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Effect of Regulated Deficit Irrigation and Partial Root-Zone Drying on Some Quantitative Indicators and the Efficiency of Adding Nitrogen Fertilizer to (*Zea mays* L.) By Using N^{15} Isotope

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Abstract: Water availability for agriculture is being reduced as a consequence of global climate change, environmental pollution and growing demand for other uses. Therefore, great emphasis is placed on crop management for dry conditions with the aim of increasing water use efficiency. To see how restricted irrigation systems effect water use efficiency and corn yield, field experiment was conducted for 2 years 2007and 2008 in an semi arid area in North of Syria at the National Research Center in Tel Hadia, partial root-zone drying (PRD), an innovative irrigation system in which both halves of the root system are alternately dried and well watered, was compared with two deficit irrigation levels 85%, 65% and full irrigation 100% from field capacity. Results indicated that there are high significant differences between irrigation treatments ($p<0.05$) in grain yield where, 100% irrigation treatment had significantly overyielded on 85% and 65% (9187,7867, 5962) kg/ha, respectively, The first irrigation method (drip line to raw plant) had significant increase in grain yield (7670, 6820) kg/ha on the second irrigation method (PRD), respectively. The highest evapotranspiration was observed in the first method as (546, 398 mm) under (100, 85%) irrigation treatments respectively, but it was found (352, 311mm) in (PRD) method for same treatments, respectively and the percentage of grain yield was obtained (0.92, 089) the first methods, respectively. The maximum leaf area index (LAI) was obtained from full irrigation as 3.07 m^2 and there was a significant difference among the treatments with respect to LAI ($p < 0.001$). The highest water use efficiency (WUE) was found in PRD – 100% as 2.63 kg/m^3 and the lowest one was found in full irrigation treatment as 1.28 kg/m^3 under the first irrigation method.

Key words: Partial root-zone drying (PRD) · Drip irrigation · Maize · Water use efficiency (WUE) · Crop evapotranspiration (ETc (and leaf area index (LAI)

INTRODUCTION

The continuous shortage of water suitable for agriculture is usually a consequence of global climate change on the one hand; environmental pollution and the increasing demand for water use on the other hand [1]. At a global level, the agricultural sector consumes about 67% of water resources, while the share of the industrial sector is 19% and the remainder is used for other purposes [2]. By the end of the twentieth century, water resources became of a strategic importance to the majority of the world countries. Water needs for agriculture in dry and semi-dry areas exceed 85% of the overall needs, but with the ever-growing population and the increasing demand for food, it has become a necessity to expand the agriculture horizontally and vertically to meet food demands. Moreover, it became necessary to raise the efficiency of water usage in irrigating crops to the maximum extent possible [3]. It can be relied on raising the efficiency of natural resources usage such as water, soil nutrients and carbon dioxide CO_2 in order to achieve the best possible productivity [4].

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The Arab region is amongst the driest regions of the world, with two-thirds of its area receive an annual rainfall not exceeding 100 mm [5] and in spite of the limited water in the Arab region, irrigated crops are the basis of Arabic agriculture, with irrigated land representing only about 22.5% of the total area of Arab agricultural lands. Furthermore, irrigated land is considered the main producer of most food products [6]. The agricultural sector in Syria consumed about 88% of the total available water resources in 2005 [7]. Despite the slight decline of this ratio in recent years to about 83%, but it is considered a large proportion compared with most world countries. Irrigated land in Syria represents about 24% of the national exploited area and this is used completely (100%) for summer crops such as cotton, maize, sunflower...etc. [8]. As agriculture consumes the majority of water resources, it was necessary to find means to raise the efficiency of using those resources. Many researches in the dry Mediterranean areas were directed to increase Water Use Efficiency (WUE) i.e. rate of photosynthesis per transpiration unit (mm) through pores [9], which can be inferred by morphological and physiological parameters and productivity indicators such as the weight of grain yield, biomass and leaf surface …etc [10]. Modern irrigation techniques that save more water, including localized irrigation and sprinkler irrigation ...etc., were adopted by many countries of the world during the last quarter of last century. However, with the continuous depletion of these resources and the repetition of drought years in many countries, more economical techniques, such as supplementary irrigation, irrigation scheduling and Regulated Deficit Irrigation (RDI), have been adopted. During recent years, Controlled Alternate Partial Root-zone Irrigation (CAPRI) or Partial Root-zone Drying (PRD), which is still prove useful for some fruit trees as one of the ways to rationalize the consumption of irrigation water and secure a good production, was tested [11]. This method expose part of the root system to soil drying, while the other part of the system is irrigated alternately [12].

Maize is of the very important crops, as it ranked third globally after wheat and rice. It is characterised by its high productivity and multi-uses. Apart from being used in feeding human in the form of corn flour, it is also used as a concentrated fodder for animals where each 100 kg is equivalent to 134 U.F. unit forage [13]. It is also rich in vitamin E, which aides animal's body, especially the poultry, to resist diseases, in addition to maintaining the quality of grain during storage [14]. Furthermore, it is also used to manufacture starch, alcohol and industrial syrup. The large variation of the geographical distribution of crop areas, especially in terms of rainfall, which ranges from 250-1500 mm/year and the ability of this crop to develop new genetic structures, enabled its adaptation in all environments through having genetic variations that gave this crop such importance [15]. Hence, corn is grown in most countries of the world, including Syria, where the cultivation of this crop, in terms of yield and area, has significantly developed and the cultivated area increased from about four thousand hectares in the late sixties to about seventy one thousand hectares for the 2008 season with an average productivity of 3972 kg/ha [8]. Corn consumption of irrigating water for the year 2009 was estimated to equal about 685 million cubic meters of intensive cultivation [16]. An experiment was carried out in 2007 & 2008 seasons at Tel Hadia Research Station, Northern Syria on maize crop which was irrigated using two methods of drip irrigation: one irrigation line per two planting lines and one irrigation line per planting line where the amount of water given to these two methods were the same and according to different levels of Regulated Deficit Irrigation (100, 85, 65)% of field capacity. The results of this experiment has shown that water use efficiency (WUE) was (1.14, 1.35, 2.21) kg/m^3, respectively, for the one irrigation line per planting line method and it was (1.26, 1.60, 2.14) kg/m^3, respectively for the one irrigation line per two planting lines model [17]. Bozkurt *et al*. [18] found that the highest production of maize was associated with a 1.4 m spacing between drip irrigation lines at 100% field capacity, where grain yield was 9.79 t/ha under Mediterranean climate conditions and this treatment has used the highest amount of water 758 mm and achieved the best water use efficiency. In an experiment which took place in the South-eastern U.S coastal plains, Stone and colleagues [19] found that irrigating maize using a drip surface and subsurface irrigation with a 1 and 2 m spacing lines showed a significant difference in biological yield when the distance between the drip irrigation lines was 2 meters.

The Partial Root-zone Drying (PRD) or Alternate Partial Root-zone Irrigation is an advanced state of deficit irrigation (DI) where using alternate irrigation on both sides of the plant root system which helps the plant to maintain moisture simultaneously. The idea of using (PRD) is a way to deal with the plant response to water deficit controlled by the plant root which generates the abscisic acid hormone (ABA) to regulate leaves pores actions [20]. As a result of plant response to (PRD), pores openings can be regulated so that it can be closed partially at a certain level of soil water deficit and thus leads to an increase in water use efficiency [21]. This method will usually lead to a saving in water usage by just under 50%, in addition to other useful effects on production quality (fruits) and on nutrients absorption with a minimal cut in production [22]. Sadras [23] found that production per unit of applied irrigation for crops under (PRD) was more significant. It was also found that the full and optimal irrigation in the US for maize ranges from 500 to 600 mm of irrigation water and that the correct assessment of the added amount of irrigation water as crop evapotranspiration (ETc) on a daily or seasonal basis, can be of great importance to better management of maize irrigation and for future strategic irrigation schemes [24]. Fifty percent of the world's population rely on nitrogen fertilization for food production where the entire world uses about 83 million tons of N annually; of those who use nitrogen fertilizer 60% use it for the major cereal crops production, rice, wheat, maize, but the efficiency of using Nitrogen fertilizer is still low, especially for wheat and maize crops where this efficiency is in the range 6-7%, indicating big losses in the system soil - plant [25]. Janat and Kalhoot [26] found through a field experiment at Tel Hadia Research Station, on cotton crop and using nitrogen fertilizer labelled with N-15 during 2004 and 2005 seasons that the plant tissues' content of nitrogen ranged between 1.5 and 1.9% when using one line of drip irrigation per two planting lines and ranged between 1.7 and 2.1% using one line of drip irrigation per planting line. Who also found that the total amount of absorbed nitrogen in the first method ranged between 144 and 393 kg N/ha and between 137 and 262 kg N/ha for the second method, whereas the utilization rate of nitrogen fertilizer was between 12 to 13% for the first method and 10 to 13% for the second [26]. It was also found that the spring potato tissues content of nitrogen N ranged between 1.6 and 1.9% in drip irrigation and according to the studied fertilization, it was also found that the total amount of absorbed nitrogen ranged between 85 and 119 kg N/ha, while the utilization rate of nitrogen fertilizer for the same plant ranged between 21 and 35% [26].

Objectives:

- The effect of different levels of irrigation treatments (100%, 85%, 65%) of field capacity on the productivity of maize whether grain and biological and on leaf area index
- Assessment of water use efficiency (WUE) and nitrogen fertilizer use efficiency (FUE) according to two methods of drip irrigation (one irrigation line per planting line, partial root-zone drying (PRD) for maize.

MATERIALS AND METHODS

Location and Climate: The experiment was carried out for two seasons 2007 and 2008, at Tel Hadia Agricultural Research Station of the Scientific Agricultural Research Centre in Aleppo - the General Commission for Scientific Agricultural Researches. The station is about 35 km south of Aleppo, (35.65° North, 36.10° East), at an altitude of about 274 m. The site is characterised by a Mediterranean climate with an average annual precipitation in the range of 250 and 350 mm. The annual seasonal precipitation were 314 and 222 mm for the years 2007 and 2008, respectively There was no rainfall during the growing season of 2007, while in 2008 the precipitation were 18.8 mm and 8.2 mm during the months of September and October, respectively. Some meteorological data were obtained from the nearby International Centre for Agricultural Research in Dry Areas (ICARDA) weather station. The monthly average from Class A Pan Evaporation in 2007 has ranged between 15.5 mm in July and 7.3 mm for October but this was 15.6 mm and 4.9 mm for the year 2008. Average temperature ranged between 32.7 ºC for July and 23 ºC for October in 2007 and 31.0 ºC and 21.0 ºC in 2008. The relative humidity as a monthly average ranged between of 35% for July and 42.8% for October in 2007 and between 44.3% and 57.2% in 2008. Wind speed at a height of two meters from the soil surface ranged between 4.1 m/s in July and 2.9 m/s in October in 2007, while in 2008 this speed ranged from 5.9 m/s to 2.5 m/s.

Soil and Water: Soil was classified as Heavy Deep Clay Red Soil *Chromoxereic Rhodo Xeralf* [27]. Soil samples were taken every 15 cm down to 120 cm depth as well as non-disturbed samples to study the bulk density, The (pH) ranged between 7.3 in surface layer and 7.8 at sub-surface depth. Electrical Conductivity of saturated paste (EC_e) ranged between 1.35 dS/m in the surface layer of the soil and gradually increased to 2 dS/m at 105-120 cm depth. The concentrations of calcium carbonate and effective calcium carbonate at the soil surface layer were 21.8 and 15.4 g/100 g soil, but these were then increased to 30.8 and 21.3 g/100 g soil at 105-120 cm depth, respectively. Soil was relatively poor with organic matter, this was 1.55 g/100 g soil at the surface layer and decreased to 0.82 g/100 g soil at 105-120 cm depth. The concentration of mineral nitrogen within the studied soil profile (0-120 cm) was between 8.2 mg/kg and 10.5 mg/kg. Concentration of available phosphorus according to the adopted method (Olsen) at the surface layer of soil was 5.7 mg/kg and decreased to 0.74 mg/kg at 75-90 cm depth. Total concentration of available potash the first and the second depths was about 685 mg/kg and decreased starting from 30-45 cm depth, where it reached 250 mg/kg at the depth 90-105 cm. Regarding soil physical and hydro-physical tests, bulk density ranged between 1 and 1.38 g/cm^3 for depths of 0-120 cm, the field capacity ranged between 38.7% and 41.5% by weight. Water samples were taken at the start of each season and the average Electric Conductivity of both seasons was 1.1 dS/m, pH 7.9, chlorine 3.2 meq/l. and sodium 3 meq/ l., indicating that the source of water was of a very light salinity. SAR was also calculated, which reached 1.53 indicating that water is safe for both spray and drip irrigation [28]. Drip irrigation method was adopted as it increases the efficiency of irrigation water to 95% [29] and it achieves a savings of water equivalent to 60% compared to surface irrigation [30].

Plant Material and Agricultural Operations: Maize (*Zea mays* L.), hybrid Basil -1 was planted for two seasons 2007 and 2008, (an individual certified hybrid which is characterized by a high productivity of up to 9-10 tons/ ha according to hybrid adoption report, the Directorate of Scientific Agricultural Research, [31], specified for intensive cultivation, where it reaches physiological maturity after about 100 days of planting. Soil was prepared through having two intersected ploughing followed by soil smoothing using disc ploughing. The experiment was planted manually using spot planting method on 14/7/2007 in the first season and on 13/7//2008 in the second season where the seed were placed in pits at a depth of 4-7 cm and at 70 cm distance between lines and about 25 cm between plants, which is equivalent to 57,000 plants/ha. Nitrogen and phosphate fertilizers were added according to soil analysis and in accordance with the Ministry of Agriculture and Agrarian Reform recommendations, 2005, where 290 and 320 kg/ha of urea (N 46%) were added for the 2007 and 2008, respectively. This addition was done though injection with the irrigation water and in two equal additions, the first when seedlings emerged and the second when the ninth leaf was grown. Furthermore an area of 1m^2 was also allocated to add N-15 labelled fertilizer in the form of urea with averaged enrichment (1.5% a.e) at the same time and repeatability of the normal fertilizer. The phosphate fertilizer was added in a single direct addition at the time of planting at the rate of 80 and 110 kg/ha in the form of triple superphosphate 46% for 2007 and 2008, respectively. The experiment was irrigated through a network of drip irrigation, where water for each experimental block was supplied through a drip irrigation pipe of 16 mm diameter (GR) with drippers spacing of 30 cm and of a length of 6 meters. The network was provided with pressure meters to ensure its optimal work (For detailed information please refer to the article [17].

Design of Experiment and Statistical Analysis: The experiment was designed according to split plot design (SPD) with three irrigation treatments (65%, 85% and 100% of field capacity) and each treatment includes two of drip irrigation models (the split), the first is one irrigation line per planting line and the second model is the partial root-zone drying (PRD), with 6 replicates per treatment. Number of experimental plots is 36, each of which is 25 m^2 with 7 planting lines each of which is 6 m long.

Measurements

Soil Moisture: Soil moisture neutron scattering meter (TROXLER Model 4300) pipes were inserted to 120 cm depth to measure the soil content at 15 cm intervals from 0 to 120 cm depth. Two tubes were inserted installed in each replicate, each tube represents a method of drip irrigation treatments [17]. The most important equations used to calculate the net amount of water and the standard evaporation-transpiration and irrigation efficiency...etc. were described in [17]. Number of irrigations in each season 2007 and 2008 was nine irrigations for the 100% treatment of a single irrigation line per planting line, when soil moisture reaches approximately 50% of field capacity, taking into account the efficiency of irrigation, which was previously calculated (93.5, 92)% [17] for 2007 and 2008 seasons, respectively. This was also applied according to the rates (0.7, 0.3) for 85% and 65% treatments, respectively. The depth was 30 cm 1st and 2nd irrigations, 45 cm for the 3rd, 60 cm for 4th and 5th and 75 cm for the 6th, 7th, 8th and 9th irrigations, the number of irrigations for both seasons was according to the months of growth (July, August, September, October), as follows (2, 3, 3, 1), respectively. Water use efficiency (WUE): was calculated according to the equation [32].

$$WPI = \Delta Y / \Delta ET$$

where: ΔY and ΔET: represent the increase in the production and evaporation - transpiration, respectively.

Yield Estimate: Grain yield was estimated by harvesting Cones or ears for three lines in the plot which includes seven lines, ears were weighed and counted immediately after harvesting, three representative cones were selected after all being graded, separate of grain and moisture was directly measured using two meters, the first was in the fields (Dickey John) and the second was in laboratory (Foss), yield indices were then calculated using the following:

- Net ratio was calculated using the relationship: (net weight of grains / weight of grains with corn) × 100.
- Grain yield (t / ha) = (weight of harvested grain × (100 - sample moisture) × net ratio × 0.118) / harvested area.
- Biological yield: five whole plants representing the plot were selected and cut from the soil surface and weighed each in the field, ears were then picked and weighed with and without the chaff, cones were separated and grains were weighed without and with ears.
- Leaf area index = leaf area per plant × number of plants per square meter [33], The leaf area per plant = the length of the leaf (ear) × width of the leaf (ear) × 0.75 × number of leaves per plant [34].

Labelled Samples: Whole plant samples were collected (two plants of each Labelled plot with N-15) of all replicates and treatments at the physiological maturity stage which is the stage preceding the final maturity in order to calculate the production of dry matter and determine the total absorbed nitrogen. Plants were separated directly after collection into the main components, which are: stem and cone leaves, weighed and then dried at a 65°C for at least an hour and then re-weighed to determine the coefficients of moisture and thus determine the dry weight based on kg/ha.

The total nitrogen was estimated using wet digestion method (Kjeldahl) and the proportion of enriched isotopic N^{15}/N^{14} was estimated using mass spectrometer, all necessary calculations to determine the percentage of nitrogen in the plant tissues and the Nitrogen derived from fertilizer Ndff and nitrogen derived from soil Ndfs and total nitrogen absorbed N-uptake and utilization rate of the added nitrogen fertilizer N-recovery, for all irrigation treatments and irrigation methods according to the calculation method [35].

Statistical Analysis: Data were analysed using statistical program GENSTAT 7 (ANOVA) to calculate the values of least significant difference (LSD) between the variables at the 5% level of significance.

RESULTS

The Amount of Added Water and Crop Evapotranspiration (Etc): Amounts of irrigation water were added to rainfall, as shown in Table (1) where precipitation was 27 mm during the growing season of 2008 and was not worth in 2007. Total reference evapotranspiration (ET_o) according to the Class A Pan Evaporation was 823 mm during 2007 season and 791 mm during 2008 season. The results showed that the ratio of (ET_c) to the amount of irrigation water added in the single irrigation line per planting line method was about 0.87 and 0.94 for the (PRD) method for the 100% treatment in 2007 season, while this ratio was calculated as 0.82 and 0.92 for the two methods, respectively, in 2008 season. The ratio of (ET_c) to the amount of irrigation water added in the 85% treatment for the two methods was about 0.88 and 1.15, respectively, for 2007 season (plant benefited from pre-existing soil water) and this ratio was 0.84 and 1.1 for the first and second methods, respectively for 2008 season.

Table 1: The average amount of added water and ET of treatments during the two seasons using two irrigation methods

		2007 season		2008 season	
Irri. Treat.	Irri. Met.	The amount of added water (mm)	ET (mm)	The amount of added water (mm)	ET (mm)
100%	1	623	543	664	545
	2	356	335	404	370
85%	1	447	392	482	404
	2	255	292	300	309
65%	1	212	276	240	302
	2	121	214	162	231

1: one irrigation line per planting line. 2: the partial root zone drying (PRD)

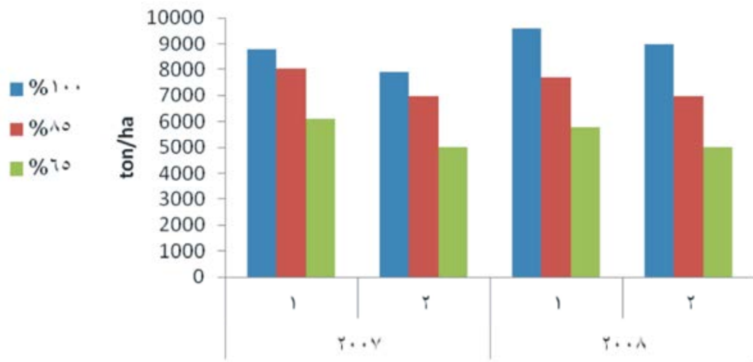

Fig. 1: Grain yield of maize using a single irrigation line per planting line and (PRD) methods in Northern Syria for two seasons

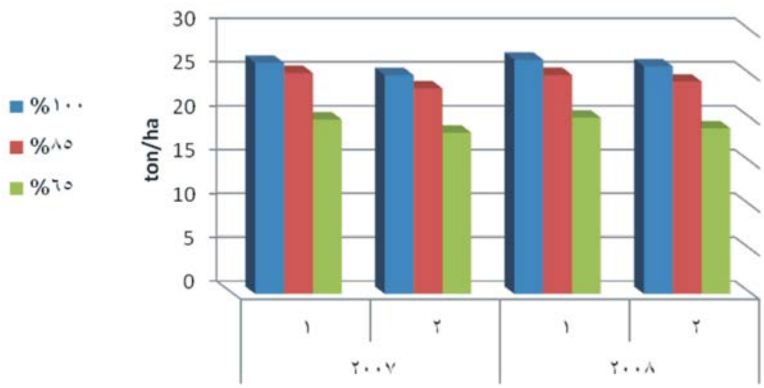

Fig. 2: Biological yield of maize using a single irrigation line per planting line and (PRD) methods in Northern Syria for two seasons

However, in the 65% treatment, the ratio of (ET_c) to the amount of irrigation water added for the two methods was about 1.30 and 1.77, respectively, for 2007 season and this ratio was 1.26 and 1.43 for the first and second methods, respectively for 2008 season. (the plant has also benefited here from pre-existing soil water between 20-75% of water added in this treatment).

Grain Yield: Figure 1 shows the grain yield of maize for two growing seasons, 2007 & 2008 using a single irrigation line per planting line and Partial Root-zone Drying (PRD) methods for irrigation treatments 100%, 85% and 65%. Highly significant differences ($p < 0.001$) in grain yield between the irrigation treatments for two seasons 2007 and 2008 were observed. The irrigation treatment 100% showed superiority over both 85% and 65% treatments and the treatment 85% was superior over the 65%. The least significant difference ($LSD_{0.05}$) was 610 kg/ha. A significant difference $p < 0.001$ between the two irrigation methods was also noted, the yield for the first method: a single irrigation line per planting line and the second: Partial Root-zone Drying (PRD) was (7670 and 6820 kg/ha, respectively) and the least significant difference was 186 kg/ha, whereby the first irrigation method was superior over the second.

Biological Yield: Figure 2 shows the biological yield of maize for two growing seasons 2007 & 2008, using a single irrigation line per planting line and Partial Root-zone Drying (PRD) methods within irrigation treatments. Highly significant differences ($p < 0.001$) in biological yield between irrigation treatments for 2007 and 2008 seasons were observed. The 100% irrigation treatment surpassed both irrigation treatments 85% and 65% and the 85% irrigation treatment surpassed the 65%. The least significant difference was 0.940 t/ha. A significant difference $p < 0.001$ between the single irrigation line per planting line and Partial Root-zone Drying (PRD) methods was also noted (23.89, 22.67 t/ha, respectively), where the first method showed a significant difference over the second and the $LSD_{0.05}$ was 0.420 t/ha.

Leaf Area Index (LAI): Table 2 shows LAI for irrigation treatments for two growth seasons 2007 & 2008, where highly significant differences for LAI between the treatments was observed. It was noticed in 2007 season

Table 2: The significant differences of the leaf area index between irrigation treatments during the two seasons

	Leaf area index	
Irri. Treat.	2007	2008
100%	2.915	3.233
85%	2.866	2.583
65%	2.149	2.081
F pr.	< 0.001	< 0.001
L.S.D $_{0.05}$	0.1424	0.4257

Table 3 The significant differences of the LAI between irrigation methods during the two seasons

	Leaf area index	
Irrigation. Methods.	2007	
A single irrigation line per planting line	2.813	2.772
Partial Root-zone Drying (PRD)	2.473	2.492
F pr.	< .001	0.004
L.S.D $_{0.05}$	0.1666	0.1771

Table 4: The average ETc for the irrigation treatments and the corresponding average production of grain and biological yields for the single irrigation line per planting line

Growing season	Irrigation treatment	(ET) (mm)	Grain yield t / ha	Biological yield t / ha
2007	100%	542	8.774	26.36
	85%	392	8.020	25.21
	65%	276	6.125	19.92
2008	100%	545	9.601	26.72
	85%	404	7.714	25.00
	65%	302	5.800	20.12

that both 100% and 85% irrigation treatments were superior over the 65% treatment, while no significant difference was noticed between 100% and 85% treatments. However, in 2008 the 100% and 85% irrigation treatments were superior over the 65% treatment and the 100% irrigation treatment surpassed the irrigation treatment of 85%.

As for the two methods of irrigation, Table 3 shows the LAI for the two irrigation methods, significant differences between the two irrigation methods were noticed, as the first method surpassed the second method.

Highly significant differences in the leaf area index ($p < 0.001$) for both 2007 and 2008 seasons were also noted, as for the grain and biological yield, the 100% irrigation treatment (3.074) surpassed both the 85% and 65% irrigation treatments (2.725 & 2.115 m^2), respectively and the irrigation treatment 85% surpassed the 65%. The least significant difference was 0.245. A significant difference ($p < 0.001$) between the two irrigation methods was also noticed (2.793 and 2.483 respectively). The LAI was 0.147, whereby irrigation method of a single irrigation line per planting line surpassed the Partial Root-zone Drying (PRD). It was previously found that the LAI ranged between 2.54 and 3.84 and that this index was associated with the level of nitrogen fertilization, taking into account that plant density was 6 plants / m^2 [33].

Relationship between the grain and biological yields and (ETc) and the irrigation method: The rise of 146 mm in evapotranspiration for the treatment of 100% over the 85% in the single irrigation line per planting line as an average of both growth seasons 2007 and 2008, has caused an increase of grain and biological yields by 1.32 and 1.44 t/ha, respectively. Moreover, the increase in ET_c for the 100% treatment over the 65% for the same irrigation method and as an average of both seasonal growth was 255 mm and this caused increases in grain and biological yields of 3.23 and 6.52 t/ha, respectively. While the increase in ET_c for the 85% treatment over the 65% in the same irrigation method and as an average of both seasonal growth was 109 mm which caused increases of 1.91 and 5.08 t/ha in grain and biological yields, respectively (Table 4).

Table 5: The average ETc for the irrigation treatments and the corresponding average grain and biological yields during the two growing seasons for the Partial Root-zone Drying (PRD) method

Growing season	Irrigation treatment	Evapotranspiration (ET) (mm)	Grain yield t / ha	Biological yield t / ha
2007	100%	335	7.918	24.96
	85%	292	6.980	23.47
	65%	214	5.017	18.44
2008	100%	370	8.993	25.95
	85%	329	6.971	24.26
	65%	231	5.024	18.92

Table 6: Water use efficiency (WUE) in grain yield of maize as an average of 2007 and 2008 seasons

	Water use efficiency (WUE) (kg /ha/mm)	
Irrigation treatment	A single irrigation line per planting line	Partial Root-zone Drying (PRD)
100%	12.8	26.3
85%	16.1	21.8
65%	16.2	22.7

Table 7: Percentage of total nitrogen in tissues (T.N) and nitrogen uptake (N uptake) and N-fertilizer use efficiency (FUE)

		65%		85%		100%	
Indicator	Growing season	1	2	1	2	1	2
T.N%	2007	1.5	1.5	1.7	1.6	1.6	1.5
	2008	1.47	1.5	1.5	1.5	1.5	1.5
N uptakeKg/ha	2007	117.2	106.2	162.5	171	141.7	153.7
	2008	162.9	153.4	214.9	210.2	214.4	209.2
FUE%	2007	9.2	5.6	14.4	9.6	17.1	12.5
	2008	10.5	8.3	16.4	12.7	20.6	14.1

However, using PRD method, it was found that the increase in ET_c for the 100% treatment over that for the 85% treatment and based on averaging 2007 and 2008 seasons was 42 mm which produced a grain and biological yield of 1.48 and 1.59 t/ha, respectively. Moreover, the increase in ET_c for the 100% treatment over that for the 65% treatment using the same irrigation method and for the average of the two mentioned growing seasons was 130 mm which produced a grain and biological yield of 3.44 and 6.78 t/ha, respectively. With the same trend, the increase in ET_c for the 85% treatment over that for the 65% treatment using also the same method of irrigation and for the average of the two mentioned growing seasons was 88 mm which produced a grain and biological yield of 1.95 and 5.19 t/ha, respectively (Table 5).

Therefore, it can be concluded that the increase in ETc for the 100% treatment over 85% treatment using PRD method which was 42 mm has produced a grain and biological yield that equals to what was caused by the increase of the ET_c using the single irrigation line per planting line despite that the increase in ET_c of the last method was higher by 350% than the PRD method. However, the increase in ET_c for the 100% treatment over 65% treatment using PRD method which was 130 mm has produced a grain and biological yield produced just a little more than what was produced by the increase in ET_c using the single irrigation line per planting line although the increase in ET_c in the last method was higher by 200% than the PRD method.

Water Use Efficiency (WUE): Table 6 shows that the effect of water use efficiency in grain yield as an average of the two growing seasons 2007 and 2008 for the two drip irrigation methods. It can be seen that 85% & 65% irrigation treatments are the most efficient treatments in the use of water for grain yield using the single irrigation line per planting line, as the 100% treatment was accounted for 0.79 of water use efficiency for both 65% and 85% treatments for the grain yield feature using that method. However, by using PRD method the efficiencies of water use in both 85% and 65% treatments were about 0.82 and 0.86 of the 100% irrigation treatment, respectively. The highest values for water use efficiency in 2007 season were 24.7 and 24.2 kg/ha/mm for both 65% (one irrigation line per planting line) and 85% (PRD) treatments, whilst the lowest value was 11.3 kg/ha/mm for the 100% treatment (one irrigation line per planting line).

For 2008, the highest value was 30.3 kg/ha/mm for the 100% irrigation treatment in the PRD method and the lowest figure was for the 65% and 100% irrigation treatments in one irrigation line per planting line method.

The Efficiency of Using Nitrogen Fertilizer: The average fertilizer use efficiency (FUE) of both 2007 and 2008 seasons (Table 7) for irrigation treatments (100%, 85%, 65%) were (18.8, 15.4, 9.8%) for the first irrigation method and (13.3, 11.2, 7)% for the PRD method. Therefore, the first method was better than the second in terms of (FUE), but regarding irrigation treatments, the 100% and 85% were relatively close on contrary to 65% treatment. The increase in the average ET_c for the 100% over the 85% irrigation treatments were (37%, & 14%) for (the first, & second) irrigation (Tables 4 and 5). This increase caused a rise in (FUE) of (22%, 19%), respectively and the increase in the average ET_c for the 85% over 65% treatments were (38%, 40%) of the irrigation method (first, & second) caused a rise in (FUE) by (56%,& 60%), respectively. Moreover, the increase in the average ET_c for the 100% over the 65% treatments were (88%, 58%) for the (first, & second) irrigation method which caused a 90% rise in (FUE) for both methods. It was concluded that the increase in the average ET_c, which consumed by plants that were irrigated using the first method over the second method and according to irrigation treatments (100%, 85%, 65%) were (54, 28, 30%), which caused rises in the nitrogen FUE by (42, 38, 41%), respectively.

DISCUSSION

It can be concluded from this study that climatic indicators are among the most important factors that explain the ecological conditions surrounding the plant during its growth stages. Looking at some of the aforementioned climate indicators of 2007 and 2008 seasons, it can be pointed out that the contrast in temperatures and evaporation and wind speed between the two seasons was very slight. However, the contrast in relative humidity was considerable between both seasons. The daily averages of temperature during the growing months were close except for October 2007 which was 2°C higher in the 2008 season. Furthermore, average monthly wind speed of October in the 2007 was higher by 0.4 m/ s than 2008. This has reflected on the evaporation from Class A Pan, with a difference which was higher for the monthly average by 2.4 mm in 2007 compared by 2008 season and the average monthly relative humidity of October 2008 was higher by about 16% than that of the 2007 season. The amount of water added to the 65% irrigation treatment of both 2007 and 2008 seasons average was about 228.7 mm, taking into account that the crop evapotranspiration under a single irrigation line per planting line was accounted for 123% of irrigation water added, where the plant absorbed existing soil water, which is desperately needed for this treatment, gradually through the growth and development stages in addition to deepening the root system, whereas the amount of water added using the same irrigation method and for the 100% and 85% treatments, were 643.5 and 464.4 mm, respectively and the ratio of crop evapotranspiration for both treatments and for 2007 and 2008 seasons' average was 83%. [36] found that the amount of water used for the treatment of full drip irrigation for the same crop was 677 mm and for the 100% treatment of PRD was 438 mm). However using PRD method and as for both 2007 and 2008 seasons' average it was noticed that although the added water for the 65% treatment was 142 mm, evapotranspiration was 155% of this amount, i.e. the plant resorted to the same previous behaviour (absorbed existing soil moisture) to compensate for its need of water in which deficit was larger.

The relationship between crop evapotranspiration and the grain yield can be summarized by studying 2007 and 2008 seasons' average and for the same irrigation method (single irrigation line per planting line). It can be concluded that the (ETc) were (546, 398, 279) mm and the grain yield was (9190, 7870, 5960) kg/ha for irrigation treatments (100, 85. 65%), respectively. Yazar *et al.* [36] found that the highest grain yield was obtained from full irrigation of 10.4 T/ ha, while the 100% treatment of PRD produced 7.74 t/ha. Hence, it can be concluded that the amount of ETc of one hectare where the 100% treatment was applied can irrigate (1.4 and 2 ha) If the 85%, 65% irrigation treatments were applied, leading to an increase in the production of about (1.80, 2.73 t/ha), respectively. However, the ETc for one hectare of the 85% treatment will cover 1.4 hectares if the 65% irrigation treatment was applied and the increase of production would be about 0.47 t/ ha. The amount of water added to the 2007 and 2008 seasons' average using (PRD) method were about (380, 278, 142) mm and the average ETc for the two seasons together were 92%, 111% .155% of the added water, respectively. Hence, at both 85% and 65% irrigation treatments, the plant had benefited from the water already available in the soil but with the variation of different stages. It was found that ETc in PRD method formed about (0.46 and 0.78) of ET_c when applying the single irrigation line per planting line method and for both irrigation treatments (100 & 85%), respectively as an average of the two

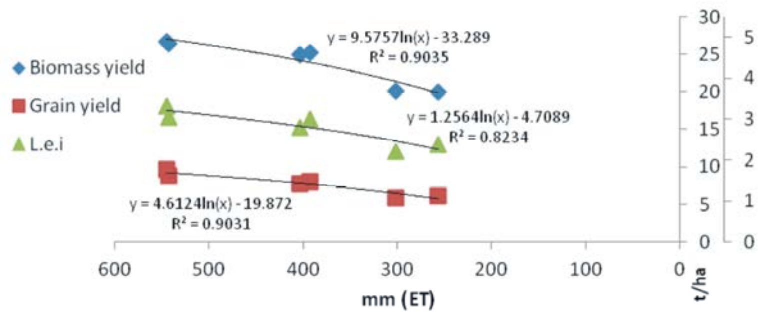

Fig. 3: Etc relation to grain and biomass yields, and LAI for 2007 and 2008 using single irrigation per planting

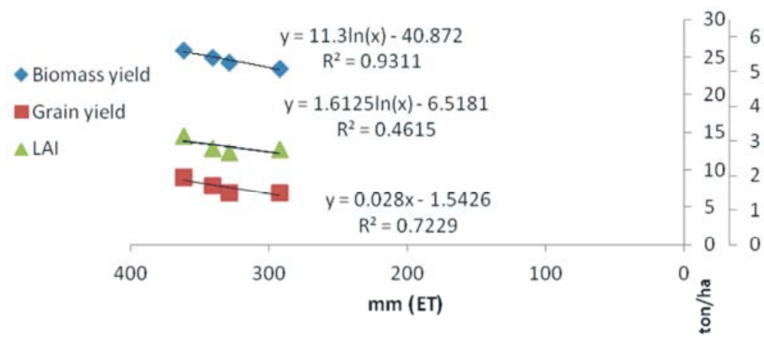

Fig. 4: Crop ET relation to grain and biomass yields, and Leaf area index for 2007 and 2008 using Partial root-zone drying (PRD)

seasons 2007 and 2008, despite the fact that the production of grain yield was (0.92, 0.88)% of the production of the single irrigation line per planting line method. To discuss the superiority of the PRD method over the other method using a different approach, it can be noticed that if the released ET_c using the single irrigation line per planting line method was used and released by adopting the PRD method, the yield, as the average of the two seasons 2007 and 2008, would have increased by (42, 12, 6%) more than the first method, for irrigation treatments (100, 85, 65%), respectively. The relation between the grain yield and the ET_c would vary according to the irrigation method used; it was noticed that this relationship differs between the single irrigation line per planting line method and the PRD irrigation method, as it is a logarithmic relation in the first method (Fig. 3), but it is a linear relationship in the second method (Fig. 4). Logically, when ET_c increases there will be an increase in production as long as the potential energy of the crop allows that, but this increase varies from one irrigation method to another; as when the average ET_c is 546 mm in the single irrigation line per planting line for 2007 and 2008 seasons, the average grain yield was about 9.187 t/ha, but if the ET_c in the PRD method was 546 mm, grain yield will be 13.,75 t/ha, i.e. an increase in production of 49% over the first method . However, if the ET_c was raised to be 650 mm, grain yield would be 10.0 t/ha for the first method and 16.66 t/ha for the second irrigation method, which means an increase in the production of the second method by 66%. This confirms the results of Du *et al.* [37] where using this method a saving of 31-33% of water was achieved when compared with the traditional drip irrigation method while maintaining almost the same production in cotton crop.

In regards of the biological yield, its relation with the ETc was a logarithmic relationship in both irrigation methods, but there is a variation in the yield dissimilar to that of grain yield; as when the average ET_c was 546 mm in the single irrigation line per planting line method for 2007 and 2008 seasons, the average biological yield was about 26.54 t / ha and for the same amount of crop evapotranspiration in PRD method, biological yield was 30.35 t/ha, which means that the percentage in production increase was 14% over the production of the first method. Hence, if the ETc was raised to be 650 mm, biological yield would be 28.73 t/ha for the first method and 32.32 t /ha for the second irrigation method, which means an increase in the production of the second method by only 12%. The relation of ET_c with the LAI of both irrigation methods are shown in Figures 3 and 4, where in Figure (3) and according to the logarithmic equation and for the single irrigation line per planting line and when exceeding the second hundred of ETc (300-800), a decline in the rates of increase of LAI was noticed as follows (26, 15, 9, 7, 6, 5%) and this decline was not only for the first irrigation method, but also for the (PRD) irrigation method which was as follows (24, 20, 15, 14, 12, 11%), respectively. The decline in the rates of increase of LAI was more consistent with the decline in the rates of increase of biological yield than that in grain yield. The highest (WUE), as shown in Table 4 and as an average of both seasons, was 26.3 kg/ha/mm for the 100% irrigation treatment using PRD method when compared to both 85% and 65% treatments, which were both somewhat close to each other, whereas that the 85% and 65% treatments were higher than the 100% treatment for the single irrigation line per planting line reaching water use efficiency of 21.8 and 22.7 kg / ha/ mm, respectively. Carrying out a simple comparison, it can be noticed that water use efficiency in PRD method has increased by 105%, 35% 40% for 100%, 85%, 65% irrigation treatments respectively, more than the first method and this confirms what has been achieved by Kang and Zhang [12] and Yazar *et al*. [36], where the highest figure and for the same irrigation method was 1.77 kg / m^3. Accordingly, using PRD method has improved water use efficiency by 120% when compared with the highest figure in the single irrigation line per two planting lines.

Fertilizer use efficiency was higher in the single irrigation line per planting line than in the PRD method and for all irrigation treatments and this confirms the results of an experiment that was carried out in China on maize in a greenhouse environment, that the recovery rate of nitrogen fertilizer in applied partial root zone irrigation (APRI) was higher than the non-irrigated half of a partial irrigation method of one side (one half) of the roots, but this ratio was less than the irrigated area using a traditional drip irrigation [38]. It was also stressed that nitrogen fertilizer use efficiency in corn increases as the frequency of drip irrigation get closer in 10 leaves stage until the emergence of inflorescences [39].

The controlled alternate partial root-zone irrigation (CAPRI) or the partial root-zone drying (PRD) is a new irrigation technique that can be used to improve water use efficiency (WUE) of crop production without a significant decrease of production and this was confirmed by the results of Hammid *et al*. [40] where the use of this method (PRD) can be proposed as a New alternative irrigation system for large areas with limited water and this was also confirmed by Du *et al*. [37] where alternate partial root zone irrigation is considered very good for saving water in cotton fields that largely suffer from water resources shortage.

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