation in θ_v between the two seasons. In the WS, the θ_v for FI was below the FC compared with the SS when the θ_v of FI was almost near the FC. The average θ_v in the SS was higher by 16%, 22%, and 32% for BM, WM, and NM, respectively, than the corresponding values in WS. This was primarily due to the applied water in the SS, which was higher than in the WS (Figure 4). For the mulch treatments, WM and BM showed higher θ_v than NM. The increased moisture retention capacity of the mulched treatments in the two growing seasons could be attributed to less evaporation from the soil, as shown in Figure 5. Besides, vapor accumulation from irrigated water trapped within the mulches cause the formation of fog, which precipitates back into the soil. These findings are in agreement with Yaghi et al. [32] and Rashid et al. [47], who found that mulched treatments showed higher soil moisture content compared to non-mulched treatments. The θ_v values of the PRD treatments showed alternately an increase in the wet side (right) of the root zone, while the dry side (left) showed a reduction in soil moisture content, as shown in Figure 5. The wet side of the root zone delivers water to the plant, while the dry side improves root ventilation. In PRD70, θ_v was between the FC and WP. However, in PRD50, θ_v was below the WP, and this had a negative impact on plant growth. The patterns of soil water dynamics in PRD-treated plants in this study were similar to those described by Barideh et al. [16] and Rashid et al. [47], who found that the soil water content in PRD treatments increased and decreased interchangeably.

3.3. Stomatal Conductance (g_s), Photosynthesis (P_n), and Transpiration (T_r)

Data in Table 2 show that irrigation quantity significantly ($p < 0.001$) affected the values of g_s at all growth stages. At 83 DAS, PRD70 and PRD50 reduced the value of g_s by 10% and 37% compared with FI, respectively. This is due to plant age, which reduces its activity. FI showed a higher P_n rate compared with the PRD treatments. At 63 DAS, P_n values under the FI plot were 10.685 µmol m^{-2} s^{-1}. This is a 7% and 16% increase compared with PRD70, and PRD50, respectively. T_r was significantly affected ($p < 0.001$) by irrigation quantity at all measured days. The lowest T_r values were observed under PRD50 treatments at 63 DAS.

However, FI treatments showed the highest T_r (4.046 mmol m^{-2} s^{-1}) at 35 DAS, which was not statistically different from PRD70. This finding indicates that the water deficit in PRD70 did not affect transpiration efficiency. At 83 DAS, PRD50 and PRD70 reduced the T_r values by 20% and 17.6%, respectively, compared with the FI treatments. In this study, the irrigation treatment significantly affected the g_s, P_n, and T_r values, indicating that both P_n and T_r are controlled by g_s, and they mutually affect each other [48,49]. Liu et al. [50] stated that under water-stressed conditions, g_s decreases due to the closure of stomata to maintain leaf water status. However, there are opposing reports on the mechanism behind stomatal closure [51]. Although some studies suggest that chemical signals, such as abscisic acid (ABA) and pH are behind stomatal closure [50,52], others endorse that hydraulic signals, such as soil, root, and shoot resistances, are responsible for stomatal closure [53]. Many questions still arise related to the mechanism behind stomatal closure, even though many studies have been conducted [51]. Farooq et al. [54] stated that stomatal closure reduces the amount of carbon dioxide going into the parenchyma cells, which causes inhabitation of CO_2 and light that ultimately affects plant photosynthesis efficiency.

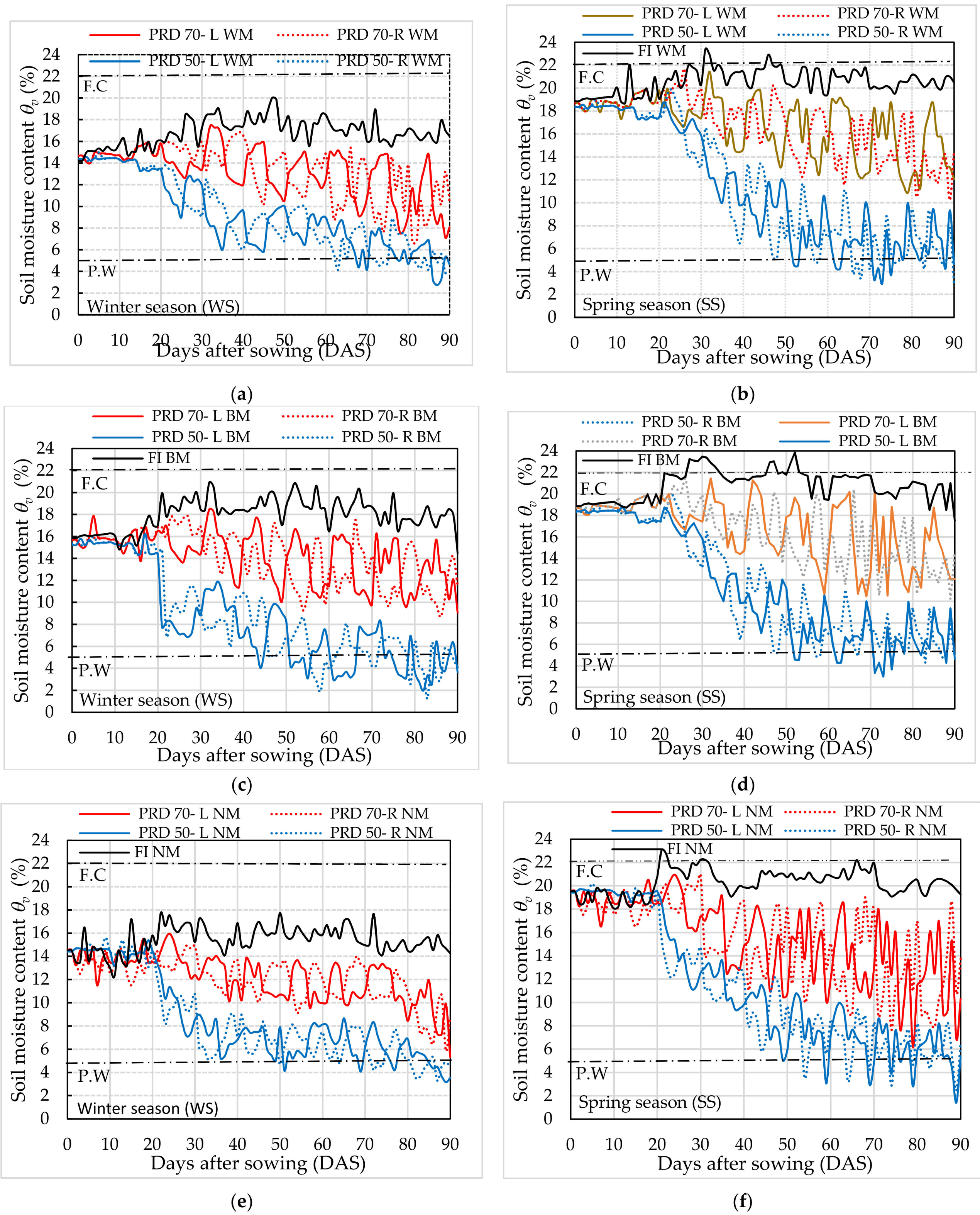


Figure 5. Soil moisture for full irrigation (FI) and deficit partial rootzone drying under 70% and 50% of evapotranspiration (PRD70 and PRD50, respectively) at the left (L) and right (R) rootzone sides combined with: (**a**) Transparent mulch (WM) during the winter season (WS), (**b**) WM during the spring season (SS), (**c**) black mulch (BM) during the WS, (**d**) BM during the SS, (**e**) no mulch (NM) during the WS, and (**f**) NM during SS. FC, field capacity, and WP, wilting point.

Table 2. Analysis of variance of stomatal conductance (g_s), photosynthesis (P_n), and transpiration (T_r) at the development stage (35 DAS), mid stage (63 DAS), and late stage (83 DAS) of squash growth during the winter (WS) and spring (SS) growing seasons.

Treatments		g_s (mol H_2O m^{-2} s^{-1})			P_n (μmol CO_2 m^{-2} s^{-1})			T_r (mmol H_2O m^{-2} s^{-1})		
		35 DAS	**63 DAS**	**83 DAS**	**35 DAS**	**63 DAS**	**83 DAS**	**35 DAS**	**63 DAS**	**83 DAS**
Season (S)	**WS**	0.2912 ^{b}	0.2192 ^{b}	0.1722 ^{b}	8.647 ^{b}	9.335 ^{b}	9.1668 ^{b}	3.115 ^{b}	2.804 ^{b}	2.887 ^{b}
	SS	0.3881 ^{a}	0.3182 ^{a}	0.2122 ^{a}	9.657 ^{a}	10.414 ^{a}	10.381 ^{a}	4.285 ^{a}	3.952 ^{a}	3.836 ^{a}
	p-value	0.0059 **	0.0006 **	0.0126 *	0.023 *	0.0465 *	0.0172 *	0.014 *	0.0002 **	0.0039 **
	LSD0.05	0.032	0.0107	0.019	0.678	1.037	0.694	0.602	0.072	0.254
Mulch (M)	**WM**	0.3445	0.3004 ^{a}	0.2257 ^{a}	10.176 ^{a}	9.961 ^{b}	10.256 ^{a}	4.046 ^{a}	3.812 ^{a}	3.852 ^{a}
	BM	0.3401	0.2660 ^{b}	0.1818 ^{b}	9.778 ^{a}	10.461 ^{a}	10.088 ^{a}	3.901 ^{a}	3.359 ^{b}	3.173 ^{b}
	NM	0.3262	0.2397 ^{c}	0.1690 ^{c}	7.502 ^{b}	9.200 ^{c}	8.976 ^{b}	3.150 ^{b}	2.963 ^{c}	3.061 ^{b}
	p-value	0.0527 ^{ns}	0.00001 **	0.0001 **	0.00001 **	0.00001 **	0.0001 **	0.00001 **	0.00001 **	0.0001 **
	LSD0.05	–	0.014	0.0095	0.451	0.151	0.273	0.169	0.093	0.132
Irrigation (I)	**FI**	0.375 ^{a}	0.3222 ^{a}	0.2284 ^{a}	10.562 ^{a}	10.685 ^{a}	10.333 ^{a}	4.044 ^{a}	3.826 ^{a}	3.603 ^{a}
	PRD70	0.333 ^{b}	0.2557 ^{b}	0.2051 ^{a}	9.0196 ^{b}	9.972 ^{b}	9.594 ^{b}	3.792 ^{a}	3.272 ^{b}	3.414 ^{b}
	PRD50	0.310 ^{c}	0.2283 ^{c}	0.1431 ^{b}	7.875 ^{c}	8.965 ^{c}	9.394 ^{b}	3.265 ^{b}	3.036 ^{c}	3.069 ^{c}
	p-value	0.0001 **	0.00001 **	0.00001 **	0.00001 **	0.00001 **	0.0005 **	0.00001 **	0.00001 **	0.00001 **
	LSD0.05	0.0149	0.016	0.028	0.416	0.313	0.44	0.261	0.092	0.142
S × M	*p*-value	0.9732 ^{ns}	0.68 ^{ns}	0.013 *	0.99 ^{ns}	0.971 ^{ns}	0.936 ^{ns}	0.664 ^{ns}	0.404 ^{ns}	0.0251 *
S × I	*p*-value	0.9948 ^{ns}	0.99 ^{ns}	0.85 ^{ns}	0.99 ^{ns}	0.989 ^{ns}	0.909 ^{ns}	0.924 ^{ns}	0.438 ^{ns}	0.0066 **
M × I	*p*-value	0.4528 ^{ns}	0.15 ^{ns}	0.23 ^{ns}	0.0002 **	0.011 *	0.171 ^{ns}	0.851 ^{ns}	0.0005 **	0.00001 **
S × M × I	*p*-value	0.9980 ^{ns}	0.99 ^{ns}	0.91 ^{ns}	1 ^{ns}	0.999 ^{ns}	0.999 ^{ns}	0.994 ^{ns}	0.788 ^{ns}	0.00001 **

WS: winter season; SS: spring season; WM: transparent mulch; BM: black mulch; NM: no mulch FI: full irrigation; PRD70 and PRD50: deficit partial rootzone drying under 70 and 50 of evapotranspiration, respectively; S, M and I: season, mulch and irrigation treatments, respectively; S × M × I: interaction between season, mulch and irrigation treatments; ^{ns}: not statistically significant; **: significant at the 1% level ($p < 0.01$); *: significant at the 5% level ($p < 0.05$); different letters indicate significant difference between treatments; bold letters and words indicate treatments names.

Our results indicated that P_n decreased with a decrease in g_s at the same stage of plant growth, but in different growth stages, a decrease in g_s did not cause a decrease in P_n. For instance, at the mid stage (63 DAS), the P_n values increased despite g_s reduction in both the mulch and irrigation treatments for the two growing seasons (Table 2). This could be explained by the squash leaves having reached their maximum area at this stage, when plants reach their peak values of most photosynthetic parameters [55]. The leaf g_s, P_n, and T_r in the PRD treatments were significantly lower than that of FI at all measured days. In the PRD treatment, two sides of the root were alternately irrigated. The side of the root that undergoes a water deficit for a period induces ABA, which reduces g_s, affecting both transpiration and photosynthesis efficiencies. However, the watered side of the root keeps the plant in a preferable situation [13]. In the current study, due to water stress under PRD treatment, plants induced ABA from the root to the leaves, resulting in the accumulation of ABA in the leaves causing stomatal closure [50,52]. Several studies showed that plants under PRD could enhance leaf T_r [56] and improve the P_n rate [57] compared to FI. These results are in agreement with other studies [5,58], which indicated that g_s decreases with increasing water stress levels.

The g_s, P_n, and T_r were significantly affected by mulching treatments. However, at 35 DAS, g_s showed no significant difference ($p > 0.05$) between mulch and non-mulched treatments. At 63 DAS, compared with NM, WM and BM increased g_s by 20% and 10%, respectively, indicating that plants under mulched treatments were healthier at the mid growth stage. At 83 DAS, the NM treatment reduced the P_n value by 11% and 12.5% compared with the BM and WM treatments, respectively (Table 2). At 35 DAS, the non-mulched treatments reduced the T_r by 19% and 22% compared with the BM and WM treatments, respectively. Our results agree with the findings described by Ibarra-Jiménez et al. [59] and Lira-Saldivar et al. [36], who found that plastic mulch significantly increased photosynthetic activity in zucchini plants compared with non-mulched treatments. This finding is due to the advantage of plastic mulch, which can control soil temperature, enhance soil moisture, and elevate crop photosynthesis [60]. Yang et al. [61] and Zhang et al. [62] emphasized that soil hydrothermal state is an essential element in photosynthesis. The proper soil moisture and temperature situation under mulched treatments boost the movement of water from the deep soil to the surface soil by capillary and steam action, increasing the intercellular CO_2 concentration in the ear-leaf [62]. These activities help increase carbon sources for leaf photosynthesis, thereby decreasing the limitations of stomatal factors [63] and leading to consistently higher P_n in mulched than non-mulched treatments.

Data in Table 2 indicate that g_s, $P_{n,}$ and T_r were significantly affected by growing season for all measured days. The highest g_s was 0.3881 and 0.2912 mmol m^{-2} s^{-1} in the SS, and WS at 35 DAS, respectively. The Tr in SS and WS followed the same trend as g_s; the highest T_r was observed at 35 DAS. At 63 DAS, the P_n value in the SS increased by 10%, compared with in the WS. Urban et al. [64] revealed that high temperatures affect all physiological processes in plants. Furthermore, Jones et al. [65] and Scherrer et al. [66] asserted that environmental factors, such as radiation, air temperature, and wind, affect the size of the stomata aperture. In this study, the physiological trend (g_s, P_n, and T_r) could be explained by the environmental differences between the two growing seasons, where the SS had higher air temperature, radiation, and wind speed than the WS (Figure 1).

The effects of the growing season, mulch treatment, and irrigation quantities on g_s, P_n, and T_r were significant at all squash stages (Table 2). This finding indicates that sowing squash during a suitable growing season and choosing a suitable combination of irrigation volume and plastic mulch could enhance squash physiological response, which would ultimately increase the yield and IWUE.

The g_s was not significantly affected by interactions between growing season, mulch, and irrigation quantities, as shown in Table 2. However, at 83 DAS, the interaction between season and mulch showed a significance difference ($p < 0.05$). No interaction effect on P_n was observed, except for interaction between irrigation and mulch, which significantly affected ($p < 0.05$) P_n values at 35 DAS and 63 DAS. In 35 DAS, comparing with same irrigation strategies FI, BM increased P_n 3% and 20%, respectively compared with WM and NM. In PRD70, P_n values under BM and WM were not different, while BM and WM enhanced P_n values 37%, and 36%, respectively, compared with NM. in PRD50, BM increased P_n 21%, 39%, compared with WM and NM, respectively. Data in Table 2 indicate that there was no significant interaction between growing season, mulch, and irrigation on Tr, except after 83 DAS. This indicates that squash plants were not able to withstand environmental changes at a late stage of growth, and there was a water deficit due to the age of the plants. Tr values were reduced under PRD strategies compared with FI for both mulched and non-mulched treatments. At 63 DAS, WM increased Tr 6% and 14% compared with BM, and NM, respectively under FI strategy. Using PRD70 and PRD50 Tr values under WM was higher 18% and 38% compared with BM, and NM, respectively. At 83DAS, under FI, Tr under BM was higher 10%, and 17%, respectively, compared with WM and NM. In PRD 70, WM increased Tr 22%, and 40%, respectively, compared with BM and NM. in PRD50, Tr was reduced dramatically due to water stress. However, WM increased Tr by 9% while BM increased by 7%, compared NM.

3.4. Chlorophyll Index (SPAD Value)

The chlorophyll index (SPAD value) was statistically analyzed, as shown in Table 3. High chlorophyll content is a desired attribute, as it implies a low degree of photoinhibition of the photosynthetic apparatus [67]. Li et al. [42] suggested that SPAD values could perfectly trace the variations in chlorophyll content of plants. At 35 and 83 DAS, squash plants sown in the SS showed high chlorophyll content (SPAD value) compared with those sown in the WS. This could be due to the higher photosynthesis rate (P_n), observed in squash plants sown in the SS, compared with those sown in the WS (Table 2). Li et al. [68] and Peiguo and Mingqi [69] emphasized that the relative chlorophyll and photosynthetic rate interact positively with each other, as chlorophyll represents the primary chloroplast component of photosynthesis.

Table 3. Analysis of variance of the chlorophyll index (SPAD value) at the development stage (35 DAS), mid stage (63 DAS), and late stage (83 DAS) of squash growth during winter (WS) and spring (SS) growing seasons.

Treatments		Chlorophyll Index (SPAD Value)		
		35 DAS	63 DAS	83 DAS
Season (S)	**WS**	43.88 ^{b}	42.99 ^{b}	41.66 ^{b}
	SS	48.31 ^{a}	43.88 ^{a}	45.85 ^{a}
	p-value	0.0083 **	0.196 ^{ns}	0.010 *
	LSD 0.05	1.746	–	1.81
Mulch (M)	**WM**	48.09 ^{a}	45.61 ^{a}	46.28 ^{a}
	BM	46.75 ^{b}	46.21 ^{a}	45.00 ^{b}
	NM	43.46 ^{c}	38.42 ^{b}	39.98 ^{c}
	p-value	0.00001 **	0.00001 **	0.0001 **
	LSD 0.05	1.12	1.27	0.99
Irrigation (I)	**FI**	48.35 ^{a}	45.81 ^{a}	46.07 ^{a}
	PRD70	45.73 ^{b}	43.05 ^{b}	43.53 ^{b}
	PRD50	44.22 ^{b}	41.38 ^{c}	41.66 ^{c}
	p-value	0.00001 **	0.00001 **	0.0005 **
	LSD 0.05	1.66	1.09	1.41
S × M	*p*-value	0.0016 **	0.035 *	0.023 *
S × I	*p*-value	0.806 ^{ns}	0.101 ^{ns}	0.440 ^{ns}
M × I	*p*-value	0.831 ^{ns}	0.0265 *	0.265 ^{ns}
S × M × I	*p*-value	0.718 ^{ns}	0.122 ^{ns}	0.063 ^{ns}

^{ns}: not statistically significant, **: significant at the 1% level ($p < 0.01$), *: significant at the 5% level ($p < 0.05$); different letters indicate significant difference between treatments; bold letters and words indicate treatments names.

Mulched treatments significantly affected ($p < 0.001$) chlorophyll index values (Table 3). Our study showed that the SPAD value of mulch treatments was significantly higher than non-mulched treatments. The primary reason for the high SPAD value with mulch treatment could be that the film mulch changed the soil water content (Figure 5) and the heat environment in the root area of the squash, causing a change in the physical and chemical properties of the soil, which accelerated root system growth. Kante et al. [70] showed that a reduction in the chlorophyll content of plant leaves was directly associated with root growth. This result follows the same trend as the findings of Hugar et al. [71], Nasrullah et al. [72], and Iqbal et al. [73], who found that soil mulch enhances chlorophyll content compared with non-mulched treatments.

Drought stress reduced the chlorophyll index at all growth stages. PRD70 and PRD50 reduced the chlorophyll content. Under conditions of water stress, chlorophyll content declines as a result of damage to chloroplast membranes and structure and photo-oxidation of chlorophyll [74–76]. The reduction of leaf chlorophyll values due to a water deficit has been reported for squash [23], cabbage [58], cotton [73], and wheat [67] crops.

Chlorophyll index values were not significantly affected by the interactions between S×M×I. However, the interaction between S × M was significant ($p < 0.05$) at all measured days. At 63 DAS, the interaction effect between mulch and irrigation treatments on SPAD value was significance. In FI treatments, BM increased SPAD value 6% and 23% compared with NM. In PRD70, the SPAD values under BM and WM were not different. BM and WM both increased SPAD values 17% compared with NM. Under PRD50, WM increased SPAD values 3% and 24 %, respectively compared with BM and NM. Overall, FI and BM improved Pn, Tr and SPAD value.

3.5. Fruit Quality

Table 4 shows the statistical analysis of squash fruit quality, total soluble solids (TSS), total acidity (TA), and vitamin C (V_C) under mulch and irrigation treatments for the WS and SS. The fruit qualities of the FI treatment were significantly different ($p < 0.001$) to those of the PRD treatments. Squash plants under the PRD50 treatments reduced TSS, TA, and V_C by 17%, 25%, and 19%, respectively, compared with the FI treatment. The severe water stress treatment (PRD50) negatively affected the squash fruit quality. This finding could be explained by the water deficit causing a reduction in fruit water potential [25]. These results are in agreement with the findings of Al-Ghobari and Dewidar [24], Abd El-Mageed et al. [34], Kuslu et al. [77] and Zhang et al. [25], who found that water-stressed treatments reduced fruit qualities compared with non-stressed water. Fruit quality under PRD can be affected by many factors, including plant type, developmental stage, soil type, and environmental conditions [62].

Table 4. Analysis of variance of squash fruit quality, total soluble solids (TSS), total acidity (TA), and vitamin C (V_C) for winter and spring growing seasons.

Treatments		**TSS (%)**	**TA (% Citric Acid)**	**V_C (mg/100 g FW)**
Season (S)	WS	4.98 ^{b}	0.311	0.727
	SS	5.52 ^{a}	0.334	0.746
	p-value	0.036 *	0.1785 ^{ns}	0.602 ^{ns}
	LSD 0.05	0.149	–	–
Mulch (M)	WM	5.47 ^{b}	0.340 ^{b}	0.760 ^{b}
	BM	5.63 ^{a}	0.342 ^{a}	0.775 ^{a}
	NM	4.71 ^{c}	0.287 ^{c}	0.675 ^{c}
	p-value	0.00001 **	0.0002 **	0.0018 **
	LSD 0.05	0.052	0.018	0.045
Irrigation (I)	FI	5.85 ^{a}	0.373 ^{a}	0.813 ^{a}
	PRD70	5.63 ^{b}	0.313 ^{b}	0.733 ^{b}
	PRD50	4.86 ^{c}	0.281 ^{c}	0.663 ^{c}
	p-value	0.0001 **	0.00001 **	0.00001 **
	LSD 0.05	0.048	0.017	0.043
S × M	*p*-value	0.0003 **	0.0457 *	0.036 *
S × I	*p*-value	0.00001 **	0.0047 **	0.182 ^{ns}
M × I	*p*-value	0.357 ^{ns}	0.958 ^{ns}	0.908 ^{ns}
S × M × I	*p*-value	0.635 ^{ns}	0.917 ^{ns}	0.906 ^{ns}

^{ns}: not statistically significant, **: significant at the 1% level ($p < 0.01$), *: significant at the 5% level ($p < 0.05$); different letters indicate significant difference between treatments; bold letters and words indicate treatments names.

Mulching significantly affected ($p < 0.0001$) all fruit quality attributes. Mulch treatments increased the TSS, TA, and V_C by 16%, 16%, and 13%, respectively, compared with non-mulched treatments. This result is consistent with those of Lira-Saldivar et al. [36] and Li et al. [78], who found that soil mulching enhances fruit quality, compared with non-mulching. Abd El-Mageed et al. [34] indicated that mulch could reduce the influence of water stress on squash fruit quality, as mulch reduces soil evaporation, while preserving soil moisture content near the root zone.

Growing seasons did not significantly ($p > 0.05$) affect fruit quality, except for TSS. The interaction effect between S×I on TSS and TA was significant ($p < 0.001$). However, there was no significant ($p > 0.05$) difference in the value of V_C. Squash fruit qualities were not significantly affected by the interactions of S × M × I. In contrast, the effect of the interaction of S × M showed a significant difference ($p < 0.05$) between all fruit qualities.

3.6. Yield and Irrigation Water Use Efficiency (IWUE)

Statistical analysis of squash yield and IWUE are shown in Table 5. Squash yield was significantly ($p < 0.05$) affected by growing season. The squash yield obtained in the SS was higher (19%) than that in the WS. The reduction of squash yield in the WS could be due to extreme lower temperatures and solar radiations during the WS than SS (Figure 1). Similar results were obtained for cucumber by Wan et al. [79] and for squash by Amer [37], who reported that the different yields, obtained in different growing seasons, were due to non-favorable weather conditions. Similarly, the higher yield recorded during the SS was due to an increase in physiological properties (g_s, P_n, and T_r) and the chlorophyll index, compared with WS (Tables 2 and 3).

Table 5. Analysis of variance of squash fresh fruit yield and irrigation water use efficiency (IWUE) for winter (WS) and spring (SS) growing seasons.

Treatments		Fresh Fruit Yield (Mg ha^{-1})	IWUE (kg m^{-3})
Season (S)	**WS**	72.12 ^{b}	26.71 ^{a}
	SS	85.88 ^{a}	12.92 ^{b}
	p-value	0.0118 *	0.0005 **
	LSD 0.05	6.49	1.35
Mulch (M)	**WM**	87.46 ^{a}	22.51 ^{a}
	BM	85.30 ^{a}	21.74 ^{b}
	NM	64.23 ^{c}	15.20 ^{c}
	p-value	0.00001 **	0.0001 **
	LSD 0.05	3.41	0.45
Irrigation (I)	**FI**	80.62 ^{a}	15.07 ^{c}
	PRD70	82.53 ^{a}	20.48 ^{b}
	PRD50	73.85 ^{c}	23.90 ^{a}
	p-value	0.0001 **	0.0001 **
	LSD 0.05	2.51	0.52
S × M	*p*-value	0.0001 **	0.0001 **
S × I	*p*-value	0.0003 **	0.0001 **
M × I	*p*-value	0.474 ^{ns}	0.0001 **
S × M × I	*p*-value	0.773 ^{ns}	0.0001 **

^{ns}: not statistically significant, **: significant at the 1% level ($p < 0.01$), *: significant at the 5% level ($p < 0.05$); different letters indicate significant difference between treatments; Bold letters and words indicate treatments names.

The mulching treatments showed a significant difference ($p < 0.0001$) in squash yield compared with the non-mulched treatments (Table 5). Mulched treatments increased squash yield by 36% compared with non-mulched treatments. However, no statistical difference was observed between mulched treatments (BM and WM). The yield increase observed in the plastic mulch treatment could be attributed to its ability to reduce evaporation, fertilizer leaching, weed accumulation, and soil compaction and increase soil temperature, which enhances root growth [30,31]. These properties led to higher soil moisture and nutrient holding in the root zone, which eventually enhanced squash yield, compared with NM. Many studies have reported that mulch enhances crop yield in squash [34], cucumber [59], chili [80] and broccoli [35].

Squash yield was significantly ($p < 0.001$) affected by irrigation treatments. The highest squash yield was obtained under the PRD70 treatment (82.53 Mg ha^{-1}). Although this yield was not significantly different from that of the FI treatment (80.62 Mg ha^{-1}). This suggests that reducing the irrigation volume perfectly could improve fruit yield. The higher squash yield in the PRD70 treatment than the FI treatment could be partially explained by the PRD having parallel drip lines that irrigate the root zone of the plant interchangeably. This could reduce water losses due to deep percolation in sandy soil, resulting in nutrient availability near the root zone in plants under PRD treatments. Another possible reason for the PRD70 plot having a higher yield than the FI plot is that plastic mulch could prevent soil evaporation to some degree. Therefore, plots under the FI treatment might be over irrigated, and irrigation of 70% of crop water requirement supplies sufficient water for crop growth without stress [81]. Hakim et al. [17] indicate that plants receiving FI could encounter higher soil moisture in the root zone, which reduces root activity, delaying maturity, and lowering yield compared with plants under PRD treatments. This result is consistent with the findings of Qin et al. [20] and Hooshmand et al. [19], who found that the yield of the FI treatment was lower than the deficit treatments, but not significantly different. Howerver, the squash yield obtained in this study was more than three times higher than the squash yield obtained by Al-Omran et al. [82] under the same environmental conditions. This finding could be attributed to the higher plant density and good fertilization program used in this experiment, resulting in a higher squash yield compared with the mentioned study.

The interaction effects between S × M × I were not statistically significant ($p > 0.05$) for squash yield, while there were strong significant ($p < 0.001$) interactions between S × M and S × I (Table 5). It is worth mension that sowing squash in the SS under non-mulched treatment was almost doubled the squash yield compared to sowing in the WS. The variation of squash yield under mulched treatments in the SS and WS was not considerable. This shows that WM and BM were effective during both growing seasons (Figure 6). The highest squash yield was recorded under SS-BM-PRD70 treatment (95.84 Mg ha^{-1}), while the lowest yield (46.06 Mg ha^{-1}) was obtained under WS-NM-PRD50. In the WS, the highest squash yield obtained was 87.9 Mg ha^{-1} in WM PRD70, while in the SS, the lowest squash yield obtained was 75.33 Mg ha^{-1} in NM PRD50. The Squash yield obtained under SS-NM-FI and WS-NM-FI were 77.4, and 53.1 Mg ha^{-1}, respectively, while in SS-WM-PRD50 and WS-WM-PRD50 were 85.29, and 79.34 Mg ha^{-1}, respectively (Figure 6). This shows that using the PRD strategy and soil mulching technique reduces 50% of applied water, while increasing squash yield in both growing seasons. These results suggest that in arid and semi-arid regions where there are water scarcity problems, soil mulch with PRD50 could be used as a water-saving strategy to maintain the squash yield.

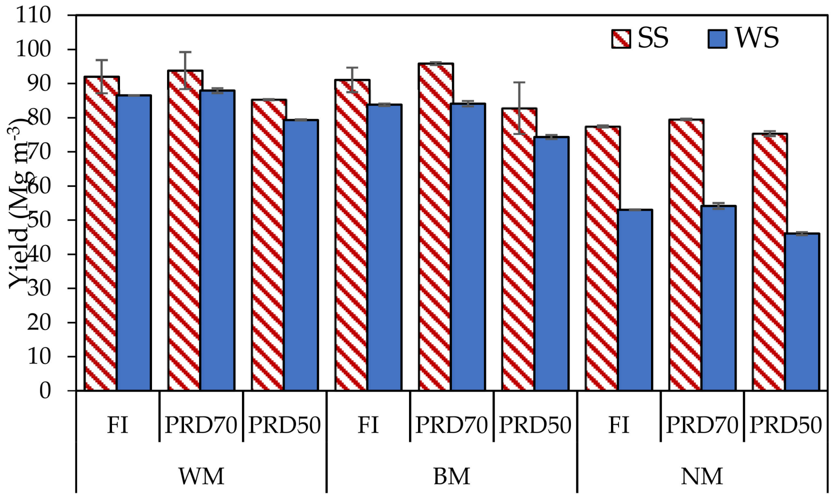


Figure 6. Squash yield under irrigation and mulch treatments during the winter and spring seasons.

Data presented in Table 5 and Figure 7 show that the effect of S, M, and I on IWUE was significant ($p < 0.001$). The IWUE in the WS was two times higher than in the SS. This result could be due to the water applied to squash in the SS, which was higher than that applied in the WS. This finding is in line with those recorded by Rouphael and Colla [83], Abd El-Mageed and Semida [9], Abd El-Mageed et al. [34] and Silva et al. [38], who worked on squash and observed that the IWUE was affected by environmental factors under different growing seasons.

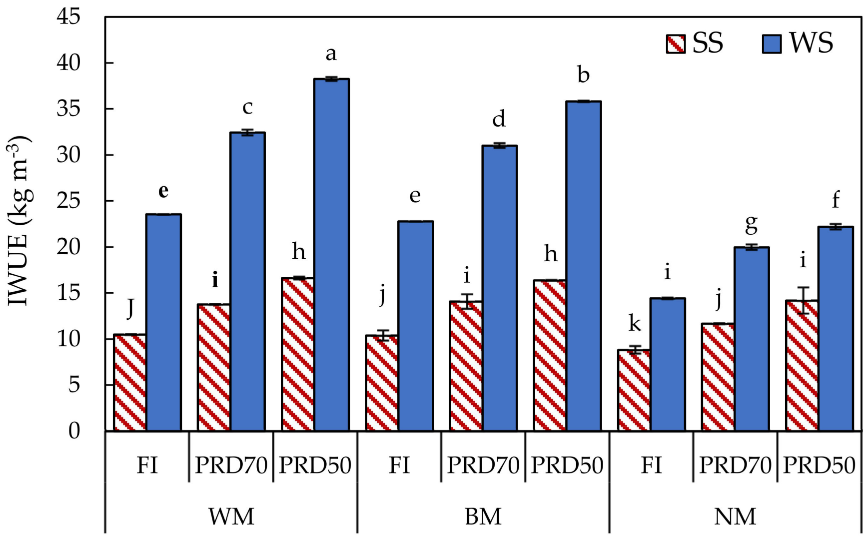


Figure 7. Squash irrigation water use efficiency (IWUE) during winter (WS) and spring (SS) under mulch treatments (black mulch-BM, transparent mulch-WM and non-mulch- NM) and irrigation treatments (full irrigation-FI, partial root drying with 50% of evapotranspiration- PRD50, partial root drying with 70% of evapotranspiration-PRD70); the data is the mean value ± standard error; different letters indicate significant difference between treatments.

In terms of the mulching treatments, WM increased the IWUE by 48% compared with the NM treatments (Table 5). Soil mulching decreased evaporation and increased the soil moisture content near the root zone, which positively affected the squash yield, and finally, it contributed to higher IWUE. This result is consistent with the findings of Zhang et al. [81], Chen et al. [84], and Yang et al. [61], who found that mulching treatments had higher IWUE than the control treatment (NM).

In terms of irrigation quantities, the highest IWUE was observed under PRD50 treatments (23.90 kg m^{-3}). The corresponding value for the FI treatments was 15.07 kg m^{-3} (Table 5). PRD50 and PR70 increased the IWUE by 59%, and 36%, respectively, compared with the FI treatment. These results are in agreement with Amer [37], Abd El-Mageed et al. [34], and Zhang et al. [81], who found that water-stressed treatments increase the IWUE, compared with FI.

Data presented in Table 5 show that the interaction effects of the S×M, S×I, M×I, and S×M×I on IWUE were significant ($p < 0.001$). The highest IWUE (38.24 kg m^{-3}) was recorded under WS-WM-PRD50, while the lowest value was 8.82 kg m^{-3} under SS-NM-FI (Figure 7). The IWUE in the WS were doubled compared with SS for mulch treatments under same irrigation treatments. It can be seen from Figure 7 that PRD50 obtained higher IWUE in mulch and non-mulched treatments, compared with PRD70 and FI. Overall, Sowing squash in WS, FI-NM obtained squash yield of 53.1 Mg ha^{-1} with IWUE 14.42 kg m^{-3}, while PRD50-WM obtained 79.34 Mg ha^{-1} with IWUE 38.24 kg m^{-3}. This result led to conculde that sowing squash in WS using PRD50-WM saves 50% of applied water while increases squash yield by 49%, compared with FI-NM.

4. Conclusions

The effect of growing season DI integrated with PRD, and soil mulching on the yield and IWUE of squash plants, was studied. The results indicated that plant density postively affected squash yield in both growing seasons for all treatments. The spring growing season positively affected squash yield. In contrast, the SS negatively affected the IWUE, compared with the WS. Moreover, soil mulching enhanced the physiological properties of the squash plants (g_s, P_n, and T_r), fruit quality (TSS, TA, and Vc), increasing the squash yield, and IWUE, compared with non-mulched treatments. g_s, P_n and T_r were significantly affected by growing season for all measured days. Furthermore, PRD70 and PRD50 reduced the chlorophyll index at all growth stages. Mulch treatments increased the TSS, TA, and V_C, compared with non-mulched treatments. However, growing seasons did not significantly affect fruit quality. In addition, PRD strategy improved both squash yield and IWUE in both growing seasons. This emphasizes that sowing squash plants in the winter season, using PRD50 and plastic mulch as water-saving strategies, could increase the yield and IWUE in arid and semi-arid regions.

Author Contributions: Conceptualization, H.M.A.-G., T.K.Z.E.-A. and A.A.E.-S.; methodology, A.A.E.-S., A.H.F. and M.S.A.; software, A.A.E.-S., A.H.F. and M.S.A.; validation, H.M.A.-G., T.K.Z.E.-A. and A.A.E.-S.; formal analysis, A.H.F. and M.S.A.; investigation, A.H.F. and M.S.A.; resources, H.M.A.-G. and T.K.Z.E.-A.; data curation, A.A.E.-S., A.H.F. and M.S.A.; writing—original draft preparation, A.A.E.-S. and A.H.F.; writing—review and editing, H.M.A.-G., T.K.Z.E.-A., A.A.E.-S. and A.H.F.; visualization, T.K.Z.E.-A. and A.A.E.-S.; supervision, H.M.A.-G. and T.K.Z.E.-A.; project administration, H.M.A.-G. and T.K.Z.E.-A.; funding acquisition, H.M.A.-G., T.K.Z.E.-A. and M.S.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research at King Saud University, through research group No. RG-1441-321.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group No. RG-1441-321.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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