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Application of Some Drought Stress Indices to Study Response of Durum Wheat *Triticum durum* to Different Levels of Water Depletion

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ABSTRACT

A pot experiment was conducted to investigate the effect of five levels of soil water depletion from field capacity (30, 40, 50, 60, and 70%) on some growth, yield and yield components of durum wheat (***Triticum durum* L.)** VAR-ACSAD/65, with testing ten stress and drought indices to indicate the suitable index that could be simply used to interpret drought stress conditions. Results indicated significant effect of soil water depletion levels on wheat plant height, tillers per plant, spikes per plant, spike length, and total chlorophyll content, increasing water depletion levels decreased all recorded data. The effect on spike numbers per plant; spike length; number of seeds per spike; 1000 seeds weight (gm); seed yield per plant; straw yield per plant; biological yield per plant and harvest index were negatively dependent on drought stress to the level of no seed yield under the highest water depletion level 70%. Drought indices could classify to three categories; unity to zero, zero to higher value, high values to lower values. The relationship between drought indices were either positive or negatively correlated to plant seed yield. All studied crop drought indices were suitable for studying crop drought cases. The wheat variety acsad/65 was sensitive to drought stress.

NTRODUCTION

Wheat a universally grown crop that is consumed for human food and animal feed. Wheat plants are divided into two major groups bread wheat (hexaploid) and Durum wheat (tetraploid). The predicted global demand for wheat in the 2020's may reach 1,050 million tons (Lantican et al., 2002, Figueroa et al., 2018), while in developing countries the mandate will be 60%higher by 2050, but simultaneously wheat production might decreased due to climate change (Manickavelu et al., 2012). Iraqi Kurdistan region wheat crop area is more than 700,000 hectares with majority of rain-fed area, which depends on annual precipitation that, ranges between 375-724 mm. (Mohammed, 2012). Drought stress is considered as the main abiotic environmental factor that decreases wheat plants growth and yield (Rampino et al., 2006). Drought is a meteorological idiom that defines as "The chief characteristic of a drought is a decrease of water availability in a particular period over a particular area" (Hisdal et al., 2000). Drought stress is the main limiting factor of cereal rain-fed crops production in Iraqi Kurdistan region. Wheat yield in the region rises according to the improved production facilities, but still the main obstruction is fluctuation of

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annual precipitation amount and periods during the critical crops growth stages (Araus et al., 2002). Progressive retort of plants to avoid or tolerate drought effect is maximizing root: shoot ratio or deeper root architecture (Sharp et al., 2004), abscisic acid and proline accumulation in leaves (Agul Sh, 2011, Ruan et al., 2004), maintaining stomatal closure and decline of relative water content (Ahmed and Ali, 2015, A Mahmood et al., 2005), increasing antioxidant enzymes that related to decrease of chlorophyll content (Zaefyzadeh et al., 2009). Drought indices are an essential appliance for evaluating plant growth under water depletion conditions. Agricultural drought indices were first introduced by palmer in 1965 as palmer drought index or sometimes it is called palmer drought severity index (PDSI) that needs four inputs to be calculated (Temperature, precipitation, location latitude and available water capacity) (Palmer, 1965). Crop moisture index (CMI) was presented as an attempt to focus on evapotranspiration rather than precipitation, it is calculated as the difference between actual and potential evapotranspiration (Palmer, 1968). Soil moisture drought index (SMDI) was proposed to indicate the quantity of water needed to keep the soil moisture at field capacity state according to precipitation, temperature, and soil moisture (Hollinger et al., 1993). Crop specific drought index (CSDI) was presented to investigate the rain-fed crops growth under different precipitation amounts (Meyer et al., 1993). Whereas for crop and drought studies there were different models to investigate the crop response to drought stresses and the pioneer model was Drought susceptibility index (DSI) that was proposed to indicate the susceptibility of a studied crop to drought stress based on the differences between the yield in stressed and non-stressed environments (Fischer and Maurer, 1978). Drought intensity index (DII) was introduced to indicate the severity of drought effect by subtracting the sum of crop yield under drought stress divided by non-stressed crop yield from unity (Blum et al., 1989, Szilagyi, 2003). Mean Productivity (MP) was advised to study the mean yield in both conditions stressed and non-stressed situations and in the same paper another equation was advised Tolerance index (TI) to indicates the difference between both crop yields in two conditions (Rosielle and Hamblin, 1981). Stress tolerance index was studied by (Schneider et al., 1997) to indicate the tolerance index for stressed plants. Yield Stability Index (YSI) was submitted estimate the yield of the same genotype in stressed and non-stressed environments (Rosielle and Hamblin, 1981). Yield index was used by (Gavuzzi et al., 1993) to compare the yield of stressed plants with the mean of all stressed plants. Geometric yield productivity was assumed to indicate the yield of stressed and non-stressed plots (Fernandez, 1993). Harmonic mean was proposed by (Anwar et al., 2011) to study the yield harmony in stressed and non-stressed plants. This study was conducted to evaluate the effect of water depletion on some growth, yield, and yield component traits and the efficacy of some drought indices to physiological consequences of drought stress on durum wheat Acsad 65.

MATERIAL AND METHODS

1) Study Site: The experiment was conducted on the fields of Erbil Agriculture Research Directorate centre during 2016-2017 wheat growing season in the glass-house.

2) Experimental design: The completely randomized experiment consisted of five treatments; 30, 40, 50, 60, and 70% depletion from field capacity, with three replications.

3) *Agronomical practices:* Plastic pots 4kg capacity were used in this study. The soil was brought from the field of erbil research directorate in ainkawa county. The soil texture was silt clay with pH 7.80, organic matter 1.13%, Electrical conductivity 0.35ds. m^{-1}, nitrogen 0.11%, phosphorus 7.3 ppm and potassium 270 ppm. Field capacity 0.305 and permanent wilting point 0.141 was estimated according to pressure plate method (Cassel and Nielsen, 1986) . Each pot was filled with 3.500 kg of dried soil that was kept in oven 65C° for three days. All pots were irrigated by adding 980ml of water to reach field capacity on the 8^{th} of December 2016, then 8 seeds of durum wheat Acsad 65 was sown in each pot with the 4 cm depth on the 28^{th} of December 2016. After 20 days from sowing the pots were subjected to the water depletion levels program according to an electrical balance that each pot was weighted daily then irrigated at the depletion level by adding water to the located weight for ensuring the field capacity depletion level (Table-1). Foliar applied liquid fertilizer was sprayed for all pods to guarantee the same nutrition level for all moisture depletion levels. On the 20^{th} of may the wheat plant were harvested.

Table 1 Total Information on Each Pot Added Water During This Study

Treatment	weight of pot (kg)	weight of soil (kg)	water added ml	Total pot weight (kg)	added water of depletion level (ml)	Total pot weight (kg)	Irrigation Times to reach field Capacity	Total added water for pot (ml)
30%	0.255	3.500	980	4.735	294	4.440	36	10584.00
40%	0.255	3.500	980	4.735	392	4.343	25	9800.00
50%	0.255	3.500	980	4.735	490	4.245	17	8330.00
60%	0.255	3.500	980	4.735	588	4.147	12	7056.00
70%	0.255	3.500	980	4.735	686	4.050	6	4116.00

4) *Data Recording*: Wheat plants flag leaf ‘s total chlorophyll were documented on the 6th of april 2017 by atLEAF instrument (Blackburn, 1998). Other recorded parameters were plant Height (cm); number of tillers per plant; spike numbers per plant; spike length; number of seeds per spike; 1000 seeds weight (gm); seed yield per plant; straw yield per plant; biological yield per plant and harvest index (equation-1) (Hay, 1995). Seed proline content was estimated according to (Bates et al., 1973, Carillo and Gibon, 2011) .

$$\text{Harvest Index} = \left(\frac{\text{Seed Yield}}{\text{Biological Yield}}\right) \times 100 \qquad \dots\dots\dots\dots..(1)$$

5) *Drought Indices*: Nine drought indices (Table- 2) were calculated to indicate the values of different drought indices such as drought intensity index (DII) (Blum et al., 1989, Szilagyi, 2003), Mean productivity (MP), Tolerance index (TI) and Yield stability index (YSI) (Rosielle and Hamblin, 1981), Drought stress susceptibility index (DSI) by two equations (Fischer and Maurer, 1978), Yield index (YI) (Gavuzzi et al., 1993), Stress tolerance index (STI) (Schneider et al., 1997), Geometric mean productivity (GMP) (Fernandez, 1993), harmonic mean (HARM) (Zahravi, 1999).

Calculated in The Study Table- 2 Different Drought and Stress Indices		
Equation Number	**Drought stress Index**	**Equation**
1	Stress Intensity (SI)	(YS/YP)
2	Drought intensity index (DII)	[1-(YS/YP)]
3	Mean productivity (MP)	(YP+ YS)/2
4	Tolerance index (TI)	(YP -YS)
5	Yield stability index (YSI)	(YS/ŶP)
6	Drought stress susceptibility index (DSI)	[1-(YS /YP)] / [1- (ŶS / ŶP)]
7	Yield index (YI)	(YS/ŶS)
8	Stress tolerance index (STI)	$(YP\times YS)/(\hat{Y}P)^2$
9	Geometric mean productivity (GMP)	$(YP\times YS)^{1/2}$
10	harmonic mean (HARM)	2(YP×YS)/(YP+YS)
YS is the yield of cultivar under stress YP is the yield of cultivar under irrigated conditions ŶS is the mean yield of all cultivars under stress ŶP is the mean yield of all cultivars under irrigated conditions		

6) *Statistical analysis:* All recorded data were subjected to standard analysis of variance and means were compared using Duncan Multiple Range Test (DMRT) at 5% of probability using SPSS computer analysis version 22 according to (Weinberg and Abramowitz, 2008) and(Landau, 2004).

RESULTS & DISCUSSION

1. Effect of Water Depletion levels on Some Growth Characteristics of Durum Wheat (Triticum durum L.) VAR/ ACSAD/65: Water depletion levels imposed significant effects on recoded data of vegetative growth of Acsad/65 durum wheat as shown in table (3). The highest plant height was (84.00 cm) recorded with 30% depletion, while the lowest plant height was (41.33 cm) with 70%water depletion level. The number of tillers per plant was at maximum level (2.20 tiller. plant^{-1}) in the lowest water depletion level 30%, meanwhile the highest water depletion level 70% decreased tiller numbers to only (1 tiller. plant^{-1}). The highest number of spikes per plant was (1.63 spike. plant^{-1}), while the lowest data of spikes per plant was (0.55 spike.plant^{-1}) recorded under 70% depletion of water. These results concerning wheat height may be related to decrease of plant cell turgidity and minimizing cell division and expansion (Blum and Sullivan, 1997). Tillers number indicate that the plant suffered from water depletion that causes decline of fertile tillers number (Ahmadizadeh et al., 2011). Total chlorophyll was at the peak (57.07 atLEAF) in flag leaf of wheat plants that were subjected to 30% water depletion level, but it was at the lowest record (49.46 atLEAF) under 70% water depletion level. This result may be due to that 70% water depletion causes alteration of chemical reactions which forms chlorophyll molecules (Keyvan, 2010, Sadras and Calderini, 2009). Spike length was at maximum level (6.18 cm) under lowest water depletion 30%, while minimum length was (2.48 cm) under strongest water depletion 80%.

This data indicated the importance of water as raw material for all biochemist processes in plants (Ahemd and Ali, 2015).

Table-3 Effect of Water Depletion levels on Some Growth Characteristics of Durum Wheat (Triticum durum L.) VAR- ACSAD/65.

Treatment	plant height (cm)	(Tillers. Plant^{-1})	(Spike. Plant^{-1})	chlorophyll (atLEAF)	spike length (cm)
30%	84.00 a	2.20 a	1.63 a	57.07 a	6.18 ab
40%	79.77 b	1.57 b	1.33 b	53.58 b	5.78 b
50%	76.89 b	1.33 c	1.17 c	52.60 b	5.05 c
60%	72.00 c	1.17 d	1.00 d	51.47 bc	4.83 c
70%	41.33 d	1.00 e	0.55 e	49.46 c	2.84 d
Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.05 based on multiple range test of Duncan.					

2. Effect of Water Depletion levels on Some Yield and Yield components of Durum Wheat (Triticum durum L.) VAR/ ACSAD/65: The Effect of water depletion levels were significant on all recorded yield and yield components data (Table- 4). Highest observed data for seeds per spike, Seed yield per plant, Straw yield per plant, Biological yield per plant, and harvest index were (40.57 gm, 11.17 gm, 24.62 gm, 35.80gm, and 31.20%) respectively under the lowest water depletion level 30%. The lowest values for all previously mentioned data were zero except straw and biological yield was (3.14 gm). Thousand seeds weight was at maximum weight 57.14 gm when the depletion level was 30% and the minimum weight was zero with the highest depletion level 70%, it is worth mentioning that there were no significant differences between three depletion levels 30, 40, and 50%. These results indicate the importance of water for plants growth and yield because it provides the plant with energy through photosynthesis, so when there is deficiency of water there will be inhibition of photosynthesis light reactions that extend to cell membrane damage due to dehydration (Raza et al., 2014, Lambers et al., 2008).

Table-4 Effect of Water Depletion levels on Some Yield and Yield component Characteristics of Durum Wheat (Triticum durum L.) VAR- ACSAD/65.

Treatment	Thousand Seeds Weight (gm)	Seed yield. Plant^{-1} (gm)	(Straw yield. Plant $^{-1}$)	(Biological yield. Plant^{-1})	(Harvest index)
30%	**57.14 a**	**11.17 a**	**24.62 a**	**35.80 a**	**31.20 a**
40%	**57.03 a**	**5.96 b**	**16.45 b**	**22.41 b**	**26.48 ab**
50%	**55.06 a**	**2.92 c**	**11.22 c**	**14.14 c**	**21.70 b**
60%	**43.01 b**	**2.51 c**	**8.44 d**	**10.96 d**	**23.38 b**
70%	**0.00 c**	**0.00 d**	**3.14 e**	**3.14 e**	**0.00 c**
Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.05 based on multiple range test of Duncan.					

3. Effect of Water Depletion levels on Proline content of Durum Wheat (Triticum durum L.) VAR/ ACSAD/65: The proline content were significantly affected by water depletion levels (figure-1) and the lowest proline content was (0.34 µg. g^{-1}) in wheat seeds under 30% water depletion level and the highest proline content in wheat seeds was (2.08 µg. g^{-1}) under 60% water depletion. It is worth mentioning that in the highest water depletion level 70% there wasn't any seed yield so we neglected the data for this reason. It was suggested that free proline accumulation according to water stress serves as osmotic adjustment and storage of carbon and nitrogen. Proline acts as a free radical that prevent cell damage by free radicals due to its opposite concentration relation with water(Keyvan, 2010, Ahmed and Ali, 2015).

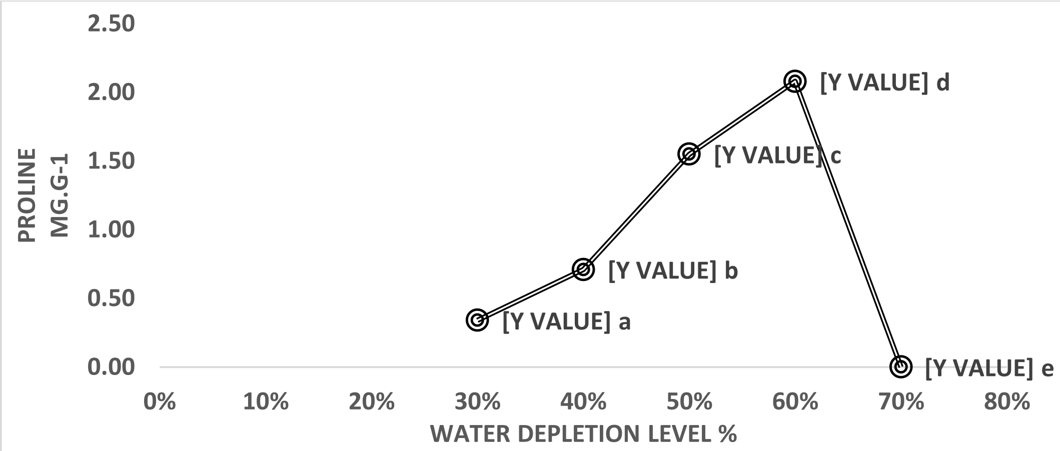

Table-5 Effect of Water Depletion levels on Some Stress and Drought Indices of Durum Wheat (Triticum durum L.) VAR- ACSAD/65.

Figure- 1 the wheat seeds proline content under water depletion levels.

Water Depletion Level	Stress Intensity Index (SII)	Yield Stability Index (YSI)	Stress Tolerance Index (STI)	Drought Intensity Index (DII)	Stress Susceptibility Index (SSI)	Tolerance Index (TI)	Yield Index (YI)	Mean Productivity (MP)	Geometric Mean Productivity (GMP)	Harmonic Mean (HARM)
30%	1.00	1.00	1.00	0.00	0.00	0.00	4.90	5.59	11.17	11.17
40%	0.54	0.46	0.53	0.46	0.60	5.21	2.62	2.98	8.10	7.67
50%	0.28	0.24	0.28	0.72	0.94	8.07	1.36	1.55	5.87	4.84
60%	0.23	0.19	0.23	0.77	1.01	8.66	1.10	1.26	5.18	4.10
70%	0.00	0.00	0.00	1.00	1.31	11.48	0.00	0.00	0.00	0.00
R^2	0.92	0.87	0.91	0.92	0.92	0.92	0.91	0.91	0.94	0.97

4. Effect of Water Depletion levels on Some Drought Indices: Studied drought indices in this study were classified according to unity or non-unity values where three indices such as stress intensity index, yield stability index, and stress tolerance index the highest value are (1) so the higher the index value till unity the stronger the index indicator. Stress intensity index the lower the index value more sever stress condition faces the plant under study (Table- 5). While with yield stability index the lower the index value demonstarts higher drought effects on yield and the (0) data means no seed production under 70% water depletion. Stress tolerance index postulated the wheat plant tolerance for drought conditions and the lower the value the weaker the plant (Fischer and Maurer, 1978, Ramirez-Vallejo and Kelly, 1998).

Drought intensity index reveals that increasing the value above zero indicates the intense of drought stress and when there was no yield as a response to drought stress the data will be (1). For both indices stress susceptibility index and tolerance index it was clear that the higher the value of the index the stronger the stress impact. Yield index was measured to indicate the yield loss due to the drought impact and the results ensures the complete influence of drought, worth mentioning that there was no yield under 70% water depletion. Mean productivity equation was designed to indicate the productivity based on stressed and non-stressed yield so the lower the value the heavier the impact of drought on wheat plant yields. Geometric mean productivity and harmonic mean were recorded and it was obvious that the highest values were for no stress wheat plants and the severer the drought the lower the value of these two indices till zero (Shahrabian and Soleymani, 2014, Akçura et al., 2011, Boussen et al., 2010, Łabędzki and Bąk, 2014).

Table-6 Correlation between plant seed yield of Durum Wheat (Triticum durum L.) Var ACSAD/65 and some studied Drought indices.

(seed yield. plant)	*(DII)*	*(SI)*	*(MP)*	*(TOL)*	*(YSI)*	*(SSI)*	*(YI)*	*(STI)*	*(GMP)*	*(HARM)*
1.00										
-1.00	**1.00**									
1.00	**-1.00**	**1.00**								
1.00	**-1.00**	**1.00**	**1.00**							
-0.04	**0.07**	**-0.07**	**-0.04**	**1.00**						
0.99	**-0.99**	**0.99**	**0.99**	**0.03**	**1.00**					
-0.99	**0.99**	**-0.99**	**-0.99**	**0.06**	**-0.99**	**1.00**				
1.00	**-1.00**	**1.00**	**1.00**	**-0.04**	**0.99**	**-0.99**	**1.00**			
1.00	**-1.00**	**1.00**	**1.00**	**-0.03**	**1.00**	**-0.99**	**1.00**	**1.00**		
0.94	**-0.94**	**0.94**	**0.94**	**-0.26**	**0.92**	**-0.93**	**0.94**	**0.94**	**1.00**	
0.98	**-0.97**	**0.97**	**0.98**	**-0.21**	**0.96**	**-0.97**	**0.98**	**0.97**	**0.99**	**1.00**

Correlation data (table-6) indicates strong positive relationship between seed yield and values of stress intensity, mean productivity, yield stability, yield index, stress tolerance index, geometric mean productivity and harmonic. Negative relationship was observed between seed yield and values of drought intensity index, tolerance index, and stress susceptibility index (Ajalli and Salehi, 2012). It was obvious from these results that we could calculate the response of a crop to drought environment according to the yield and if we assume the average precipitation based on irrigated water amount to each pot the range will be 473.66, 304.58, 176.06, 105.26, and 30.55 mm for one season and from table (1) have the irrigation frequency which declared the importance of rain fall .

during the season so we have highest yield under 30% which were higher than other levels. According to water stress coefficient guide when the yield response factor is lower than unity, so the crop genotype is tolerant to drought, relative yield decrease and relative evaporation deficit was calculated according to equation (2), where Ky is the Yield response factor, Ya is yield in actual stress level, Ymax is the yield under no stress condition, ETa is actual evapotranspiration from watering amount in table (1), and ETmax is the maximum evapotranspiration in no stress condition (Allen et al., 1998). The yield response factor in this study was 1.22 so the wheat variety is susceptible to drought (Najarchi et al., 2011).

$$\left(1-\frac{Ya}{Ymax}\right) = Ky\left(1-\frac{ETa}{ETmax}\right) \qquad \ldots\ldots\ldots\ldots.. \ (2)$$

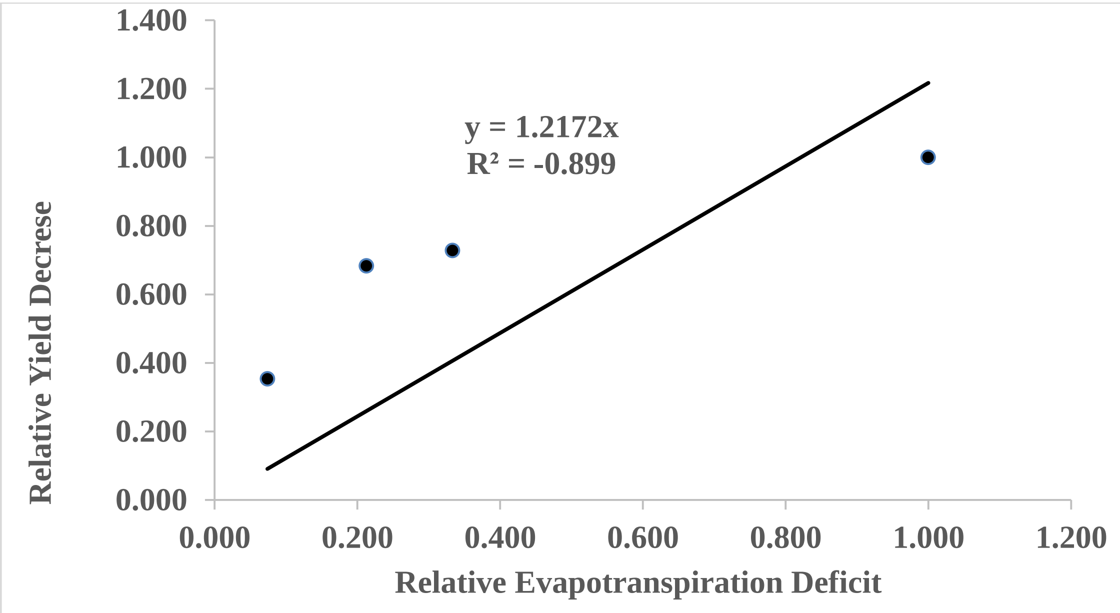

Figure 2 The Yield Response Factor Under Five Levels of Depletion from Field Capacity

CONCLUSION:

Wheat growth and yield characteristics were highly dependent on water depletion, increasing depletion level decreased studied characteristics to completely yield loss under 70% water depletion. Proline accumulation in seeds were increased according to elevation of water depletion observed. Drought indices values indicated the severity of growth and yield conditions that faces the plant. We can classify drought indices to three groups, first group start from unity to zero value includes (STI, YSI, and STI); second group starts from zero higher values including (DII, SSI, and TI); third group start from high value to zero or lower value include (YI, MP, GMP, and HARM). The spring durum wheat variety Acsad 65 was sensitive to drought in this study. Future studies are recommended to evaluate proposed suitable indices under natural conditions and compare it with pot plants to suggest the suitable index for wheat drought stress.

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تطبيق بعض مؤشرات الاجهاد الناتج عن الجفاف لدراسة استجابة الحنطة الخشنة Triticum durum لمستويات مختلفة من انخفاض رطوبة التربة

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(المستخلص)

أجريت تجربة سنادين لدراسة تأثير خمسة مستويات لانخفاض الرطوبة من السعة الحقلية (30 ، 40 ، 50 ، 60 ، 70٪) على بعض صفات النمو والحاصل ومكوناته للحنطة الخشنة (Triticum durum L.) صنف أكساد -65، اختبرت الدراسة عشرة دلائل خاصة بلاجهاد والجفاف للإشارة إلى الدليل المناسب الذي يمكن استخدامه ببساطة لتفسير ظروف الشد الناتج عن الجفاف. أشارت النتائج إلى وجود تأثير معنوي لمستويات انخفاض الرطوبة على ارتفاع نبات الحنطة ، عدد الآشطاء لكل نبات ، وعدد السنابل لكل نبات ، وطول السنبلة ، ومحتوى الكلوروفيل الكلي. حيث أدت زيادة استنزاف الرطوبة إلى انخفاض جميع البيانات المسجلة لعدد السنبلة لكل نبات ؛ طول السنبلة، عدد البذور في السنبلة ؛ وزن 1000 بذرة (جم) ؛ حاصل البذور لكل نبات ؛ حاصل القش لكل نبات ؛ اعتمد الحاصل البيولوجي لكل نبات و دليل الحصاد بشكل سلبي على إجهاد الجفاف إلى الحد الذي انعدم فية انتاج البذور تحت ظروف أعلى مستوى لآستنفاذ الرطوبة 70٪. يمكن تصنيف دلائل الجفاف إلى ثلاث فئات ؛ من قيمة الواحد إلى الصفر ، والصفر إلى القيمة الأعلى ، والقيم العالية إلى القيم الأدنى. كانت العلاقة بين دلائل الجفاف موجبة أو سلبية مع حاصل بذور للنبات الواحد. كانت جميع دلائل جفاف المدروسة مناسبة لدراسة حالات جفاف المحاصيل بشكل عام. و اتضحت من النتائج و احتساب عامل استجابة الحاصل للحنطة صنف أكساد / 65 انه كان حساساً لإجهاد الناتج عن الجفاف.

الكلمات المفتاحية: دليل الشد الناتج عن الجفاف، برولين، معدل انتاجية الهندسي، معدل التناسق