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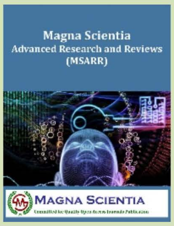

(Research Article)

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Evaluation of durum wheat advanced lines and cultivars under different irrigation regimes

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Abstract

Twenty six durum wheat advanced lines and four commercial cultivars were evaluated under two, three, and four irrigation regimes (a total of 44, 56, and 70 cm of water applied, respectively) at the Norman E. Borlaug Experimental Station, Sonora, Mexico, during the fall-winter 2021-2022 crop season. The plot size consisted of two beds five meters long with two rows and separated by 80 cm. Sowing was carried out on December 15, 2021, in dry soil at the rate of 100 kg ha^{-1}. The experimental design used was alpha lattice with three replications. The analysis of variance was performed with SAS and the mean comparison with the LSD test ($p \leq 0.05$). The entire experimental plots were harvested with a wintersteiger type Nr:1540-46 classic cereal thresher. The variables evaluated were: days to flowering, plant height (cm), days to physiological maturity, and grain yield (kg ha^{-1}). Highly significant statistical differences were detected between the number of irrigations and between the genotypes evaluated; the highest grain yield was obtained with four complementary irrigations with an average of 8,428 kg ha^{-1}, followed by three irrigations with 7,709 kg ha^{-1}, and two irrigations with 6,788 kg ha^{-1}. The advanced lines BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/12/ARTICO/AJAIA_3//HUALITA/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR84/3/HUI/P and TJILKURI/3/BARJ/PAGA_2//MARA_1/BARNACLA_1/5/MOHAWK/AYSR_1/4/RCEE_2/CMOS_3/3/GUAYACAN INIA/GUANAY//FUMA_5 showed average grain yields greater than 8 t ha^{-1}, with 8,092 and 8,059 kg ha^{-1}, respectively, while commercial cultivars CIRNO C2008, Don Lupe C2020, CENEB Oro C2017, and Noroeste C2021, showed 7,110, 7,663, 7,819, and 7,947 kg ha^{-1}, respectively. The overall grain yield average was 7,641.5 kg ha^{-1}. Minor differences were detected in days to flowering which had a range of 72-77 days with an average of 75.2, days to physiological maturity with a range of 115-120 and avg of 116.9, and plant height with a range of 83-93 cm and avg of 87.5 cm.

Keywords: Durum wheat; *Triticum durum*; Irrigation regimes; Grain yield

1. Introduction

Wheat (*Triticum* spp.) is one of the three basic cereal grains more important worldwide, which along with rice (*Oryza sativa* L.) and maize (*Zea mays* L.) make up part of the human diet, contributing with about one fifth of the total caloric intake as well as proteins [1,2]. Wheat is cultivated in approximately 220 million ha, being China, India, Rusia, and the United States the main producers [3]. Mexico ranks 29 in worldwide production with 3,862,914 million t. In Mexico, wheat is an essential cereal in the population diet, due to its nutritional contribution and low cost, available to low

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income people in rural and urban areas [4]; wheat production is carried out under irrigated and rainfed conditions, and almost 90% of the production is concentrated in the states of Sonora, Guanajuato, Sinaloa, Baja California, Jalisco, and Chihuahua [5]. During the 2020-2021 fall-winter crop season, the area sown with wheat nationwide was 475,000 ha with an average grain yield of 6.61 t ha^{-1} and a production volume of 3.14 million t [5]. In the state of Sonora, 236,472 ha were harvested with an average grain yield of 7.28 t ha^{-1} and a production of 1.72 million t, which represented 55% of the total national production [5]. CIRNO C2008 a durum wheat (*Triticum durum* Desf.) [6], is the most widely grown cultivar in the state of Sonora [7], however, during the crop season 2016-2017, the new race of leaf rust (*Puccinia triticina* E.) BBG/BP_CIRNO overcame the genetic resistance of this cultivar [8], which was conferred by the gene LrCamayo in chromosome 6BL [9]. In greenhouse tests, this new race did not affect some cultivars released previously like Samayoa C2004, Patronato Oro C2008, CEVY Oro C2008, Sawali Oro C2008, Movas C2009, CONASIST C2015, Barobampo C2015, and Norteño C2016 [10]. During the fall-winter crop seasons 2019-2020 to 2021-2022, CIRNO C2008 covered 92% of the area sown with wheat in southern Sonora [7,11,12]. During the crop season 2021-2022, the percentage area grown with durum wheat cultivars in this region was: CIRNO C2008 91.85%, Quetchehueca Oro C2013 [13] 3.97%, CENEB Oro C2017 [14] 1.93%, Baroyeca Oro C2013 [15] 1.06%, and Don Lupe C2020 [16] 0.03% [12]. Southern Sonora is prone to limitations in water availability [17], since the agricultural area is irrigated with water from dams [18], therefore, the objective of this work was to evaluate and determine the grain yield potential of advanced durum wheat lines and commercial cultivars under different irrigation regimes.

2. Material and methods

This work was carried out at the Norman E. Borlaug Experimental Station which belongs to the National Institute for Forestry, Agriculture, and Livestock Research, located in block 910 in the Yaqui Valley, Sonora, Mexico (27º22´3.01” N and 109º55´40.22” W; 37 msnm), during the 2021-2022 fall-winter crop season in a clay soil. This region of southern Sonora is characterized by a dry warm climate (BW(h)) and extreme heat (BSo) according to the Köppen´s classification modified by Garcia [19]. The germplasm evaluated consisted of 26 advanced durum wheat (*T. durum*) lines originated from the International Maize and Wheat Improvemente Center (CIMMYT) and four commercial cultivars: CIRNO C2008, CENEB Oro C2017, Don Lupe C2020, and Noroeste C2021 [20] (Table 1), which were subjected to three different irrigation regimes (two, three, and four complementary irrigations).

Table 1 Durum wheat cultivars and advanced lines evaluated under different irrigation regimes at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico, during the fall-winter crop seasons 2021-2022

No.	Pedigree	Selection history
1	CIRNO C2008	CGSS02Y00004S-2F1-6Y-0B-1Y-0B
2	CENEB ORO C2017	CDSS07Y00184S-099Y-099M-12Y-1M-04Y-0B
3	Don Lupe C2020	CDSS12B00145T-099Y-014M-14Y-3M-0Y-OB-MEXICALI-0CEN-100CEN
4	Noroeste C2021	CDSS11B00325T-049Y-054M-39Y-0M
5	AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/3/SOMBRA_20/4/SNITAN/5/SOMAT_4/INTER_8/6/GUAYACAN INIA/POMA_2//SNITAN/7/SOOTY_9/RASCON_37//JUPARE C 2001/3/SOOTY_9/RASCON_37//CAMAYO/4/SOOTY_9/RASCON_37//SOMAT_3.1/3/SOOTY_9/RASCON_37//STORLOM/8/SOOTY_9/RA	CDSS13Y00451T-099Y-019M-19Y-4M-0Y
6	CALERO/7/HUBEI//SOOTY_9/RASCON_37/3/2*SOOTY_9/RASCON_37/4/SOOTY_9/RASCON_37/6/LIRO_3/LOTAIL_6/4/MUSK_4/3/PLATA_3//CREX/ALLA/5/SOMAT_4/INTER_8/8/SOOTY_9/	CDSS13Y00431T-099Y-014M-5Y-2M-0Y

	RASCON_37//JUPARE C 2001/3/SOOTY_9/RASCON_37//CAMAYO	
7	STOT//ALTAR 84/ALD/3/PATKA_7/YAZI_1/4/SOMAT_3/PHAX_1//TILO_1/LOTUS_4/5/SOOTY_9/RASCON_37//WODUCK/CHAM_3/6/BAROYECA ORO C2013/7/WID22202/4/SORA/2*PLATA_12//SOMAT_3/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/5/CF4-JS 21//TECA96/TILO_1	CDSS13B00720T-099Y-099M-1Y-4M-0Y
8	TARRO_1/2*YUAN_1//AJAIA_13/YAZI/3/SOMAT_3/PHAX_1//TILO_1/LOTUS_4/4/CANELO_8//SORA/2*PLATA_12/5/CBC 501 CHILE/GUANAY/4/CNDO/PRIMADUR//HAI-OU_17/3/SNITAN/7/ALTAR 84/BINTEPE 85/3/STOT//ALTAR 84/ALD/4/POD_11/YAZI_1/5/VANRRIKSE_12/SNITAN/6/SOOTY_9/RASCON_	CDSS14B00835T-099Y-099M-5Y-1M-0Y
9	P91.272.3.1/3*MEXI75//2*JUPARE C 2001/11/BOOMER_33/ZAR/3/BRAK_2/AJAIA_2//SOLGA_8/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT/12/STR/4/JO69/3/JO69/CRA//CIT71/5/ALTAR 84/	CDSS14B00875T-099Y-099M-6Y-1M-0Y
10	SOOTY_9/RASCON_37//JUPARE C 2001/5/GREEN/SOMO/3/GODRIN/GUTROS//DUKEM/4/YAZI_1/AKAKI_4//SOMAT_3/3/AUK/GUIL//GREEN/6/CBC 509 CHILE/5/2*AJAIA_16//HORA/JRO/3/GAN/4/ZAR/7/CIRNO C 2008/3/KNIPA/TAGUA//PLANETA/TRILE/8/ALTAR 84/STINT//SILVER_45/3/GUANAY/4/GRE	CDSS14B00886T-099Y-099M-13Y-1M-0Y
11	SOOTY_9/RASCON_37//JUPARE C 2001/5/GREEN/SOMO/3/GODRIN/GUTROS//DUKEM/4/YAZI_1/AKAKI_4//SOMAT_3/3/AUK/GUIL//GREEN/6/CBC 509 CHILE/5/2*AJAIA_16//HORA/JRO/3/GAN/4/ZAR/7/GUAYACANINIA/2*SNITAN/3/ALTAR 84/BINTEPE 85//CAMAYO/8/CBC 509 CHILE/5/2*AJAIA_16//H	CDSS14B00887T-099Y-099M-12Y-1M-0Y
12	SOOTY_9/RASCON_37//JUPARE C 2001/5/GREEN/SOMO/3/GODRIN/GUTROS//DUKEM/4/YAZI_1/AKAKI_4//SOMAT_3/3/AUK/GUIL//GREEN/6/CBC 509 CHILE/5/2*AJAIA_16//HORA/JRO/3/GAN/4/ZAR/7/ALTAR 84/STINT//SILVER_45/3/GUANAY/4/GREEN_14//YAV_10/AUK/5/SOMAT_4/INTER_8/6/BCRIS/	CDSS14B00902T-099Y-099M-5Y-1M-0Y
13	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/6/SOOTY_9/RASCON_37//JUPARE C 2001/3/SOOTY_9/RASCON_37//CAMAYO/7/CBC 509 CHILE/5/2*AJAIA_16//HORA/JRO/3/GAN/4/ZAR/6/AJAIA_12/F3LOCA	CDSS14B00915T-099Y-099M-3Y-4M-0Y

14	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/7/CBC 509 CHILE/5/2*AJAIA_16//HORA/JRO/3/GAN/4/ZAR/6/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/CHEN_1/TEZ/3/GUIL//CIT71/CII/5/	CDSS14B00927T-099Y-099M-10Y-1M-0Y
15	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/12/ARTICO/AJAIA_3//HUALITA/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR 84/3/HUI/P	CDSS14B00931T-099Y-099M-19Y-3M-0Y
16	TARRO_1/2*YUAN_1//AJAIA_13/YAZI/3/SOMAT_3/PHAX_1//TILO_1/LOTUS_4/4/CANELO_8//SORA/2*PLATA_12/5/CBC 501 CHILE/GUANAY/4/CNDO/PRIMADUR//HAI-OU_17/3/SNITAN/7/ALTAR 84/BINTEPE 85/3/STOT//ALTAR 84/ALD/4/POD_11/YAZI_1/5/VANRRIKSE_12/SNITAN/6/SOOTY_9/RASCON_	CDSS14B00970T-099Y-099M-21Y-1M-0Y
17	AMRIA/BAROYECA ORO C2013/5/CAMON_5//HUI/YAV79/3/ALTAR 84/STINT//SILVER_45/4/AJAIA_12/F3LOCAL (SEL.ETHIO.135.85)//PLATA_13/3/PLATA_6/GREEN_17/8/RANCO//CIT71/CII/3/COMDK/4/TCHO//SHWA/MALD/3/CREX/5/SNITAN/6/CALAMON_5/7/ZAKA/3/AJAIA_12/F3LOCAL(SEL.ETHIO.1	CDSS15B00083S-099Y-099M-10Y-4M-0Y
18	CNDO/VEE//PLATA_8/3/6*PLATA_11/6/PLATA_8/4/GARZA/AFN//CRA/3/GTA/5/RASCON/7/PAGA_7/8/ALTAR 84/BINTEPE 85/3/STOT//ALTAR 84/ALD/4/POD_11/YAZI_1/5/VANRRIKSE_12/SNITAN/6/SOOTY_9/RASCON_37//WODUCK/CHAM_3/9/BIRK_2/BARNACLA_7/4/GODRIN/GUTROS//DUKEM/3/THKNEE_	CDSS15B00089S-099Y-099M-38Y-2M-0Y
19	TRIDENT/3*KUCUK/7/CMH83.2578/4/D88059//WARD/YAV79/3/ACO89/5/2*SOOTY_9/RASCON_37/6/1A.1D 5+1-06/3*MOJO/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/8/CMOS_3//SOMAT_4/INTER_8/3/SOOTY_9/RASCON_37/4/HAMRI/CALAMON_1/5/BAROYECA ORO C2013	CDSS16Y00255S-099Y-099M-4Y-3M-0Y
20	CMOS_3//SOMAT_4/INTER_8/3/SOOTY_9/RASCON_37/4/HAMRI/CALAMON_1/5/BAROYECA ORO C2013/9/ZAKA/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/SOOTY_9/RASCON_37//WODUCK/CHAM_3/8/STOT//ALTAR 84/ALD/3/THB/CEP7780//2*MUSK_4/6/ECO/CMH76A.722//BIT/3/ALTAR 84/	CDSS16Y00424S-099Y-099M-8Y-1M-0Y
21	CMOS_3//SOMAT_4/INTER_8/3/SOOTY_9/RASCON_37/4/HAMRI/CALAMON_1/5/BAROYECA ORO C2013/6/GUAYACAN INIA/2*SNITAN/3/SOMAT_3/GREEN_22//2*RASCON_37/2*TARRO_2	CDSS16Y00425S-099Y-099M-12Y-1M-0Y

22	RCEE_2/CMOS_3/3/GUAYACAN INIA/GUANAY//FUMA_5/4/BAUN_6/PAGA_4/5/MIRADOUX/3/AG 1-22/2*ACO89//2*UC1113	CDSS16Y00434S-099Y-099M-1Y-1M-0Y
23	CMH83.2578/4/D88059//WARD/YAV79/3/ACO89/5/2*SOOTY_9/RASCON_37/6/1A.1D 5+1-06/3*MOJO/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/7/C F4 20 S/CALAMON_2/3/CANELO_9.1//SHAKE_3/2*AJAIA_2/8/SNITAN*2/RBC/9/IHWIR/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLAT	CDSS15B00581S-099Y-099M-11Y-4M-0Y
24	SOMAT_3/GREEN_22/4/GODRIN/GUTROS//DUKEM/3/THKNEE_11/7/CMH83.2578/4/D88059//WARD/YAV79/3/ACO89/5/2*SOOTY_9/RASCON_37/6/1A.1D 5+1-06/3*MOJO/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/8/SOMAT_3/GREEN_22/4/GODRIN/GUTROS//DUKEM/3/THKNEE_11/5/YAV79/BAR	CDSS15B00613S-099Y-099M-19Y-3M-0Y
25	SOOTY_9/RASCON_37//STORLOM/8/RISSA/GAN//POHO_1/3/PLATA_3//CREX/ALLA*2/7/EUDO//CHEN_1/TEZ/3/TANTLO_1/5/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT/6/MOJO/KITTI/9/SOOTY_9/RASCON_37//WODUCK/CHAM_3/3/PNIO_4/10/GUAYACAN INIA/GUANAY//FUMA_5/3/BAROYECA ORO C	CDSS15B00674S-099Y-099M-15Y-2M-0Y
26	TJILKURI/3/BARJ/PAGA_2//MARA_1/BARNACLA_1/5/MOHAWK/AYSR_1/4/RCEE_2/CMOS_3/3/GUAYACAN INIA/GUANAY//FUMA_5	CDSS16Y00981T-099Y-099M-20Y-4M-0Y
27	WID802/6/SNITAN/MALV_1//SNITAN/3/CANELO_9.1/SNITAN//PNIO_4/5/ZAKA/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/SOOTY_9/RASCON_37//WODUCK/CHAM_3	CDSS15B00294S-099Y-099M-1Y-4M-0Y
28	MIWOK/7/2*BYBLOS/5/PHON/4/VRKS_3/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/6/GUAYACAN INIA/GUANAY//PORRON_4/BEJAH_7/3/VANRRIKSE_12/SNITAN	CDSS15B00683T-099Y-099M-2Y-3M-0Y
29	ICAKASSEM2/12/TAHIA_1/11/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/RAFI97/9/MALMUK_1/SERRATOR_1/10/BARNACLA_4/13/ZAKA/3/AJAIA_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA_13/4/SOOTY_9/RASCON_37//WODUCK/CHAM_3/5/TADIZ/PAGA_4	CDSS15B00921T-099Y-099M-5Y-4M-0Y
30	MARGHERITA//GHMA_1/ARCH_3/7/GEROMTEL-3/5/GUAYACAN INIA/POMA_2//SNITAN/4/D86135/ACO89//PORRON_4/3/SNITAN/6/CIRNO C 2008	CDSS16Y00827T-099Y-099M-7Y-1M-0Y

Sowing was carried out on December 15, 2021, in dry soil and the irrigation was applied for seed germination. The experimental design used was alpha lattice with three replications; plots consisted of two beds five m long with two rows each and separated by 0.80 m (8 m^2). The analysis of variance was performed with SAS 9.4 and the mean comparison with the LSD test ($p \leq 0.05$). Seed density was 100 kg ha^{-1}; fertilization consisted of the formula 241-52-00, applying 103-52-00 before sowing and 138-00-00 before the first complementary irrigation. The irrigation management followed the recommendations of Figueroa-López *et al*. [21]: the first complementary irrigation was applied during tillering-stem elongation (stages 29-30) [22], the second during booting (stage 43), the third during flowering-anthesis (stages 61-65), and the fourth during beginning of grain-filling (stages 77-83). The total amount of water applied for each treatment (two, three, and four complementary irrigations) was 44, 56, and 70 cm, respectively. For control of broad leaf weeds Situi XP (Metsulfuron methyl + Thifensulfuron methyl) [23] was used at the rate of 30 g of commercial product ha^{-1}, and for narrow leaf weeds Axial XL (Pinoxaden + Cloquintocet-mexyl) at the rate of 1 L ha^{-1} [24]; Muralla Max (Imidacloprid + Betacyfluthrin) was used at the rate of 250 mL ha^{-1} [25] for control of the green aphid (*Schizaphis graminum* Rondani). For rust control on susceptible cultivar CIRNO C2008, Velficur 25 EW (Tebuconazole) [26] was applied at 0.6 L ha^{-1} during flowering-anthesis; no preventive or curative fungicides were applied to the rest of the advanced lines and cultivars since they are resistance to leaf rust (*Puccinia triticina* Eriks.) and to stripe or yellow rust (*Puccinia striiformis* f. sp. *tritici* Eriks.). A 650 L cylinder-type Yukon sprayer with 14 ADIA-01 nozzles was used with a volume of 300 L ha^{-1}, for application of the agrochemicals. The entire experimental plots were harvested with a wintersteiger type Nr:1540-46 classic cereal thresher. The variables evaluated were: days to flowering, plant height (cm), days to physiological maturity, and grain yield (kg ha^{-1}). The temperature, relative humidity, and rainfall as well as the accumulated number of cold and heat units was obtained from the weather station CIANO-910, which belongs to the automated weather station network of Sonora [27]; data were recorded from December 1, 2021 to April 30, 2022. A cold unit was considered as one hour recorded by the weather station with a temperature below 10 °C [28].

3. Results and discussion

A statistical significant difference ($p \leq 0.05$) was detected among irrigation regimes for days to flowering and days to physiological maturity (Table 2). The earliest wheat plants were those under two irrigations regime which causes drought stress, plants accumulate several organic and inorganic solutes in its cytosol to lessen its osmotic potential for maintenance of cell turgor; photosynthesis is negatively affected by changing the inner structure of chloroplasts, mitochondria, and chlorophyll content and minerals. The destruction of the photosystem II oxygen releasing complex and reaction center can disturb the production and use of electrons, causing lipid peroxidation of the cell membrane by production of reactive oxygen species [29] which cause partial reduction of oxygen, and cause rupturing of membranes becoming leaky, thereby affecting respiration, photosynthesis, and the overall development of the plant. Reactive oxygen species also damage the production of cellular components such as carbohydrates, nucleic acids, lipids, and proteins [30].

Table 2 Effect of complementary irrigations on days to flowering, days to physiological maturity, plant height, and grain yield of four commercial durum wheat cultivars and 26 advanced lines, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico, during the 2021-2022 fall-winter crop season

Irrigations	**DF**	**PM**	**PH (cm)**	**GY (kg/ha^{-1})**
Two	73.96 c	114.68 c	82.81 b	6,788 c
Three	76.15 a	117.41 b	89.43 a	7,709 b
four	75.44 b	118.45 a	90.07 a	8,428 a
CV	1.18	0.97	2.99	4.47
LSD	0.31	0.39	0.92	120.40

DF = days to flowering; PM = days to physiological maturity; PH = plant height; GY = grain yield. CV= coefficient of variation; LSD= least significance difference ($p \leq 0.05$).

Drought affects all plant development stages from germination, vegetative and reproductive growth to grain filling and maturation of the crop [31]. It reduces nitrogen uptake efficiency and utilization by plants; the deprived nutrient uptake is due to impaired membrane permeability and active transport and reduced transpiration rate, resulting in repressed root absorbing power. Plant height was higher for the three and four irrigations regime and statistically different to the other irrigation regime by a difference of 6.62 and 7.26 cm, respectively (Table 2). Reddy *et al.* [32] reported a 17.4 to 25.9% height reduction in plants from two hard-red winter wheat cultivars (TAM 111 and TAM 112) under water-deficit (WD) stress conditions as compared to plants under normal irrigation. They also reported that TAM 112 used more water, produced more biomass and grain yield under WD compared to TAM 111. Leaf-level data at the grain filling stage indicated that TAM 112 had elevated abscisic acid content and reduced stomatal conductance and photosynthesis as compared to TAM 111. Sustained WD during the grain filling stage also resulted in greater flag leaf transcriptome changes in TAM 112 than TAM 111. Transcripts associated with photosynthesis, carbohydrate metabolism, phytohormone metabolism, and other dehydration responses were uniquely regulated between cultivars. The two complementary irrigation regime rendered a grain yield reduction of 11.94 and 19.46% as compared to the three and four irrigation regimes, respectively (Table 2), with 6,788 kg/ha^{-1}. Water stress per se is not only critical for plant growth and production, but also the water stress that occurs at specific phenological stage of the plant. Kharrou *et al.* [33] reported that the grain yield of winter wheat differed under different irrigation regimes in a semi-arid region of Morocco; two surface irrigation scheduling treatments were applied: one based on the FAO-56 dual procedure [34] (full irrigation; the timing and the amounts of water to apply were planned in order to avoid crop water stress), and the other according to the existing rule adopted by the irrigation agency (existing rule approach. Predetermined annual quota according to surface water availability in dams, is allocated for irrigation at the beginning of the season); they also applied drip irrigation consisting of FAO-56 single approach [35]. The main difference between the three treatments was the annual amount of irrigation water, which was 455, 396, and 362 mm for full irrigation, existing rule, and drip irrigation treatments, respectively. Despite the five irrigations in full, the existing rule irrigation, and drip irrigation, the grain yield was 5,000, 3,900, and 6,200 kg ha^{-1}, respectively. The low yield obtained with existing rule treatment could be explained by the crop water stress, since all crop management factors were similar for all treatments; there was a large irrigation interval in February during the wheat stem elongation stage which causes a reduction in number of heads/m^2 (up to about –11%), and by the insufficient water amount applied in March, which occurred during the heading and flowering stage, affecting grain formation especially the number of seeds/head. Zhang and Oweis [36] reported that after ten years of supplemental irrigation in northern Syria with bread wheat (*Triticum aestivum* L.) and durum wheat, they found that the sensitive growth stages of wheat to water stress were from stem elongation to booting, followed by anthesis and grain-filling. Average days to flowering (DF), days to physiological maturity PM), plant height (PH), and grain yield (GY) of durum wheat lines and cultivars evaluated are presented in Table 3. Although there were statistical differences in DF, PM, and PH, the variation was minor. The overall avg of DF was 75.2 d with a range of 72 to 77 d, for PM the avg was 116.9 d with a range of 115 to 120 d, and for PH the avg was 87.5 cm with a range of 83 to 93 cm. However, for GY differences were much higher, ranging from 7,083 to 8,092 kg ha^{-1}. Although there were 20 lines and three cultivars within the first statistical group, the maximum difference reached 611 kg in relation to the lowest GY of that group. Outstanding lines that surpassed the 8,000 kg ha^{-1}, were BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/12/ARTICO/AJAIA_3//HUALITA/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR84/3/HUI/P (15) and TJILKURI/3/BARJ/PAGA_2//MARA_1/BARNACLA_1/5/MOHAWK/AYSR_1/4/RCEE_2/CMOS_3/3/GUAYACAN INIA/GUANAY//FUMA_5 (26) with 8,092 and 8,059 kg ha^{-1}, respectively. It is the first year of evaluation for GY of line 26 and the second for line 15, so they are good prospects to become candidates for commercial release, if their performance during the next crop seasons keeps the same trend; although, other lines like 20, 8, 9, and 24, might fall within that category. The avg GY was 7,947, 7,819, 7,663, and 7,110 kg ha^{-1} for commercial cultivars Noroeste C2021, CENEB Oro C2017, Don Lupe C2020, and CIRNO C2008, respectively.

Table 3 Average values obtained from the effect of two, three, and four complementary irrigations on days to flowering, days to physiological maturity, plant height, and grain yield of four commercial durum wheat cultivars and 26 advanced lines, at the Norman E. Borlaug Experimental Station, in the Yaqui Valley, Sonora, Mexico, during the 2021-2022 fall-winter crop season

Entry No.	**DF**	**PM**	**PH (cm)**	**Grain yield (kg ha^{-1})**
15	73 ij	115 kl	91 abc	8092 a
26	77 a	117 bcdefghi	88 bcdef	8059 a
20	77 ab	118 abcd	86 efg	7951 ab
4	76 abcde	118 abc	85 efg	7947 ab
8	77 abc	116 defghijkl	86 cdefg	7937 ab
9	72 j	116 fghijkl	91 abcd	7929 ab
24	75 bcdefg	118 abcde	86 defg	7928 ab
27	73 ij	116 efghijkl	85 efg	7883 abc
7	77 abcd	119 ab	89 abcde	7880 abc
2	76 abcdef	117 cdefghijk	88 abcdef	7819 abc

12	75 defg	118 bcdef	93 a	7810 abc
6	77 a	120 a	88 bcdef	7793 abc
13	76 abcde	115 ijkl	87 bcdef	7743 abc
19	76 abcdef	115 jkl	87 cdefg	7713 abcd
3	76 abcde	118 bcdefg	87 cdefg	7663 abcde
14	73 ij	115 kl	88 abcde	7593 abcde
5	75 efgh	117 cdefghij	89 abcde	7542 abcde
10	73 hij	117 cdefghijk	90 abcde	7540 abcde
11	76 abcde	118 bcdefg	84 fg	7530 abcde
28	74 fghi	115 hijkl	85 efg	7521 abcde
21	76 abcde	117 bcdefghij	89 abcde	7512 abcde
18	76 abcdef	117 bcdefghi	92 ab	7494 abcde
22	76 abcde	117 bcdefgh	85 efg	7481 abcde
30	73 ij	116 ghijkl	85 efg	7430 bcde
25	76 abcde	119 ab	89 abcde	7350 bcde
29	75 cdefg	118 abcde	87 bcdef	7344 bcde
17	74 ghi	116 cdefghijkl	87 cdefg	7294 cde
16	74 hij	115 l	89 abcde	7274 cde
1	77 abc	118 bcdef	83 g	7110 de
23	75 efgh	116 cdefghijkl	86 efg	7083 e
CV	1.18	0.97	2.99	4.47
LSD	1.59	2.03	4.69	613.08

DF = days to flowering; PM = days to physiological maturity; PH = plant height; GY = grain yield. CV= coefficient of variation; LSD= least significance difference (p ≤ 0.05). Numbers in a column with the same letter are not statistically different.

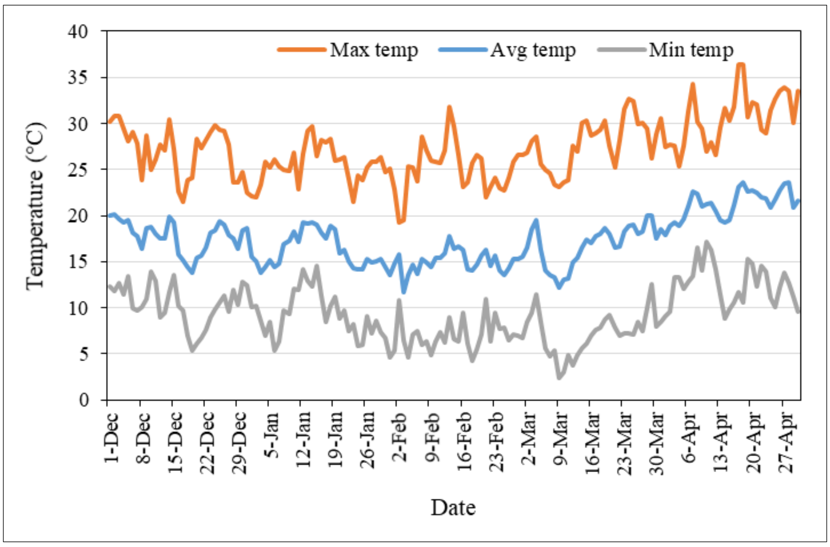

Figure 1 Average temperature, maximum and minimum recorded by the weather station CIANO-910, installed at the Norman E. Borlaug Experimental Station, during the fall-winter crop season 2021-2022

The fall-winter crop season 2021-2022 had predominant weather conditions which were favorable for plant growth and development, which in turn rendered good grain yield (Figure 1). The average temperature during December 2021 was 17.76 °C, 16.15 in January, 15 in February, and 16.82 °C in March, 2022. Despite some peaks of maximum temperature as on January 13, 14, and February 13, 2022, which were above 29 °C, they did not last more than an hour. The total number of cold units was 589; from the second fortnight of December, the number gradually increased up to February whose maximum was 207 (Figure 2), a different trend to the crop season 2020-2021, where the maximum number of cold units was recorded in January [37]. The accumulation of cold units favors tillering and the normal development of the crop; as the number of cold units increases, the physiological processes of the plant take place more slowly and consequently the growth period extends, which generally induce a greater grain yield [28].

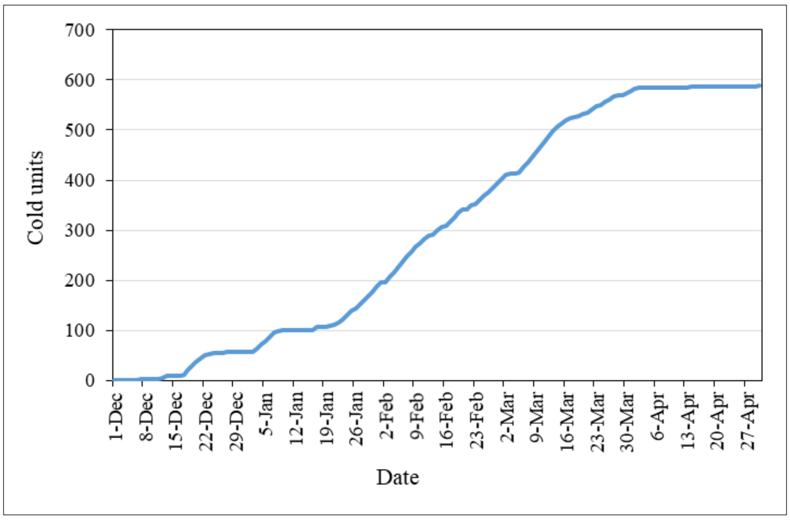

Figure 2 Accumulation of cold units recorded by the weather station CIANO-910, installed at the Norman E. Borlaug Experimental Station, during the fall-winter crop season 2021-2022

4. Conclusion

The highest average grain yield of 26 advanced durum wheat lines and four commercial cultivars was obtained with four complementary irrigations with 8,428 kg ha^{-1}, followed by three irrigations with 7,709 kg ha^{-1}, and two irrigations with 6,788 kg ha^{-1}.

The advanced lines BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/5/SILK_3/DIPPER_6/3/ACO89/DUKEM_4//5*ACO89/4/PLATA_7/ILBOR_1//SOMAT_3/12/ARTICO/AJAIA_3//HUALITA/10/PLATA_10/6/MQUE/4/USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/THKNEE_11/9/CHEN/ALTAR 84/3/HUI/P and TJILKURI/3/BARJ/PAGA_2//MARA_1/BARNACLA_1/5/MOHAWK/AYSR_1/4/RCEE_2/CMOS_3/3/GUAYACAN INIA/GUANAY//FUMA_5 showed average grain yields greater than 8,000 kg ha^{-1}, with 8,092 and 8,059.

Commercial cultivars CIRNO C2008, Don Lupe C2020, CENEB Oro C2017, and Noroeste C2021, showed an average grain yield of 7,110, 7,663, 7,819, and 7,947 kg ha^{-1}, respectively.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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