Asian Journal of Plant Sciences

ISSN 1682-3974

OPEN ACCESS Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2023.82.96

Research Article
Performance of Partial Root-Zone Drying Technique on Yield, Water Productivity and Quality of Cucumber

[1]R.E. Abdelraouf, [2]A.E. Hamza, [3]M.A.A. Abdou and [4]Dalia M. Elsoofy

[1,3]Department of Water Relations and Field Irrigation, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St., Dokki, Giza 12622, Egypt
[2]Department of Vegetable Research, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St., Dokki, Giza 12622, Egypt
[4]Department of Soils and Water, Faculty of Agriculture, El Fayoum University, Faiyum, Egypt

Abstract
Background and Objective: Saving irrigation water and improving the productivity and quality of cultivated crops is the main goal for all dry areas that suffer from limited irrigation water. Therefore the main goal was to maximize water productivity of cucumber "$WP_{cucumber}$", using the automatic partial roots-zone drying "PRD" technique. **Materials and Methods:** Two field experiments were conducted to study the effect of automatic irrigation "AC" and the performance of PRD on $WP_{cucumber}$ and quality. Experimental designs were arranged in a split-plot design. Irrigation method (Manual control "MC" and "AC") were used in main plots and PRD technique (100% FI, 75% FI and PRD) and were used in sub-main plots. **Results:** The study recommends the application of AC in irrigation and the application of PRD technique compared to MC and irrigation at 100% FI. Perhaps the recommendation is due to the many benefits of AC and PRD techniques. Indeed, despite the negative impact of the PRD technique on increasing moisture stress, the many advantages created by this technique overcame and outweighed this only drawback as it led to an increase in the size of the root spreading area and an increased application efficiency by increasing the size of the roots, which led to an increase in the area of absorption of water and nutrients, which ultimately reflected on the increase of $WP_{cucumber}$ and quality characteristics. **Conclusion:** It is necessary to apply the PRD technique with its AC management when the goal is to save water, increase $WP_{cucumber}$ and improve the quality under the conditions of arid areas.

Key words: Automatic irrigation, cucumber, greenhouses, partial roots drying, water productivity, prd technique, manual control of irrigation

Citation: Abdelraouf, R.E., A.E. Hamza, M.A.A. Abdou and D.M. Elsoofy, 2023. Performance of partial root-zone drying technique on yield, water productivity and quality of cucumber. Asian J. Plant Sci., 22: 82-96.

Corresponding Author: Abdelraouf Ramadan Eid Abdelghany, Department of Water Relations and Field Irrigation, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St., Dokki, Giza 12622, Egypt

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water resources are one of the most important constraining factors for agricultural production. Therefore, irrigation techniques play an important and major role in supporting and improving the agricultural economy, which has led to the scarcity of freshwater becoming a real and major problem that the global economy will face shortly. Therefore, in all uses and activities of life, the use and consumption of water must be improved as well as the treatment of freshwater as an important and scarce commodity[1,2].

Many different methods must be followed and adopted to maximize and raise the efficiency and rationalization of water use. Some of these methods relate to the soil, others relate to the cultivated plant, while water belongs to other methods, which are supplied and provided for plant irrigation[3,4]. Deficient irrigation (DI) and partial root drying (PRD) are very good strategies and methods for saving and rationalizing irrigation water[5,6] which includes alternating watering and watering for each side of the roots of the plant. This PRD technology strategy results in moderate moisture stress in the plant, which results in partial closure of the stomata of the non-irrigated site and thus reduces losses through transpiration openings without significant and significant impact on photosynthesis and thus crop productivity. It is also considered a promising strategy when used to irrigate many crops[7,8]. It has been suggested that PRD can stimulate and stimulate root growth, while with DI application some plant roots may die if these dry conditions persist. The investigation also determined that RDI and PRD strategies are effective as well as promising irrigation strategies by applying them to the cultivation of maize plants in the dry conditions of sandy soil in Egypt. The concept of the theoretical background of the PRD technique is to irrigate a part of the plant root system, which maintains the upper part of the plants in suitable and favourable water conditions, while on the contrary, drying the other part of the roots leads to the formation and creation of chemical signals to the roots (mainly and mainly hormones). These chemical signals produced and generated from the roots of the cultivated plants are transmitted to the upper part of these plants to stimulate, activate and activate the reduction of stomata openings and the growth of shoots[9]. Partial drying technology prevents significant water loss by transpiration and also reduces the uptake of carbon dioxide that would occur under normal dry conditions[10]. Several results and data from previous studies demonstrated and confirmed that under-irrigation techniques, especially PRD technology, may increase WP in addition to maintaining as well as improving crop yields of irrigated plants. A wide range of positive PRD-specific responses of plants could explain these effects. The application of the root drying technique led to changes in the morphological characteristics of plant stomata and the lack of conductivity, which affected the transpiration process and contributed to the increase in water productivity and also led to an improvement in plants' photosynthetic capacity and thus had a positive and effective effect on net photosynthesis[11,12]. It also allowed and provided the appropriate reduction of vegetative activity and helped in increasing the canopy area of the grains/fruits, making them more exposed to solar radiation (more light penetrating the green canopy) which may lead to an improvement and increase in yield and quality[13-17]. In addition to what has been mentioned, it leads to improving root growth and development as well as increasing and improving the effective biomass of plant roots with PRD technology, which in turn increases and improves the water and hydraulic conductivity of cultivated plants and increases water absorption[18]. Several studies and research results have also shown and confirmed that PRD technology increases the activity of microorganisms inside the soil as well as its high ability to absorb nutrients[19]. Recently showed an increase in phosphorous and nitrogen uptake of various PRD-treated crops with the so-called and named 'birch effect'. This impact is named in the honor of Birch, who discovered that re-wetting previously dry soil leads to increased nitrogen mineralization. According to Dodd *et al.*[9], the "birch effect" is caused by the changes in the physical processes (disruption of soil aggregation and consequent P-shaped release). Although, it also influences some biological processes (stimulating soil microbial biomass and other activities in the mineralization of soil organic compounds), many research efforts must be made with different soil types to determine when the rate of nutrient uptake increases with the application of PRD technique[20].

The use of automatic irrigation with accurate irrigation scheduling also provides irrigation water as it provides the different and cultivated crops with their exact water needs at the required and appropriate time to improve water productivity[21,22]. This automatic irrigation scheduling also led to the adjustment of the estimated amount of water required for the needs of the plants, along the different stages of growth as it provides irrigation water and gives all the plants the basic and exact needs of water as well as the necessary and nutritious materials for growth, which ultimately reflects on the optimal production of the cultivated crops[23].

Therefore the main goals of this study were to maximize water application efficiency and improve crop and water productivity of cucumber crops, using an automatic partial roots-zone drying technique under greenhouses conditions.

MATERIALS AND METHODS

Location and the climate of the experimental site: The location of the research experiments that took place during the 2020 and 2021 seasons at the National Research Centre (NRC) research station and regeneration site was (latitude 30°30'1.4"N, longitude 30°19'10.9"E), 21 m+MSL (mean sea level) under the conditions of the Nubariya Area in the Buhaira Governorate in Egypt. This area is characterized by a dry climate in summer with cold winters. The average data for temperature, wind speed and relative humidity were obtained through meteorological data for the Nubaria area through the Central Laboratory for Agricultural Climate (CLAC) of the Centre Agricultural Research located at the nearest meteorological station to the area of the experiment in Nubaria.

Soil characteristics and irrigation water quality: Irrigation was carried out from an open irrigation canal of freshwater passing through the experimental area, with an average pH of 7.37 and 0.44 dS m^{-1} as electrical conductivity (EC). While, the main properties of sandy soils are estimated in Table 1.

Experimental design: The experimental design and treatments were arranged in a split-plot design with three replications for cultivating cucumber cultivar (Barracuda) during the winter buttonhole. Irrigation control systems manual control (MC) and automatic control (AC) were put in main plots and partial roots drying (PRD) (100% FI (control), 75% FI and PRD (50% FI)) and were used in sub-main plots as shown in Fig. 1.

Estimation of the irrigation water requirements for cucumber: The seasonal irrigation water requirements were estimated according to ETo- the Penman-Monteith equation (FAO-56). The irrigation water requirement for the

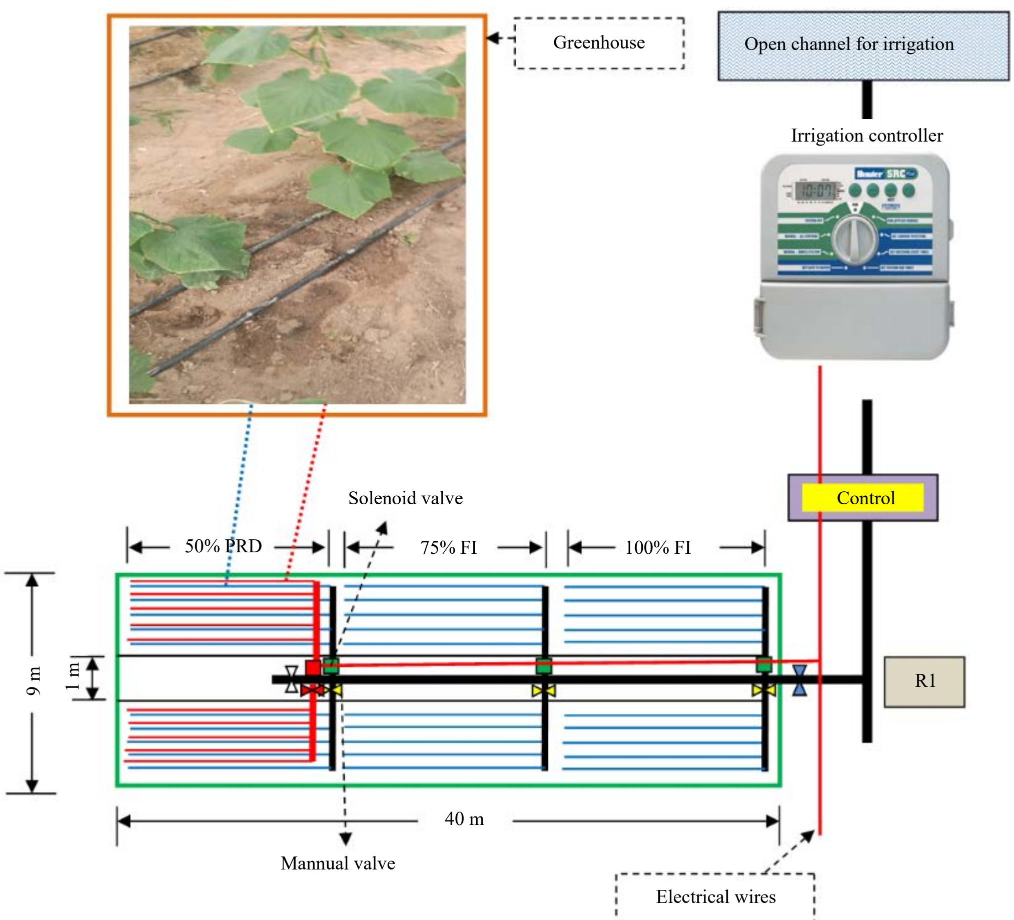


Fig. 1: Layout of the experimental design

PRD: Partial root-zone drying, FI: Full irrigation and R1,2,3: Replications of experimental units cucumber plants was 5950 $m^3\ ha^{-1}$ for season 2020 but it was 5900 $m^3\ ha^{-1}$ for season 2021. Irrigation water requirement for the cucumber plants was calculated by the following Eq. 1 for drip irrigation system:

$$IR_{cucumber} = \frac{ET_O \times Kc \times Kr}{IE} - R + LR \quad (1)$$

Where:

$IR_{cucumber}$	=	Irrigation requirements cucumber (mm/day)
ET_O	=	Reference evapotranspiration by Penman-Monteith equation (FAO-56) (mm/day)
Kc	=	Cucumber crop factor[24]
Kr	=	Reduction factor
IE	=	Irrigation efficiency for drip irrigation system (%)
R	=	Rainfall (mm)
LR	=	Leaching requirement of soil salts (mm)

Irrigation requirements for cucumber were converted from mm/ha/day to m^3/ha/day[25].

Cucumber fertilization: The fertilization requirements for greenhouses cucumber were presented in the following Table 2 for each season in 2020 and 2021.

Soil moisture distribution (SMD) and water stress in the roots zone ($WS_{roots\text{-}zone}$): The distribution of soil moisture was estimated and determined with all the parameters under study for three soil depths which are 0-15, 15-30 and 30-45 cm. The ground moisture percentage at (4%) represented the wilting point and the treatments close to it represented the most moisture stress before irrigation, while, the treatments close to the field capacity (15%) suffered from less water stress.

Soil moisture was measured in the effective root zone of all treatments before irrigation and the field capacity and wilting point were determined as specific lines for the extent of exposure to water or moisture stress to the roots of cultivated plants[26]. Measurements were taken at soil depths at the mid-growth stage. Soil moisture was measured by a profile probe device.

Roots volume of the plant: To determine and measure the size of the roots of cucumber plants, the radius of the horizontal roots was measured and the effective vertical length of the root spreading area was measured, which enabled us to estimate the effective root volume within the soil sector through the following equations 2, 3, 4 and 5 as shown as in Table 3 roots growth at med-stage from plant age.

Application efficiency of irrigation water (AE_{IW}): The application efficiency of irrigation water "AE_{IW}" is the actual storage of water in the root zone to the water applied to the field. AE_{IW} was calculated using Eq. 6 and as shown in Fig. 2a-b:

Table 1: Characteristics of the soil in the experimental area

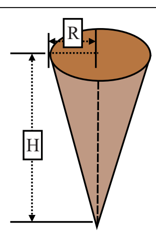
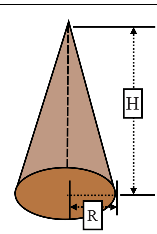
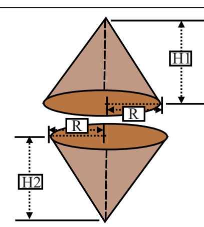
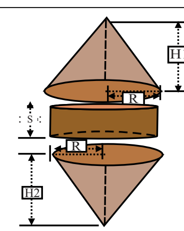
Physical properties			
Soil layer depth (cm)	0-15	15-30	30-45
Texture	Sandy	Sandy	Sandy
Course sand (%)	49.43	54.71	42.54
Fine sand (%)	46.76	41.58	53.56
Silt+clay (%)	3.81	3.71	3.90
Bulk density (t/m)	1.67	1.65	1.66
Chemical properties			
EC1:5 (dS m^{-1})	0.45	0.52	0.66
pH (1:2.5)	8.52	8.51	8.83
Total CaCO (%)	7.13	2.45	4.67

Table 2: Fertilization requirements for greenhouses cucumber

N	P_2O_5	K_2O
160 kg fed^{-1}	82 kg fed^{-1}	200 kg fed^{-1}
384 kg ha^{-1}	196.8 kg ha^{-1}	480 kg ha^{-1}

Hectare = 2.4 fed

Table 3: Estimation of roots volume

Cases	Case 1	Case 2	Case 3	Case 4
3D shape of the true volume of the wheat plant roots				
Root volume equation	$\text{Cone volume} = \frac{3.14\times R^2\times H}{3}$ (2)	$\text{Cone volume} = \frac{3.14\times R^2\times H}{3}$ (3)	$\text{Total volume for two cones} = \frac{3.14\times R^2\times H_1}{3} + \frac{3.14\times R^2\times H_2}{3}$ (4)	$\text{Total volume for two cones and cylinder} = \frac{3.14\times R^2\times H_1}{3} + \frac{3.14\times R^2\times H_2}{3} + 3.14R^2\times S$ (5)

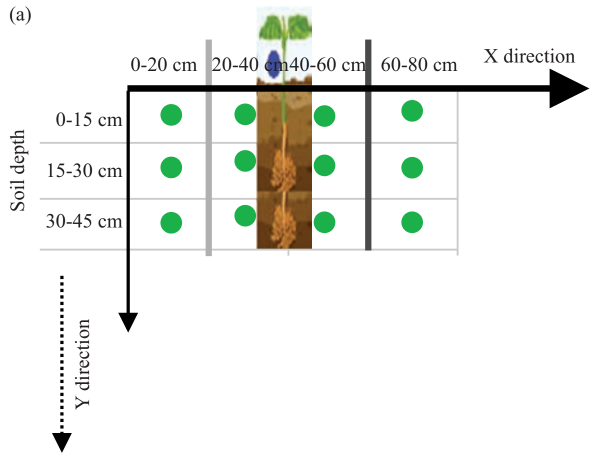


Fig. 2(a-b): Estimation of application efficiency of irrigation water under traditional irrigation and partial roots drying technique, (a) One lateral with traditional irrigation and (b) Two laterals with PRD
Soil depth, X-direction: 0-20, 20-40, 40-60, 60-80 cm and Y-direction: 0-15, 15-30, 30-45 cm

$$AE_{IW} = \frac{Ds}{Da} \quad (6)$$

where, AE_{IW} is the application efficiency of irrigation water (%), Da is the depth of applied water (mm), Ds is the depth of stored water in the root zone, mm by Eq. 7:

$$Ds = (\theta_1 - \theta_2)\times d \quad (7)$$

where, Ds is the stored water in the soil layer depth (mm), θ_1 is the average of soil moisture content after irrigation (g/g) in the root zone, θ_2 is the average of soil moisture content before irrigation (g/g) in the root-zone at peak water requirements.

Yield: At harvest time of cucumber, the total weight of fruits in each treatment was recorded by harvesting cucumber as kg per 1 m^2 were calculated, fruits twice weekly and then the total yield as ton/hectare was calculated.

Water productivity of crop: Water productivity of cucumber "$WP_{cucumber}$" was calculated according to Tabassum and Hossain[27] by Eq. 8 as follows:

$$WP_{cucumber} = \frac{Ey}{Ir} \quad (8)$$

where, $WP_{cucumber}$ is water productivity of cucumber ($kg_{cucumber}$/$m^3_{irrigation\ water}$), Ey is the economical yield ($kg_{cucumber}$/hectare/season), Ir is the applied amount of irrigation water ($m^3_{irrigation\ water}$/hectare/season).

Quality of cucumber fruit: Weight, length, diameter and total soluble solids (TSS) percentage of cucumber fruits were determined by using Refract meter according to AOAC[28].

Statistical analysis: The MSTATC program was used to analyze all obtained of the experimental data from two seasons of the study and Fisher's Least Significant Difference (LSD) test at p = 0.05 was used to determine significant differences among means[29].

RESULTS AND DISCUSSION

Soil moisture distribution and water stress ($WS_{roots-zone}$) inside roots-zone of the cucumber plant: The moisture distribution within the root zone of the automatic irrigation and the partial drying technique of the roots before and after irrigation was shown in Fig. 3 and 4. The distribution was similar on both sides of the roots of the plant when irrigated with 100% and 75% FI but the wet soil volume, when treated with 100% FI, was greater than the wet soil volume when irrigated with 75% FI, while there was a significant difference in the distribution of soil moisture on both sides of the roots of one plant when irrigated with the partial drying technique of the roots, where the volume and content of soil moisture on one side were much greater than the other side that is not irrigated. In the next irrigation, the same distribution is repeated for all the treatments except for the treatment of irrigation with the partial drying technique of the roots. There has been a change in the part that was not irrigated the previous time. It will irrigate this time and leave the other side of the plant without irrigation. In the following irrigation, the

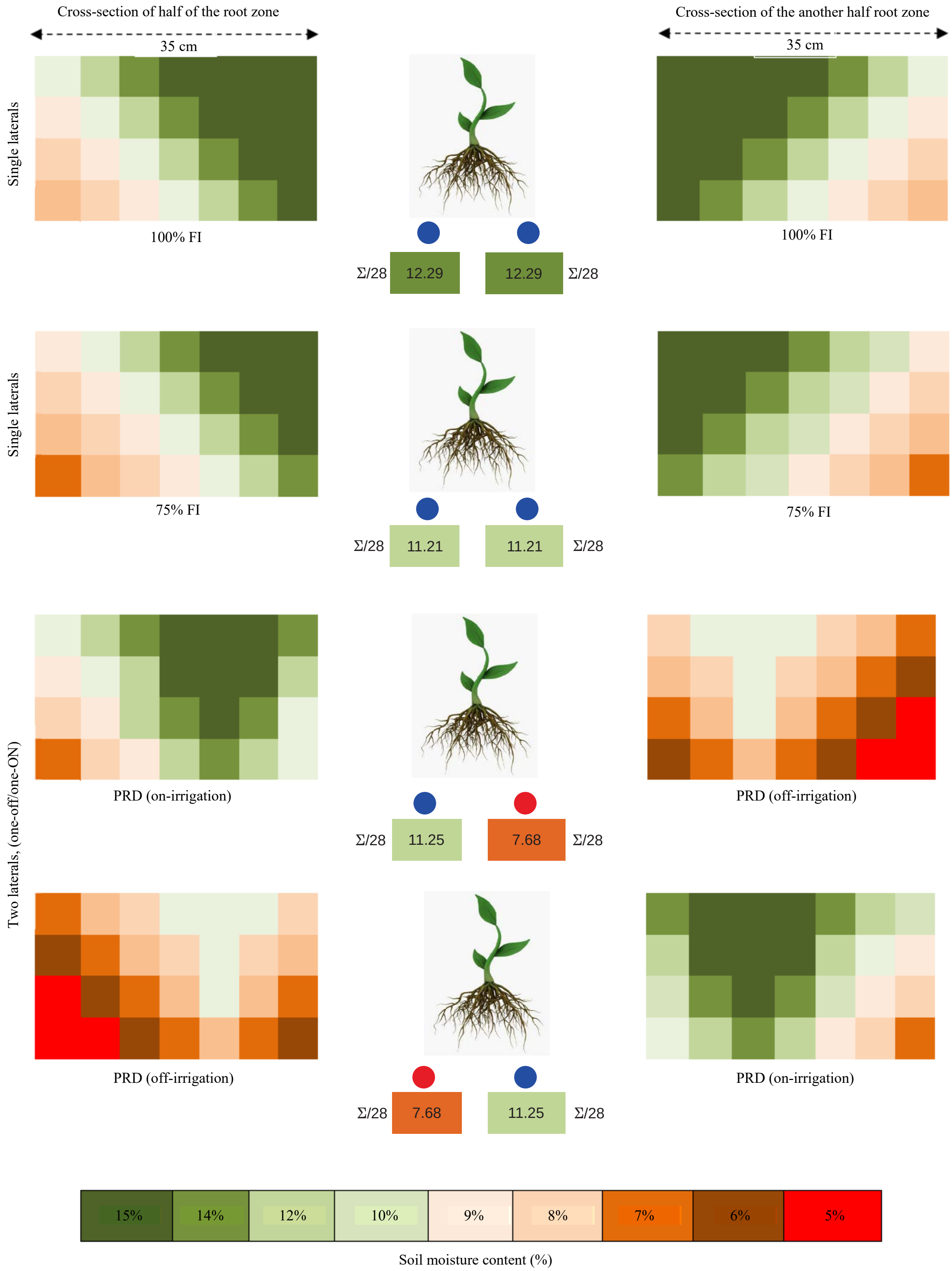


Fig. 3: Effect of automatic irrigation and partial root-zone drying technique on the soil moisture distribution after irrigation at med-stage for season 2020 only

Season 2021 and manual irrigation were taken the same patterns approximately

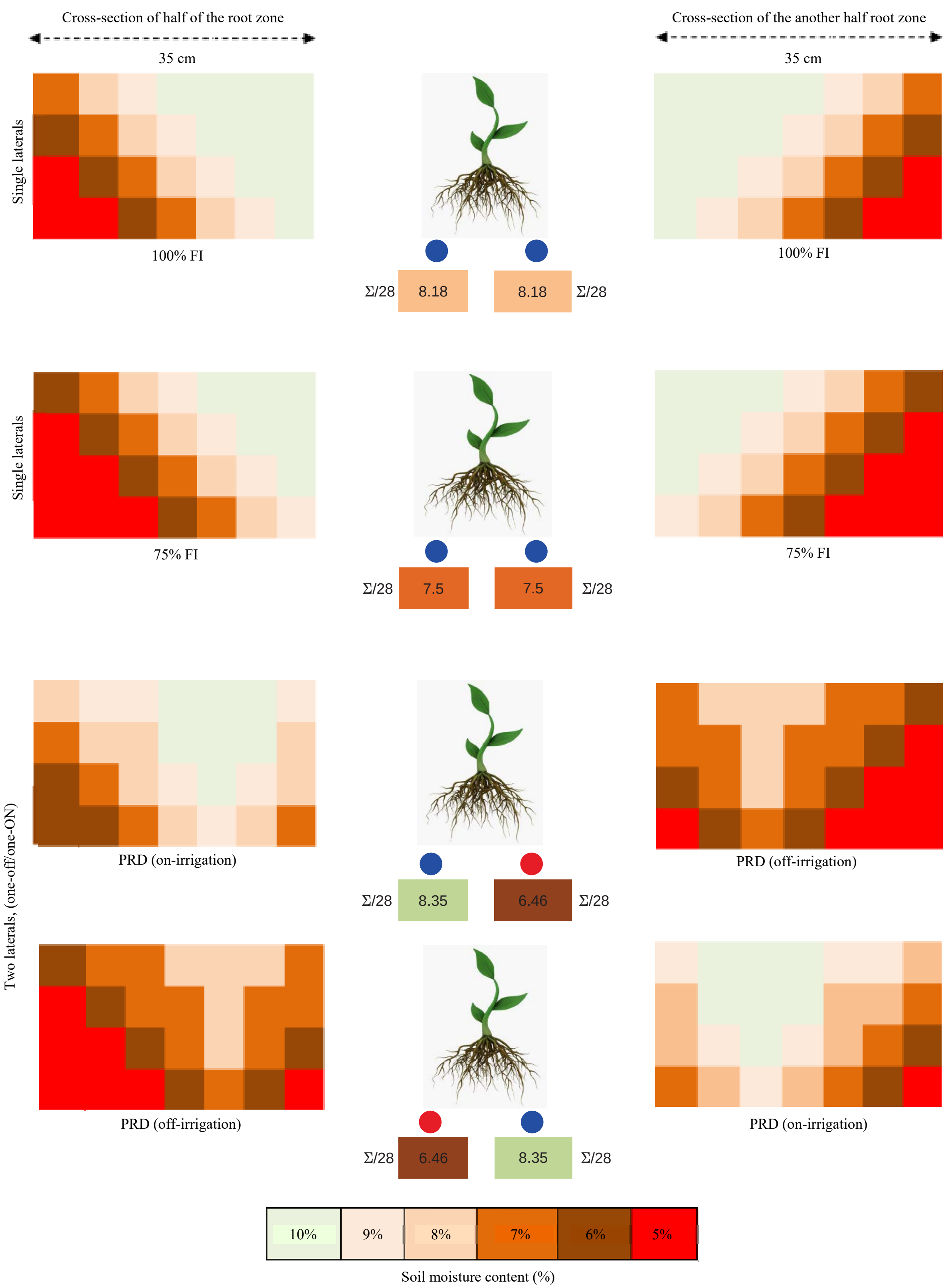


Fig. 4: Effect of automatic irrigation and partial root-zone drying technique on the soil moisture distribution before irrigation at med-stage for season 2020 only

Season 2021 and manual irrigation were taken the same patterns approximately opposite occurs and so on with each irrigation, the irrigation is done alternately when Irrigation with partial drying of the roots until harvest. The moisture distribution of the soil before irrigation took the same shape as the moisture distribution of the soil before irrigation but with very low levels of moisture content, which was approaching the permanent wilting point, which represents the maximum point of moisture stress. From the above, it is clear that many benefits can be obtained from applying the partial drying technique to the roots through the formation of chemical signals and the mechanical opening and closing of stomata and other benefits that have been mentioned due to the difference resulting from the distribution and moisture content on both sides of the roots of the same plant.

There was a significant effect of automatic irrigation and PRD technique on the increasing of soil moisture content within the root zone "SMC" (Fig. 5a-f). SMC values were increased by increasing the amount of water irrigation volume. The highest values of the average SMC were under 100% FI and the lowest values were at PRD with both manual and automatic irrigation. When irrigating with 100% or 75% FI, the average moisture content increases and decreases in both root-spreading areas of the cultivated plants. You note that this moisture fluctuation for the entire root zone is very close to the level of field capacity, while when irrigating with the root drying technique, we find that at the time when one side of the root zone is wet and this part of the field capacity is close to wetness. The other side of the root zone is dry and closer to the permanent wilting point. Although the root spread area when irrigated with 100 and 75% FI is less water stress, the difference in water stress on both sides of the plant when irrigating with partial drying of the roots will make the difference and the many advantages that were mentioned previously. It was also noted that automatic irrigation is less stressful for the area of root spread compared to manual irrigation and this seems logical as a result of the irregularity of the irrigation process that depends on the human factor, which is sure not to adhere to the irrigation process on the specified dates, which automatic irrigation does not miss. These results were in agreement with those obtained by the previous studies[30-35].

Roots volume of cucumber plant ($RV_{cucumber\ plant}$): The effect of automatic irrigation control and root drying technique on the $RV_{cucumber\ plant}$ (Fig. 6). A slight increase in the $RV_{cucumber\ plant}$. with the automatic control of irrigation compared to the manual control as shown in Fig. 6. This may be due to the irregularity of manual irrigation, which led to the addition of large quantities of water more than what is required at times with the growth stages of cucumber plants, which did not allow increasing and growing of the roots, which led to their dwarfing compared to the automatic control that was programmed regularly and did not happen with him giving quantities of water. In excess, which allowed the natural growth of the roots and increase their size compared to manual irrigation, which depends on the human factor. The data in Fig. 6 shows the effect of the root partial drying technique on the $RV_{cucumber\ plant}$. The volume of roots increased with the root drying technique (50% of complete irrigation) significantly increased compared to irrigation at 100 and 75% FI. This was because irrigation with the partial drying technique of the roots and the wet conditions it created on one side of the roots and dry conditions on the other side stimulated the growth of the roots on the dry side in search of the soil moisture and growth downwards. Increasing the size of the roots compared to irrigation at 75% FI and the least growing of the root volume when irrigating with 100% FI, which had the least water stress and there were no exceptional conditions to stimulate the growth of the roots more than usual for growth. Figure 6 also showed the effect of the interaction between automatic irrigation and root drying technique on the $RV_{cucumber\ plant}$. The highest values of root size were when the automatic control of irrigation and root drying technique, where the characteristics of the single effect of both factors were combined and the highest $RV_{cucumber\ plant}$ was achieved with them. These obtained results were in agreement with[18,20].

Application efficiency of irrigation water (AE_{IW}): The effect of automatic irrigation control and root drying technique on the AE_{IW} (Fig. 7). Figure 7 shows an increase in the AE_{IW} with automatic irrigation control compared to manual control. This may be due to the decrease in the size of the roots with the manual irrigation system, which led to the escaping of large quantities of water outside the small size root spreading area compared to the large size of the roots under the automatic control system. The data in Fig. 7 showed the effect of the partial drying technique of the roots on the AE_{IW}. The AE_{IW} increased with the increase in the size of the roots with the root drying technique (50% of the complete irrigation) significantly more compared to the irrigation at 100 and 75% FI. This was due to the increase in the size of the roots compared to irrigation at 75% FI and the least growth of the size of the roots when irrigated with 100% FI. The data in Fig. 7 also showed the effect of the interaction between automatic irrigation and root drying technique on the AE_{IW}. The highest values of the additive efficiency were at the automatic control of irrigation and the root drying technique,

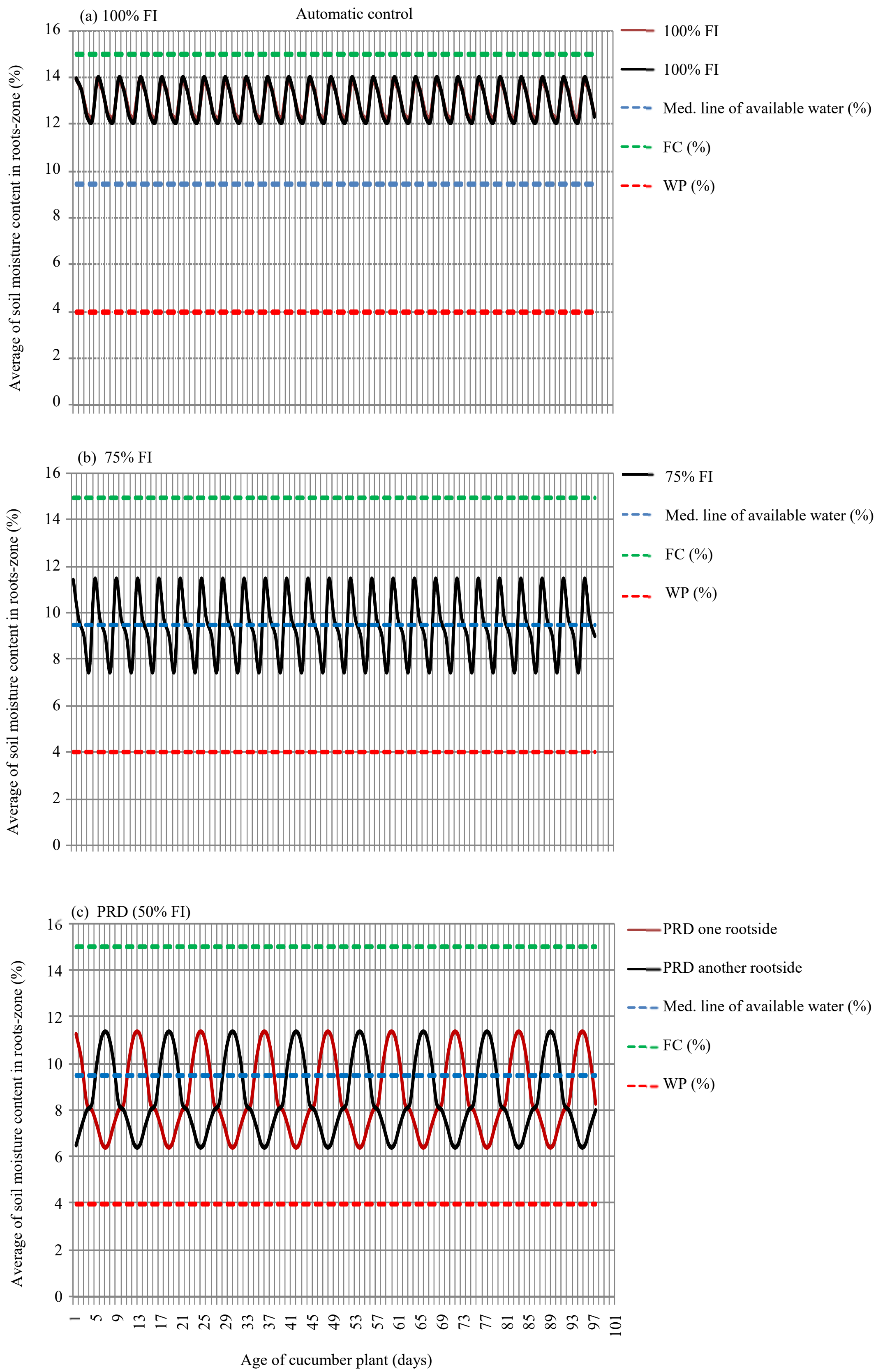


Fig. 5(a-f): Continue

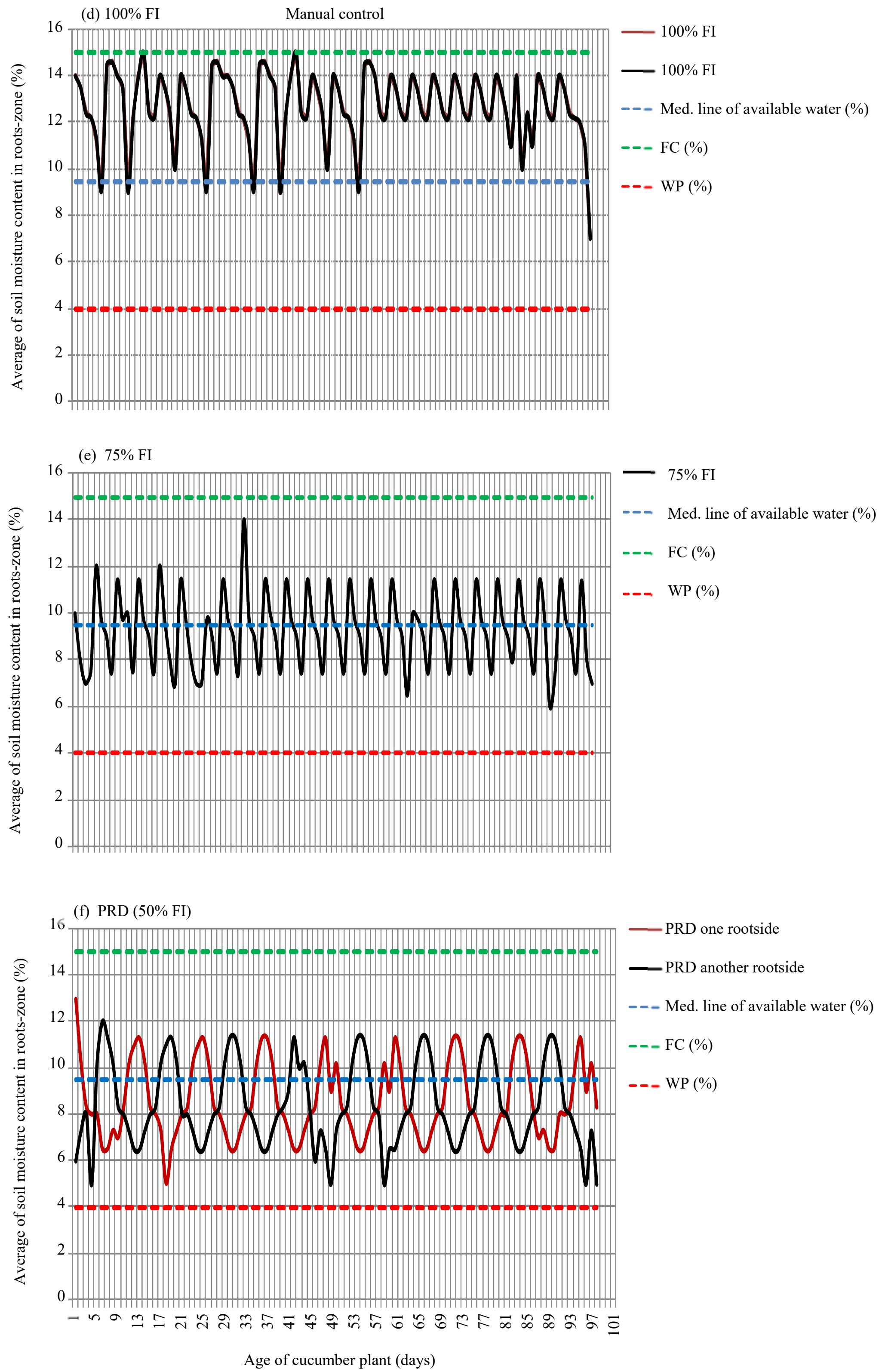


Fig. 5(a-f): Effect of automatic irrigation and partial root-zone drying technique on the water stress in roots-zone of cucumber plant before irrigation at all growth stages for season 2020 only

Season 2021 was taken the same patterns approximately

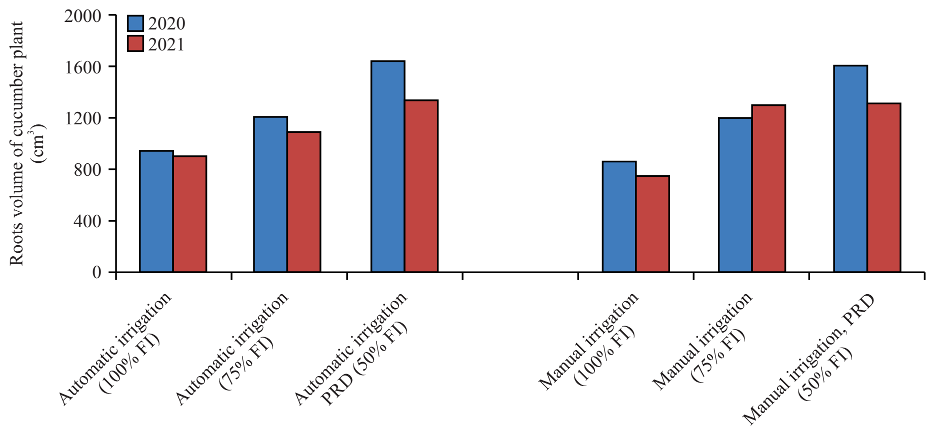


Fig. 6: Effect of automatic irrigation and partial root-zone drying technique on the roots volume of cucumber plant for seasons 2020 and 2021

X-axis: Different automatic irrigation and partial root-zone drying technique

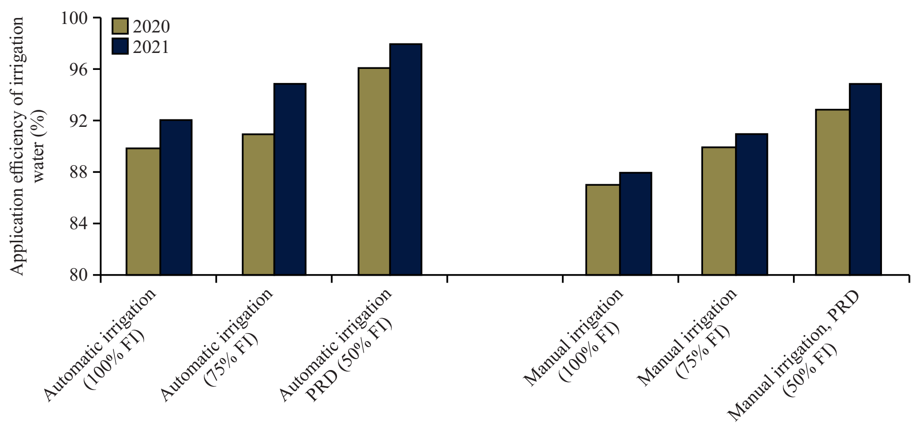


Fig. 7: Effect of automatic irrigation and partial root-zone drying technique on application efficiency of irrigation water for seasons 2020 and 2021

X-axis: Different automatic irrigation and partial root-zone drying technique

where the advantages of the single effect of both factors were combined and the highest AE_{IW} was achieved due to the highest volume of cucumber roots with them.

Yield of cucumber ($Y_{cucumber}$): The data in Fig. 8 and Table 4 showed the effect of automatic irrigation control and root drying technique on the $Y_{cucumber}$. The data in Fig. 8 shows an increase in the $Y_{cucumber}$ with automatic irrigation control compared to manual control. This may be due to the increase in the efficiency of the addition resulting from the increase in the size of the roots with the automatic irrigation system, which led to the lack of escaping the amount of added irrigation water carrying nutrients with it outside the root spreading area compared to the low efficiency of the addition of small root size under the manual irrigation control system. The increase in the efficiency of addition and root size for irrigation with automatic control had a significant positive effect on increasing the absorption of irrigation water and nutrients compared to manual irrigation, which ultimately reflected positively on the increase in $Y_{cucumber}$. The data in Fig. 8 shows the effect of partial drying of the roots on the $Y_{cucumber}$. The productivity of cucumbers increased with the increase in the efficiency of the addition of irrigation water and with the increase in the size of the roots with the radical drying technique of the roots (50% of the complete irrigation) compared to the irrigation at 100 and 75% of the full irrigation. This was due to the increase in the rate of absorption of water and nutrients with an increase in the efficiency of the addition and the size of the roots compared to irrigation at 75% of full irrigation and the least $Y_{cucumber}$ when irrigating with 100% of

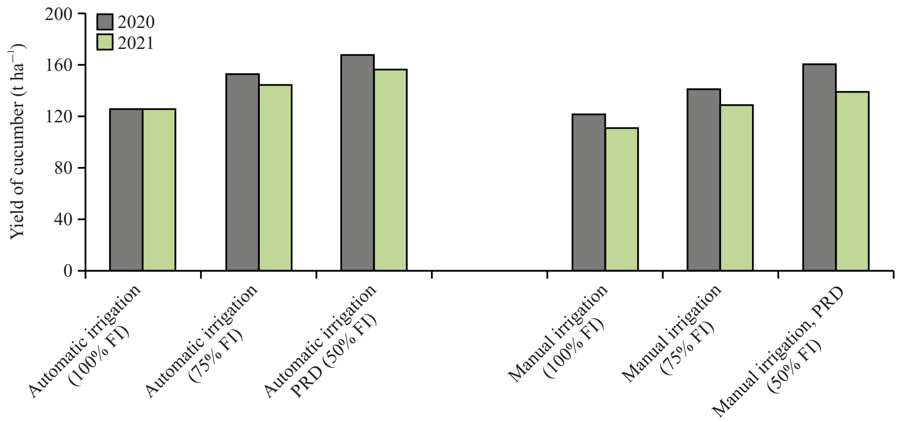


Fig. 8: Effect of automatic irrigation and partial root-zone drying technique on the yield of cucumber for seasons 2020 and 2021
X-axis: Different automatic irrigation and partial root-zone drying technique

Table 4: Effect of automatic irrigation and partial root-zone drying technique on the yield and water productivity of cucumber for seasons 2020 and 2021

		Yield (t ha^{-1})		Water productivity (kg m^{-3})	
SI	PRD	2020	2021	2020	2021
Automatic		149.20±18.94^{A}	142.84±13.66^{a}	37.4	35.8
Manual		141.37±16.75^{B}	126.77±12.36^{b}	35.4	31.8
LSD 5%		0.091	0.788		
	100% FI	123.70±2.46^{C}	118.65±7.98^{c}	20.8	20.1
	75% FI	147.75±6.72^{B}	137.40±8.88^{b}	33.1	31.1
	PRD	164.40±4.67^{A}	148.35±9.61^{a}	55.3	50.3
LSD 5%		2.466	0.933		
Automatic	100% FI	125.50±1.00^{E}	125.90±0.75^{e}	21.1	21.3
	75% FI	153.70±2.20^{C}	145.50±0.50^{b}	34.4	32.9
	PRD	168.40±1.60^{A}	157.10±0.90^{a}	56.6	53.3
Manual	100% FI	121.90±2.10^{F}	111.40±0.40^{f}	20.5	18.9
	75% FI	141.80±1.40^{D}	129.30±0.30^{d}	31.8	29.2
	PRD	160.40±2.00^{B}	139.60±0.50^{c}	53.9	47.3
LSD 5%		3.488	1.319		

SI: System of irrigation, PRD: Partial root-zone drying and FI: Full irrigation, Capital alphabets show the highest mean values while small alphabets represent the lower mean values

full irrigation as it was the least efficient for addition and the size of the roots, which helped the escaping of a lot of irrigation water outside the area. Root spread and also a decrease in the rate of nutrient absorption, which negatively affected the $Y_{cucumber}$. The data in Fig. 8 also showed the effect of the interaction between automatic irrigation and root drying technique on the $Y_{cucumber}$. The highest values of $Y_{cucumber}$ were when the automatic control of irrigation and the root drying technique, where the advantages of a positive unilateral effect of both factors combined and the $Y_{cucumber}$ was achieved with them. The obtained results were in agreement with[7-12,36].

Water productivity of cucumber ($WP_{cucumber}$): Figure 9 and Table 4 showed the effect of automatic irrigation control and root drying technique on $WP_{cucumber}$. The data in Fig. 9 showed an increase in the $WP_{cucumber}$ with automatic irrigation control compared to manual control. This may be due to the increase in the $Y_{cucumber}$. The data in Fig. 9 shows the effect of the PRD technique on the $WP_{cucumber}$. The $WP_{cucumber}$ increased with the increase of yield and the decrease in the volume of irrigation water with the radical drying technique of the roots (50% FI) compared to the irrigation at 75% FI and the lowest value of $WP_{cucumber}$ occurred with 100% FI. The data in Fig. 9 also showed the effect of the interaction between automatic irrigation and the PRD technique on the $WP_{cucumber}$. The highest values of $WP_{cucumber}$ occurred, when the automatic control of irrigation and the PRD technique, where the advantages of a positive unilateral effect of both factors combined and the highest value of $WP_{cucumber}$ was achieved with them.

Quality of cucumber fruits: Weight, length, diameter and T.S.S. content in the cucumber fruits were affected by the automatic irrigation and PRD technique. The results obtained

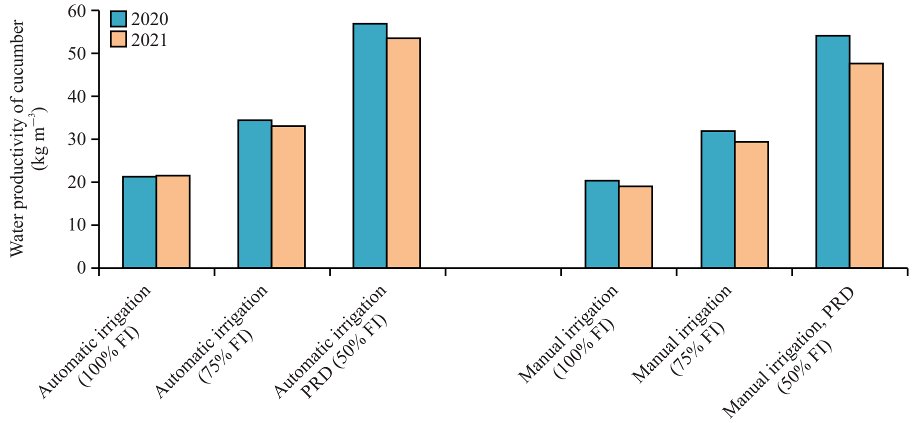


Fig. 9: Effect of automatic irrigation and partial root-zone drying technique on the water productivity of cucumber for seasons 2020 and 2021

X-axis: Different automatic irrigation and partial root-zone drying technique

Table 5: Effect of automatic irrigation and partial root-zone drying technique on some quality traits of cucumber fruits for seasons 2020 and 2021

	Fruit weight (g)	Length (cm)	Diameter (cm)	TSS (%)
Season 2020				
Auto	121.87±7.71[a]	11.50±0.99	4.30±0.73	5.17±0.36
Manual	112.77±6.26[b]	10.53±0.60	4.20±0.74	4.40±0.50
LSD at α 0.05	0.497	NS	NS	NS
100% FI	109.65±3.39[c]	10.40±0.93[b]	3.55±0.15[c]	4.45±0.59[c]
75% FI	117.75±8.43[b]	10.90±0.43[ab]	4.05±0.15[b]	4.70±0.41[b]
PRD	124.55±4.51[a]	11.75±0.90[a]	5.15±0.27[a]	5.20±0.51[a]
LSD at α 0.05	3.215	0.929	0.332	0.219
Auto×100% FI	112.20±2.20[c]	10.80±1.20	3.60±0.10	4.90±0.10
Auto×75% FI	125.00±3.00[ab]	11.20±0.20	4.10±0.10	5.00±0.00
Auto×PRD	128.40±2.30[a]	12.50±0.30	5.20±0.30	5.60±0.30
Manual×100% FI	107.10±2.10[d]	10.00±0.50	3.50±0.20	4.00±0.50
Manual×75% FI	110.50±1.00[cd]	10.60±0.40	4.00±0.20	4.40±0.40
Manual×PRD	120.70±1.00[b]	11.00±0.50	5.10±0.30	4.80±0.30
LSD at α 0.05	4.546	NS	NS	NS
Season 2021				
Auto	117.90±5.57[a]	11.00±0.85	4.63±0.67	5.37±0.38[a]
Manual	110.80±6.27[b]	10.27±0.53	4.80±0.50	4.73±0.58[b]
SD at α 0.05	5.217	NS	NS	0.09071
100% FI	108.85±2.92[c]	10.10±0.94	4.15±0.15[c]	4.50±0.56[c]
75% FI	113.05±6.64[b]	10.70±0.63	4.65±0.45[b]	5.15±0.22[b]
PRD	121.15±3.39[a]	11.10±0.46	5.35±0.22[a]	5.50±0.37[a]
LSD at α 0.05	2.084	NS	0.073	0.198
Auto×100% FI	111.40±0.40[c]	10.40±1.40	4.10±0.10[e]	5.00±0.00[c]
Auto×75% FI	119.00±2.00[b]	11.10±0.10	4.30±0.20[d]	5.30±0.20[b]
Auto×PRD	123.30±3.30[a]	11.50±0.10	5.50±0.10[a]	5.80±0.20[a]
Manual×100% FI	106.30±1.30[d]	9.80±0.00	4.20±0.20[de]	4.00±0.20[d]
Manual×75% FI	107.10±0.11[d]	10.30±0.70	5.00±0.30[c]	5.00±0.10[c]
Manual×PRD	119.00±2.00[b]	10.70±0.20	5.20±0.20[b]	5.20±0.20[bc]
LSD at α 0.05	2.947	NS	0.1031	0.2793

SI: System of irrigation, PRD: Partial root-zone drying, FI: Full irrigation and a is the largest value and e is the lowest value and the means followed by the same alphabetical letters were not significantly different at the probability level of 0.05

in Table 5 also showed a significant improvement in all the quality characteristics of the cucumbers understudy when applying both the automatic control irrigation and the partial drying technique of the roots compared to manual irrigation and the addition of 100% of the full irrigation. This may be due to the increased uptake of water and nutrients from a larger volume of root propagation and the creation of a healthy root propagation zone with less moisture stress, which was achieved with automatic control irrigation and partial root drying technology compared to manual irrigation and irrigation with the addition of 100 or 75% of full irrigation which was stunned when applied due to the size of the roots and moisture stress in the root zone, which hindered the absorption of water and nutrients and led to water and nutritional stress in the root zone, which ultimately reflected on the decrease in the values of quality properties. These obtained results were in agreement[13-17,19].

CONCLUSION

The study concluded by recommending the application of automatic control of irrigation and application of the root drying technique compared to manual irrigation, which depends on the human factor, which is not free from forgetfulness and error in the application and irrigation at a level of 100% full irrigation. Perhaps the recommendation is due to the many benefits of automatic irrigation and the partial root drying technique. Indeed, despite the negative impact of the partial roots drying technique on increasing moisture stress, the many advantages created by this technique overcame and outweighed this only drawback as it led to an increase in the size of the root spreading area and an increased application efficiency of irrigation water by increasing the size of the roots, which led to an increase in the area of absorption of water and nutrients, which ultimately reflected on the increase and improvement of productivity, water productivity and quality characteristics of cucumbers under the conditions of cultivation under greenhouses in sandy soils.

SIGNIFICANCE STATEMENT

This study revealed an improvement in the cultivation of cucumbers using the drip irrigation system under dry and semi-arid climatic conditions and it also led to an increase in yield, water productivity and quality of cucumber fruits using PRD technology and automatic irrigation. The results of this study will help farmers to select and manage (PRD) technology with automatic irrigation to maximize and improve crop productivity, water productivity and quality of cultivated crops with minimal additional costs.

REFERENCES

1. dos Santos, T.P., C.M. Lopes, M.L. Rodrigues, C.R. de Souza and J.P. Maroco *et al*., 2003. Partial rootzone drying: Effects on growth and fruit quality of field-grown grapevines (*Vitis vinifera*). Funct. Plant Biol., 30: 663-671.
2. Rashid, M.A., X. Zhang, M.N. Andersen and J.E. Olesen, 2019. Can mulching of maize straw complement deficit irrigation to improve water use efficiency and productivity of winter wheat in North China Plain? Agric. Water Manage., 213: 1-11.
3. Eid, A.R. and A. Negm, 2019. Improving Agricultural Crop Yield and Water Productivity via Sustainable and Engineering Techniques. In: Conventional Water Resources and Agriculture in Egypt, Negm, A.M. (Ed.), Springer, Cham, Switzerland, ISBN: 978-3-319-95065-5, pp: 561-592.
4. Abdelraouf, R.E. and R. Ragab, 2018. Effect of fertigation frequency and duration on yield and water productivity of wheat: Field and modelling study using the saltmed model. Irrig. Drain., 67: 414-428.
5. Kang, S and J. Zhang, 2004. Controlled alternate partial root-zone irrigation: Its physiological consequences and impact on water use efficiency. J. Exp. Bot., 55: 2437-2446.
6. Grijalva-Contreras, R.L., R. Macías-Duarte, G. Martínez-Díaz, F. Robles-Contreras, M. de Jesús Valenzuela-Ruiz and F. Nuñez-Ramírez, 2013. Effect of regulated deficit irrigation on productivity, quality and water use in olive cv "Manzanilla". Am. J. Plant Sci., 4: 109-113.
7. Fereres, E. and M.A. Soriano, 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot., 58: 147-159.
8. Geerts, S. and D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric. Water Manage., 96: 1275-1284.
9. Dodd, I.C., J.C. Theobald, M.A. Bacon and W.J. Davies, 2006. Alternation of wet and dry sides during partial rootzone drying irrigation alters root-to-shoot signalling of abscisic acid. Funct. Plant Biol., 33: 1081-1089.
10. Chaves, M.M., T.P. Santos, C.R. Souza, M.F. Ortuno and M.L. Rodrigues *et al*., 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. Ann. Appl. Biol., 150: 237-252.
11. Wang, Z., S. Kang, C.R. Jensen and F. Liu, 2012. Alternate partial root-zone irrigation reduces bundle-sheath cell leakage to CO_2 and enhances photosynthetic capacity in maize leaves. J. Exp. Bot., 63: 1145-1153.
12. Yan, F., Y. Sun, F. Song and F. Liu, 2012. Differential responses of stomatal morphology to partial root-zone drying and deficit irrigation in potato leaves under varied nitrogen rates. Sci. Hortic., 145: 76-83.
13. dos Santos, T.P., C.M. Lopes, M.L. Rodrigues, C.R. de Souza and J.M. Ricardo-da-Silva *et al*., 2007. Effects of deficit irrigation strategies on cluster microclimate for improving fruit composition of moscatel field-grown grapevines. Sci. Horti., 112: 321-330.
14. Chaves, M.M., O. Zarrouk, R. Francisco, J.M. Costa and T. Santos *et al*., 2010. Grapevine under deficit irrigation: Hints from physiological and molecular data. Ann. Bot., 105: 661-676.
15. Yang, J. and J. Zhang, 2010. Crop management techniques to enhance harvest index in rice. J. Exp. Bot., 61: 3177-3189.

16. Zhang, H., T. Chen, Z. Wang, J. Yang and J. Zhang, 2010. Involvement of cytokinins in the grain filling of rice under alternate wetting and drying irrigation. J. Exp. Bot., 61: 3719-3733.
17. Price, A.H., G.J. Norton, D.E. Salt, O. Ebenhoeh and A.A. Meharg *et al*., 2013. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? Food Energy Secur., 2: 120-129.
18. Pérez-Pérez, J.G., I.C. Dodd and P. Botía, 2012. Partial rootzone drying increases water-use efficiency of lemon fino 49 trees independently of root-to-shoot ABA signalling. Funct. Plant Biol., 39: 366-378.
19. Wang, Y., F. Liu, L.S. Jensen, A. de Neergaard and C.R. Jensen, 2013. Alternate partial root-zone irrigation improves fertilizer-N use efficiency in tomatoes. Irrig. Sci., 31: 589-598.
20. Wang, Y., C.R. Jensen and F. Liu, 2017. Nutritional responses to soil drying and rewetting cycles under partial root-zone drying irrigation. Agric. Water Manage., 179: 254-259.
21. Lozano, D., N. Ruiz, R. Baeza, J.I. Contreras and P. Gavilán, 2020. Effect of pulse drip irrigation duration on water distribution uniformity. Water, Vol. 12. 10.3390/w12082276.
22. Kim, Y., R.G. Evans and W.M. Iversen, 2009. Evaluation of closed-loop site-specific irrigation with wireless sensor network. J. Irrig. Drain. Eng., 135: 25-31.
23. Luquet, D., A. Vidal, M. Smith and J. Dauzat, 2005. 'More crop per drop': How to make it acceptable for farmers? Agric. Water Manage., 76: 108-119.
24. Richard, G.A, L.S. Pereira, M. Smith, D. Raes and J.L. Wright, 2005. FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. J. Irrig. Drain. Eng., 131: 2-13.
25. Ragab, R., A. Battilani, G. Matovic, R. Stikic, G. Psarras and K. Chartzoulakis, 2015. SALTMED model as an integrated management tool for water, crop, soil and N-fertilizer water management strategies and productivity: Field and simulation study. Irrig. Drain., 64: 13-28.
26. Sandhu, O.S., R.K. Gupta, H.S. Thind, M.L. Jat, H.S. Sidhu and Yadvinder-Singh, 2019. Drip irrigation and nitrogen management for improving crop yields, nitrogen use efficiency and water productivity of maize-wheat system on permanent beds in north-west India. Agric. Water Manage., 219: 19-26.
27. Tabassum, S. and A. Hossain, 2018. Design and development of weather monitoring and controlling system for a smart agro (farm). Intell. Control Autom., 9: 65-73.
28. AOAC, 1990. Official Methods of Analysis of Association of Analytical Chemistry. 15th Edn., Arlington, Virginia, USA, ISBN: 0-935584-42-0, Pages: 684.
29. Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons Inc., New York, USA., ISBN: 978-0-471-87092-0, Pages: 704.
30. Waddell, J.T., S.C. Gupta, J.F. Moncrief, C.J. Rosen and D.D. Steele, 2000. Irrigation and nitrogen management impacts on nitrate leaching under potato. J. Environ. Qual., 29: 251-261.
31. Rahaman, M.M. and M. Azharuddin, 2022. Wireless sensor networks in agriculture through machine learning: A survey. Comput. Electron. Agric., Vol. 197. 10.1016/j.compag.2022.106928.
32. Shock, C.C., E.B.G. Feibert and L.D. Saunders, 2003. Umatilla russet and russet legend potato yield and quality response to irrigation. HortScience, 38: 1117-1121.
33. Abdelraouf, R.E. and R. Ragab, 2018. Is the partial root drying irrigation method suitable for sandy soils? Field experiment and modelling using the saltmed model. Irrig. Drain., 67: 477-490.
34. Ramadan, A., S. Mosa, M. Abdou and A.S. Allam, 2021. The efficiency of organic mulching for improving the water productivity under dry regions. Egypt. J. Chem., 64: 2285-2296.
35. Huang, L., P. Yang, S. Ren and H. Cui, 2018. Effects of continuous and pulse irrigation with different nitrogen applications on soil moisture, nitrogen transport and accumulation in root systems. Int. J. Agric. Biol. Eng., 11: 139-149.
36. Arunadevi, K., M. Singh, D. Franco, V.K. Prajapati, J. Ramachandran and G.R.M. Sankar, 2022. Real time soil moisture (RTSM) based irrigation scheduling to improve yield and water-use efficiency of green pea (*Pisum sativum* L.) grown in North India. Agronomy, Vol. 12. 10.3390/agronomy1202027.