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Evapotranspiration, Grain Yield, and Water Productivity of Spring Oat (*Avena sativa* L.) under Semiarid Climate

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Abstract

Spring oat (*Avena sativa*) is produced for grain, hay, and green manure and can be integrated into a cropping system as a cover crop. Twenty-eight oat genotypes (G1, G2, G3, …., G28), selected for their adaptability to the Southwestern United States, were evaluated for their yield performance under sprinkler irrigation during four growing seasons (2005-2008) at the Agricultural Science Center at Farmington, New Mexico State University. The genotypes were arranged in randomized complete blocs design with four replications. Irrigation scheduling was based on evapotranspiration and the depletion criterion of 40% to 45% total available water (TAW) was practiced to prevent the plants from experiencing any water stress. Crop evapotranspiration estimated by the FAO crop coefficient and reference evapotranspiration approach was low about 2 mm/day during crop initial stage and increased with plant growth and reached the maximum during crop mid-season or reproductive stage. It decreased during crop late season. Daily crop evapotranspiration varied from 0.5 to 12.6 mm in 2008 and the seasonal Spring oat evapotranspiration varied from 535.8 to 591 mm. Averaged across the four growing seasons, oat evapotranspiration was 570.4 mm. The results showed that Spring oat plant height varied significantly with genotypes and ranged from 59.1 to 100.8 cm. Oat grain yield significantly varied with years and genotypes. Grain yield varied from 3386 to 6498 kg/ha and average yield was 4245, 4265, 5477, and 4025 kg/ha during the 2005, 2006, 2007 and 2008, respectively. The best performing genotypes were G1, G2, G7, G19, G20, G21 and G23 with average yield greater than 4800 kg/ha while G3, G13, G17 and G27 showed the lowest yield among the genotypes. Oat crop water use efficiency (CWUE) varied with genotype and years and ranged from 0.53 to 1.07

kg/m^3 and averaged 0.65, 0.78, 0.91 and 0.70 kg/m^3 in 2005, 2006, 2007 and 2008, respectively. The highest CWUE was achieved by G19 and the lowest CWUE was obtained by G13. Irrigation water use efficiency (IWUE) which represents the quantity of yield produced per cubic meter of water, varied from 0.57 to 1.20 kg/m^3 while evapotranspiration water use efficiency (ETWUE) varied with genotype and year and ranged from 0.57 to 1.21 kg/m^3 with the overall IWUE mean of 0.83 kg/m^3 and ETWUE mean of 0.81 kg/m^3.

Keywords

Spring Oat, Genotypes, Evaluation, Grain Yield, Water Productivity, High Elevation, Semiarid Climate

1. Introduction

Oat (*Avena sativa* L.) hold many opportunities for development as foods, industrial and pharmaceutical products, which all add value to the oat crop [1] [2] [3]. Oat is mostly used for animal feeding and human health food [4]; however, the use of oat as animal feed has declined steadily and is replaced by other types of forage. Oat is also a health crop for human nutrition that provides the consumer with B-glucans and dietary fiber components, high tocopherol and natural antioxidant [5]. Oat grain are rich with biologically significant substances and their consumption in human diet is beneficial for human well-being [3] [6].

Oat production is showing decreasing trends with total worldwide cultivated area that varied from 38,260,751 to 9,433,141 ha and the grain yield showing increasing trend from 1296.07 to 2437.34 kg/ha during the 1961-2016 period [7]. During the same period, oat cultivated area across the United States also showed decreasing trends at the expense of wheat, barley or maize and varied from 9,666,550 to 397,000 ha with increasing trends in grain yield ranging from 1411.08 to 2516.75 kg/ha [7]. Consequently, oat production is decreasing despite the crop has great nutritional and therapeutic values.

Gorash *et al.* [8] reported that oat crop traditionally has been neglected in a number of respects, cultivated in non-optimal cropping areas as wheat, barley or maize. Lin *et al.* [9] reported oat actual evapotranspiration (ETc) range of 227 - 305 mm and water productivity that varied from 1.03 to 1.2 kg/m^3 under conventional irrigation and alternative partial root zone irrigation in Baicheng city, Jilin province of China. Zute *et al.* [10] reported average oat yield that varied from 3560 to 6620 kg/ha with the oat varieties Stmara and Laima showing the more stable yield of 5350 and 5830 kg/ha, respectively. Oat has great importance in animal production because of its high yielding potential to be produced as green fodder for forage. Singh and Singh [11] reported that oat cultivar produced green folder as high as 55,000 kg/ha while Naeem *et al.* [12] found oat green fodder yield of 81,170 kg/ha. Forsberg and Reeves [13] and Tamm [14] indicated that numerous biological, genetics, management strategies and climatic conditions impact high yields of high quality oat production. Forsberg and Reeves [13] pointed that cool and moist climate are considered the best for oat production and reported 14 oat varieties grain yield varietal and season dependent varying from 2753 to 7680 kg/ha. Tamm [15] reported variation in grain yield of some oat varieties from 3288 to 5824 kg/ha with environmental impact on the yield in Estonia. Sandhu and Horton [15] indicated that water shortage can cause serious loss of oat grain yield. Karing *et al.* [16] pointed that yield limiting factors in field crops can be divided into several groups: variety efficiency, soil fertility, agrotechnics, and meteorological conditions.

South Dakota is the most oat production State followed by North Dakota, Wisconsin, Minnesota, Iowa, Pennsylvania, New York, Texas, Michigan and Maine [17]. While oat is produced in the Northern, Midwest and Eastern United States, very limited data and information exist on Spring oat productivity across the Southwestern US under semiarid and arid climatic conditions. In the Southwestern United States, oat is a very secondary crop and is produced by only 27 farmers over 64 ha in New Mexico basically in Mora, Rio Arriba and Sandoval counties [18]. Therefore, the objectives of this study were to evaluate grain yield of some Spring oat genotypes, and to determine their water productivity under semiarid climates and high elevation at Farmington, New Mexico.

2. Materials and Methods

2.1. Station Area

This study was conducted at the Agricultural Science Center at Farmington, New Mexico State University (NMSU) (Latitude 36.69' North, Longitude 108.31' West, elevation 1720 m) during the 2005, 2006, 2007 and 2008 growing seasons. Wind speed (U_2), minimum temperature (T_{min}), maximum temperature (T_{max}), average temperature (T_{mean}), relative humidity (RH_{mean}), and solar radiation (R_s) were measured at the site by an automated weather station on a daily basis and averaged on the seasonal basis (April - August) (**Table 1**).

2.2. Crop Management

Seventeen (17) Spring oat genotypes (G1, G2, G3, …, G17) were evaluated in 2005 and other additional eleven (11) Spring oat genotypes (G18, G19, …, G28) were added to the previous list in 2006. Therefore, 17 Spring oat genotypes were evaluated in 2005 and 28 Spring oat genotypes were evaluated during 2006-2008 period. This research was part of the Uniform Northern States Oat Nursery (UNSON). The experiment was arranged in randomized complete blocs design with four replications. Spring oat was planted on April 21, 2005; May 4, 2006; May 3, 2007; April 18, 2008 and harvested on August 3, 2005; August 20, 2006; August 23, 2007; August 10, 2008 during the 2005, 2006, 2007 and 2008 growing seasons, respectively. Nitrogen, phosphorus and potassium fertilizer applied

Table 1. Average seasonal (April - August) wind speed (U_2), maximum temperature (T_{max}), minimum temperature (T_{min}), mean temperature (T_{mean}), mean relative humidity (RH_{mean}) and, solar radiation (R_s) for the 2005-2008 period.

Year	U_2 ($m \cdot s^{-1}$)	T_{max} (˚C)	T_{min} (˚C)	T_{mean} (˚C)	RH_{mean} (%)	R_s ($MJ \cdot m^{-2}$)
2005	3.0	28.2	10.5	19.3	28.0	25.0
2006	2.9	28.5	11.5	20.0	35.7	24.4
2007	2.8	28.7	11.5	20.1	41.7	24.6
2008	3.1	27.8	10.2	19.0	25.0	27.4

rates are summarized in **Table 2**. Herbicide was applied if needed and the field was fully irrigated through a center pivot irrigation system to avoid any impact of water stress on crop growth parameters and grain yield. Irrigation scheduling was based on crop evapotranspiration and the depletion criterion of 40% to 45% of the total available water (TAW) was practiced to prevent the plants from experiencing any water stress. At harvest, oat was combine harvested for grain yield. Plot grain mass and moisture content were determined. Oat grain yield was estimated in kg/ha and was adjusted to 14% moisture content.

2.3. Crop Actual Evapotranspiration Estimation (ETc)

Spring oat actual evapotranspiration was estimated according to the equation proposed by Jensen [19] and Allen *et al.* [20].

$$ETc = Kc * ETo \tag{1}$$

where ETc = actual evapotranspiration (mm), Kc = daily crop coefficient, ETo = grass reference evapotranspiration (mm).

2.4. Reference Evapotranspiration Model: ASCE-EWRI (2005)

Daily grass-reference ET was computed using the standardized American Society of Civil Engineering (ASCE) form of the Penman-Monteith (PM-ETo) equation:

$$ETo = \frac{0.408\Delta(Rn - G) + (900\gamma\ u2/(T + 273))(es - ea)}{\Delta + \gamma(1 + 0.34u2)} \tag{2}$$

where: ETo is the reference evapotranspiration ($mm \cdot day^{-1}$), Δ is the slope of saturation vapor pressure versus air temperature curve ($kPa \cdot {}^{\circ}C^{-1}$), Rn is the net radiation at the crop surface ($MJ \cdot m^{-2} \cdot d^{-1}$), G is the soil heat flux density at the soil surface ($MJ \cdot m^{-2} \cdot d^{-1}$), T is the mean daily air temperature at 1.5 - 2.5 m height (˚C), u_2 is the mean daily wind speed at 2 m height ($m \cdot s^{-1}$), es is the saturation vapor pressure at 1.5 - 2.5 m height (kPa), ea is the actual vapor pressure at 1.5 - 2.5 m height (kPa), $es - ea$ is the saturation vapor pressure deficit (kPa), γ is the psychrometric constant ($kPa \cdot {}^{\circ}C^{-1}$). The procedure developed by Allen *et al.* [20] was used to compute the needed parameters and the trend in the daily ETo for the 2005-2008 period is presented in **Figure 1**.

Table 2. Spring oat planting and harvesting date, applied fertilizer rate, precipitation and irrigation applied during the 2005-2008 period.

Year	Planting date	Harvesting date	$N-P_2O_5-K_2O-ZnSO_4$ (kg/ha)	Precipitation (mm)	Irrigation (mm)	Water supply (mm)
2005	21-Apr-05	3-Jul-05	128-44-50-0	51	591	642
2006	4-May-06	20-Aug-06	198-54-63-0	56	488	544
2007	3-May-07	23-Aug-07	179-52-61-0	64	541	605
2008	18-Apr-08	15-Aug-08	168-40-47-3	25	589	614

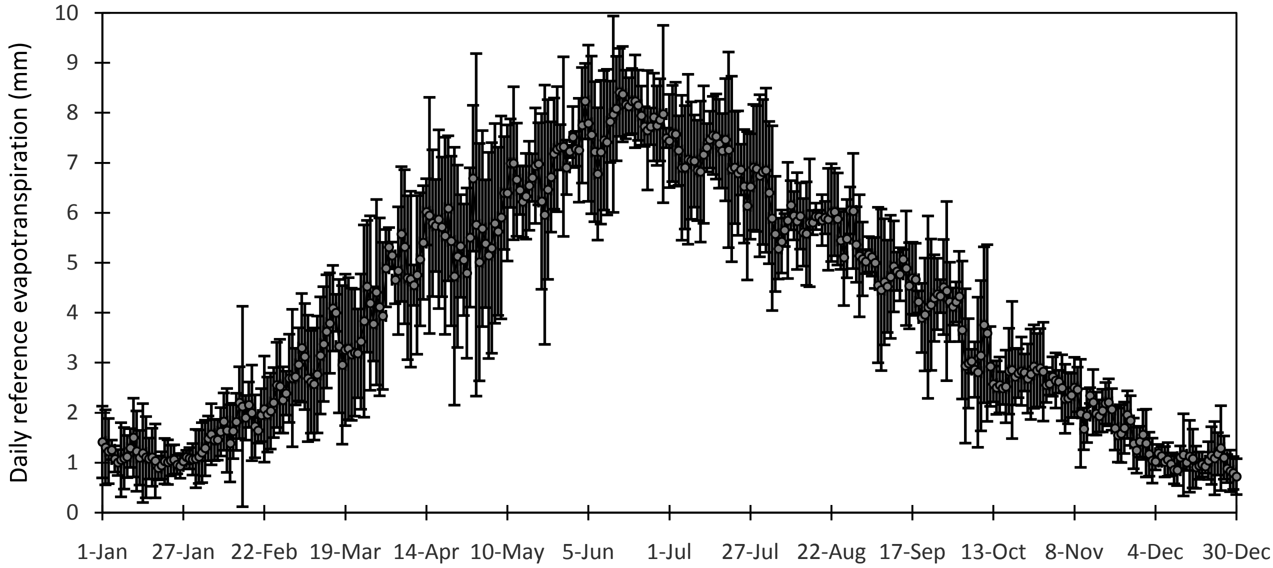

Figure 1. Seasonal course of distributions of the average daily reference evapotranspiration for the 2005-2008 period at the experimental station.

2.5. Crop Coefficients (Kc)

Spring oat was grown under non-limiting water and fertilizer conditions, and the standard FAO crop coefficients were used for crop actual evapotranspiration estimation. Spring oat crop Kc is affected by climate conditions, soil moisture status and crop growth stages. As the crop develops, the ground coverage, crop height and leaf area change. Due to differences in evapotranspiration during various growth stages, the Kc values for a given crop vary over the growing period. Oat growing period consists of the initial stage, crop development stage, mid-season stage, and late-season stage. Spring oat crop coefficients developed under a standard climatic condition by Allen *et al.* [20], as 0.3, 1.15 and 0.23 for the initial, mid-season and late-season were used to estimate Spring oat ETc for the study period. During crop development and late season stages, crop coefficient Kc was linearly interpolated between two typical values of Kc. As per FAO crop coefficient method, crop coefficient is affected by several factors among which is the plant height. The typical mid- and late-season stage Kc values were adjusted with climatic condition and Spring oat average crop height [20]:

$$\text{Kc stage} = \text{Kc stage}(tab) + \left[0.04(u_2 - 2) - 0.004(\text{RHmin} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (3)$$

where Kc stage is the adjusted daily Kc during the mid and late seasons, Kc stage (*tab*) is the standard tabulated Kc value according to FAO-56 approach [20], u_2 is the value for daily wind speed at 2 m height over grass during the mid and late growth stages (m/s), RHmin is the value for daily minimum relative humidity during the mid and late growth stages (%), and h is the average plant height for mid and late growth stages (m) (0.1 m - 10 m). We have used the average plant height across 17 genotypes in 2005 and all 28 genotypes in 2006, 2007 and 2008.

2.6. Crop Water Use Efficiency

Crop water use efficiency related to the total water supply (CWUE), evapotranspiration water use efficiency (ETWUE), and seasonal irrigation water use efficiency (IWUE) were estimated by the following equations [21]-[26]:

$$\text{CWUE} = \frac{\text{Yield}}{\text{Seasonal water supply}} \quad (4)$$

$$\text{ETWUE} = \frac{\text{Yield}}{\text{Oat seasonal ETa}} \quad (5)$$

$$\text{IWUE} = \frac{\text{Yield}}{\text{Seasonal irrigation amount}} \quad (6)$$

where CWUE, ETWUE and IWUE are in kg/m^3, Yield in kg/ha, Spring oat seasonal ETc is the seasonal cumulative ETc (mm), the seasonal irrigation amount is the sum of the irrigation amounts throughout the season (mm), and seasonal water supply is the sum of seasonal precipitation and seasonal irrigation amount (mm).

3. Statistical Analysis

The effects of oat genotypes and the seasons and their potential interaction on Spring oat yield, evapotranspiration, CWUE, IWUE and ETWUE were analyzed using analysis of variance (ANOVA) in PROC MIXED in SAS [27]. Separation of means was determined with the least significant difference (LSD) statement at the 5% significance level to identify any potential significant differences between the genotypes.

4. Results and Discussion

4.1. Spring Oat Evapotranspiration

The variation in the spring oat daily actual evapotranspiration is presented in **Figure 2**. Crop daily evapotranspiration was low during crop initial stage and increased with plant growth and reached the maximum values during crop mid-season or reproductive stage. It decreased during crop late season. Daily crop evapotranspiration varied from 0.5 to 10.9 mm in 2005, from 1.2 to 9.7 mm

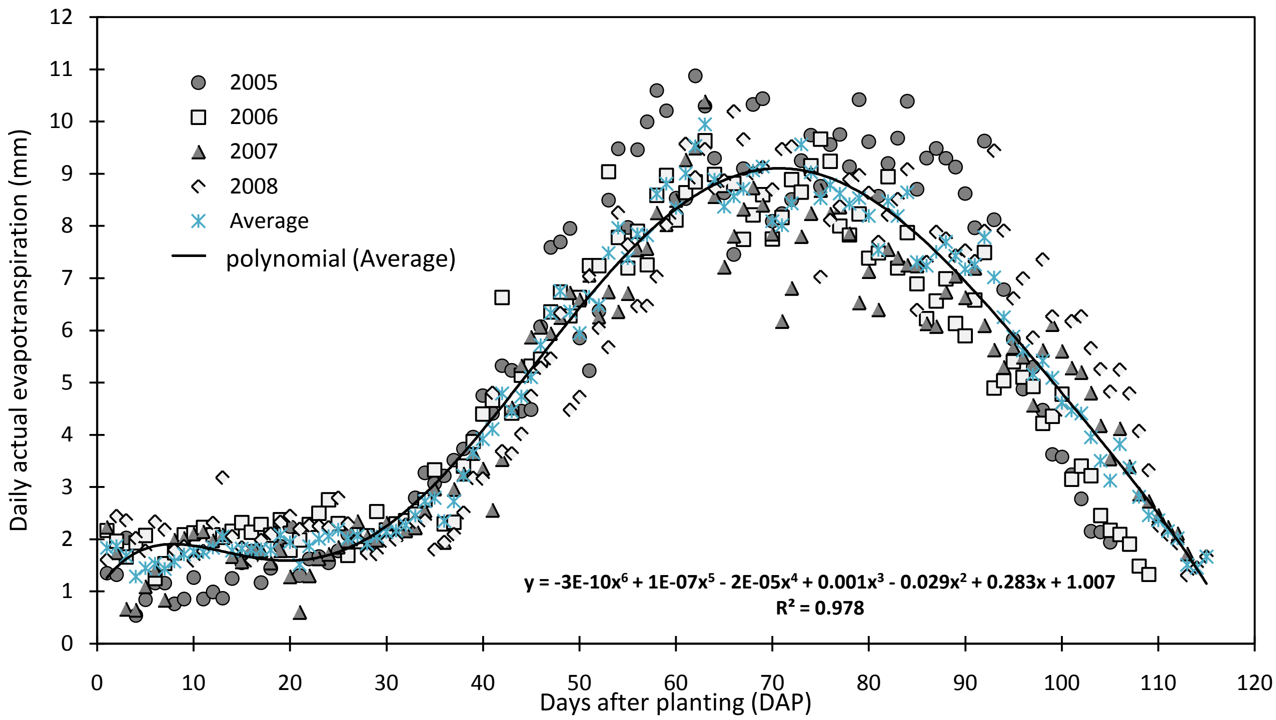

Figure 2. Seasonal course of distribution of the daily actual evapotranspiration of Spring oat for the 2005, 2006, 2007 and 2008 growing season and the seasonal average daily evapotranspiration.

in 2006, from 0.6 to 10.4 mm in 2007, and from 1.3 to 12.6 mm in 2008 (**Figure 2**) and averaged 5.4, 5.0, 4.7 and 5.1 mm/day during the 2005, 2006, 2007 and 2008 oat growing season, respectively. Seasonal Spring oat evapotranspiration was 572.2, 544.0, 535.8 and 591 mm during 2005, 2006, 2007 and 2008, respectively. Averaged across the four growing seasons, seasonal evapotranspiration was 570.4 mm while the 2005-2008 average daily evapotranspiration varied from 1.3 to 9.9 mm and averaged 5.0 mm/day. Seasonal evapotranspiration showed positive correlation with seasonal irrigation amount with R^2 of 0.61 (**Figure 3(a)**) and positive correlation with the total water supply with relatively low R^2 value of 0.30 (**Figure 3(b)**). The methodology of estimation crop ETc through reference evapotranspiration and crop coefficients developed by Christiansen and Hargreaves [28] and Jensen *et al.* [19] was successfully used by Allen *et al.* [20] and Djaman *et al.* [29] [30]. Hobbs and Krogman [31] reported Spring oat seasonal ETc ranging from 409 to 542 mm at the Agriculture Canada Irrigation Substation at Vauxhall, Alberta. Lower oat ETc values were reported by Knaggs [32] who reported oat seasonal ETc ranged from 388 to 433 mm in western Canada. Lin *et al.* [16] found oat seasonal ETc that varied from 227 to 305 mm in Jilin province of China.

4.2. Oat Plant Height

Oat plant height varied with genotypes and ranged from 75.3 to 89.3 cm in 2005, from 59.1 to 92.1 cm in 2006, from 71.1 to 98.4 cm in 2007 and from 61.8 to

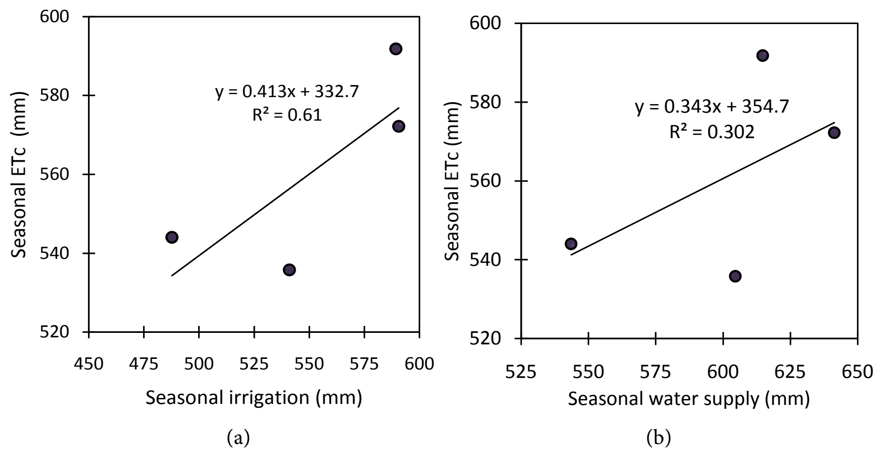

Figure 3. Relationship between oat seasonal evapotranspiration (ETc) and (a) seasonal irrigation, (b) total seasonal water supply.

100.8 cm in 2008 and averaged 82.7, 76.4, 81.9 and 77.6 cm in 2005, 2006, 2007 and 2008, respectively (**Table 3**). Plant height significantly varied among genotypes with LSD values of 3.6, 9.2, 11.4 and 10.8 in 2005, 2006, 2007 and 2008, respectively (**Table 3**). G11 obtained the lowest value in 2005 and G26 consistently obtained the shortest plant height in 2006, 2007 and 2008. G13 obtained the highest plant height value of 89.3 cm in 2005 while the G17 was the highest in 2006 and 2008 as 92.1 and 100.8 cm, respectively, and G27 obtained the highest plant height value of 98.4 cm in 2007. The results of this study are in agreement with Matiello *et al.* [33] who reported similar plant height values during their experiment in 1994 in Brazil. Higher oat plant height values were reported for the wild and early maturing group of oat in Brazil [33]. Plant height is a trait strongly related to plant lodging and yield. Federizzi and Qualset [34] indicated that the introduction of a gene for low plant height was limited due to the multipurpose use of the cereals for forage and seed yield in addition to the low soil fertility that limits plant height. Carvalho and Federizzi [35] reported that improvement in oat grain yield is related to plant breeding for plant height reduction, earliness and fertility enhancement. Tumino *et al.* [36] reported that plant height was correlated to lodging severity and indicated that GWAS analyses detected six significant associations for lodging and two for plant height among a broad collection of European hexaploid oat genotypes. Berry and Berry [37] showed that plant height is the main trait affecting plant lodging in cereals and Marshall *et al.* [38] indicated that lodging causes significant yield losses. Breeding for high yield oat genotypes should involve plant height and yield components as the primary traits to improve oat yield.

4.3. Oat Grain Yield

Oat grain yield significantly varied with years (P = 0.023) and genotypes (**Table 3**). Grain yield varied from 3425 to 4804 kg/ha in 2005, from 3510 to 5236 kg/ha in 2006, from 4581 to 6498 kg/ha in 2007 and from 3386 to 5087 kg/ha in 2008

Table 3. Variation in Spring oat plat height and grain yield as function on oat genotype and growing season during the 2005-2008 period.

Genotypes	Plant height (cm)				Grain yield (kg/ha)			
	2005	2006	2007	2008	2005	2006	2007	2008
G1	84.3	78.1	84.5	83.8	4804.0	4623.9	5632.7	5087.2
G2	82.0	76.8	78.7	78.7	4605.2	4739.3	5679.6	4342.2
G3	85.3	71.8	78.1	80.4	3713.1	3898.2	4672.9	3580.9
G4	89.0	62.9	73.7	69.4	4516.7	4100.6	5748.5	4130.2
G5	85.5	80.0	79.4	72.8	4473.8	4881.5	5856.9	3902.1
G6	82.0	78.1	79.4	85.5	3948.7	4272.0	5834.7	4304.2
G7	78.9	76.2	78.1	72.0	4484.4	5065.5	5290.1	4363.1
G8	85.6	73.0	81.3	70.3	4289.7	4617.1	5701.0	3404.1
G9	78.0	76.2	85.7	82.1	4415.5	5235.7	5851.9	3887.7
G10	84.5	73.7	85.1	71.1	4769.6	4007.7	6498.1	4223.3
G11	75.3	82.6	74.3	70.3	3424.5	4161.0	5754.3	3619.7
G12	79.1	80.0	78.1	82.1	3656.7	4241.5	5007.6	4872.8
G13	89.3	86.4	92.7	97.4	3539.4	3616.8	4632.6	3853.7
G14	78.9	70.5	73.7	62.7	3849.3	4212.2	5482.3	3943.3
G15	87.2	74.3	80.6	76.2	4200.0	4247.9	4935.8	3949.4
G16	78.2	86.4	87.0	84.5	4296.2	4105.9	5120.7	4015.2
G17	83.2	92.1	96.5	100.8	3474.8	4001.9	4580.5	3900.7
G18		84.5	92.7	96.5		3781.7	5207.8	3625.4
G19		78.1	82.6	68.6		4877.9	6491.2	3839.1
G20		77.5	83.2	76.2		4212.8	6134.8	4193.7
G21		76.8	86.4	66.9		4966.8	5921.8	3986.6
G22		83.2	77.5	73.7		4351.1	5596.4	4098.5
G23		76.8	85.1	81.3		4474.4	5614.7	4392.8
G24		61.6	74.3	67.9		3816.5	5261.2	4019.9
G25		64.8	78.7	62.7		3983.4	5136.2	3385.9
G26		59.1	71.1	61.8		3551.8	5484.5	3908.6
G27		87.0	98.4	95.9		3509.9	4614.3	3618.4
G28		72.4	76.8	72.0		3863.9	5613.4	4255.8
Average	82.7	76.4	81.9	77.3	4144.8	4265.0	5477.0	4025.2
LSD 0.05	3.6	9.2	11.4	10.8	882.3	836.1	893.1	1632.0
CV%	5.8	8.59	1	17.018	15.2	14.33	11.7	20.5
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0222	0.0003	0.0026	0.8388

(**Table 3**). The highest grain yield was achieved by G1 in 2005 and 2008, G9 in 2006, and G10 in 2007 while the lowest grain yield was achieved by G11 in 2005, G27 in 2006, G17 in 2007 and G25 in 2008. The LSD among genotypes were 882, 836, 893 and 1632 kg/ha in 2005, 2006, 2007 and 2008, respectively. Average yield was 4145, 4265, 5477, and 4025 kg/ha during the 2005, 2006, 2007 and

2008, respectively. Pecio and Bichoński [39] reported that oat grain yield averaged 5198, 3600 and 3253 kg/ha during the 2005, 2006 and 2007 seasons and significantly varied with year, applied nitrogen and pesticide rates in the Grabów Experimental Station of the Institute of Soil Science and Plant Cultivation in Puławy, Poland. Oat grain yield was 2915 kg/ha in Manitoba [40]. Knaggs [32] found oat grain yield dependence on cultivar, nitrogen rates and the previous crop before oat production and varied from 4878 to 5309 kg/ha. Doehlert *et al.* [41] reported oat grain yield that varied with genotype and ranged from 3140 to 4110 kg/ha at Carrington, Edgeley, Minot and Prosper, ND. Tamm [14] reported inter-annual variation in oat grain yield at the Jogeva Plant breeding Institute in Estonia during the 1998-2002 period. From the evaluation of 21 oat genotypes in South Australian, Zaheri and Bahraminejad [42] reported oat grain yield that varied from 3580 to 9700 kg/ha under full irrigation and from 3188 to 7011 kg/ha under rainfed conditions and the genotypes Brusher, Tarahumara and Potoroo showed better performance than the rest of oat genotypes. Hisir *et al.* [43] reported the highest oat grain yield achieved by Checota cultivar from 17 oat genotypes evaluated for their yield performance at Kahramanmaras in Turkey.

4.4. Water Productivity of Oat

Oat CWUE varied with genotype and years and ranged from 0.53 to 0.75 kg/m^3 in 2005, from 0.65 to 0.96 kg/m^3 in 2006, from 0.76 to 1.07 kg/m^3 in 2007, and from 0.55 to 0.83 kg/m^3 in 2008 (**Table 4**). Overall average CWUE was 0.65, 0.78, 0.91 and 0.70 kg/m^3 in 2005, 2006, 2007 and 2008, respectively. For the study period, Genotype average CWUE was within the range of 0.65 - 0.87 kg/m^3 and the overall average CWUE was 0.76 kg/m^3. The highest CWUE was achieved by G19 and the lowest CWUE was obtained by G13. IWUE which represents the quantity of yield produced per cubic meter of water, varied from 0.57 to 1.20 kg/m^3 and was genotype dependent and average 0.70, 0.87, 1.01, and 0.68 kg/m^3 in 2005, 2006, 2007 and 2008, respectively (**Table 4**). On the four seasons basis, average IWUE varied with genotype from 0.71 to 0.95 kg/m^3 and the overall average IWUE was 0.83 kg/m^3. Similar to the CWUE and IWUE, ETWUE varied with genotypes and years and ranged from 0.57 to 1.21 kg/m^3 averaging 0.72, 0.78, 1.02, and 0.68 kg/m^3 in 2005, 2006, 2007 and 2008, respectively (**Table 4**). The four season average ETWUE varied with genotypes from 0.70 to 0.92 kg/m^3. ETWUE averaged 0.81 kg/m^3. As the irrigation amount, total water supply and total crop evapotranspiration were similar for all tested genotypes, the trends in CWUE, IWUE, and ETWUE strongly depend on the trends in grain yield and the highest ETWUE was achieved by the genotype with the highest CWUE and IWUE (G19) and the lowest water productivity was achieved by G13. There was 21%, 40% and 1% increase in CWUE in 2006, 2007 and 2008, respectively, compared to 2005 while there was 24.6% and 44% increase in IWUE in 2006 and 2007, respectively, and 3% decrease in IWUE in 2008. ETWUE increased by 8% in

Table 4. Spring oat crop-, irrigation-, and evapotranspiration use efficiency during the 2005-2008 period.

Genotypes	CWUE (kg/m³)				IWUE (kg/m³)				ETWUE (kg/m³)			
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
G1	0.75	0.85	0.93	0.83	0.81	0.95	1.04	0.86	0.84	0.85	1.05	0.86
G2	0.72	0.87	0.94	0.71	0.78	0.97	1.05	0.74	0.80	0.87	1.06	0.73
G3	0.58	0.72	0.77	0.58	0.63	0.80	0.86	0.61	0.65	0.72	0.87	0.61
G4	0.70	0.75	0.95	0.67	0.76	0.84	1.06	0.70	0.79	0.75	1.07	0.70
G5	0.70	0.90	0.97	0.63	0.76	1.00	1.08	0.66	0.78	0.90	1.09	0.66
G6	0.62	0.79	0.97	0.70	0.67	0.88	1.08	0.73	0.69	0.79	1.09	0.73
G7	0.70	0.93	0.88	0.71	0.76	1.04	0.98	0.74	0.78	0.93	0.99	0.74
G8	0.67	0.85	0.94	0.55	0.73	0.95	1.05	0.58	0.75	0.85	1.06	0.58
G9	0.69	0.96	0.97	0.63	0.75	1.07	1.08	0.66	0.77	0.96	1.09	0.66
G10	0.74	0.74	1.07	0.69	0.81	0.82	1.20	0.72	0.83	0.74	1.21	0.71
G11	0.53	0.77	0.95	0.59	0.58	0.85	1.06	0.61	0.60	0.76	1.07	0.61
G12	0.57	0.78	0.83	0.79	0.62	0.87	0.93	0.83	0.64	0.78	0.93	0.82
G13	0.55	0.67	0.77	0.63	0.60	0.74	0.86	0.65	0.62	0.66	0.86	0.65
G14	0.60	0.77	0.91	0.64	0.65	0.86	1.01	0.67	0.67	0.77	1.02	0.67
G15	0.65	0.78	0.82	0.64	0.71	0.87	0.91	0.67	0.73	0.78	0.92	0.67
G16	0.67	0.76	0.85	0.65	0.73	0.84	0.95	0.68	0.75	0.75	0.96	0.68
G17	0.54	0.74	0.76	0.63	0.59	0.82	0.85	0.66	0.61	0.74	0.85	0.66
G18		0.70	0.86	0.59		0.78	0.96	0.62		0.70	0.97	0.61
G19		0.90	1.07	0.62		1.00	1.20	0.65		0.90	1.21	0.65
G20		0.78	1.01	0.68		0.86	1.13	0.71		0.77	1.15	0.71
G21		0.91	0.98	0.65		1.02	1.09	0.68		0.91	1.11	0.67
G22		0.80	0.93	0.67		0.89	1.03	0.70		0.80	1.04	0.69
G23		0.82	0.93	0.71		0.92	1.04	0.75		0.82	1.05	0.74
G24		0.70	0.87	0.65		0.78	0.97	0.68		0.70	0.98	0.68
G25		0.73	0.85	0.55		0.82	0.95	0.57		0.73	0.96	0.57
G26		0.65	0.91	0.64		0.73	1.01	0.66		0.65	1.02	0.66
G27		0.65	0.76	0.59		0.72	0.85	0.61		0.65	0.86	0.61
G28		0.71	0.93	0.69		0.79	1.04	0.72		0.71	1.05	0.72
Average	0.65	0.78	0.91	0.65	0.70	0.87	1.01	0.68	0.72	0.78	1.02	0.68

2006 and 41% in 2007 and decreased by 6% in 2008. The decrease in IWUE and ETWUE was due to a decrease in crop yield when the change in seasonal irrigation amount and crop water use was negligible. Seasonal crop evapotranspiration was dependent on the seasonal reference evapotranspiration and the growing season duration, rather than the crop coefficients values. Seasonal average crop coefficient value was 0.63 for all seasons and the cropping season duration was 105, 109, 113, and 115 days in 2005, 2006, 2007 and 2008, respectively (**Figure 4**). CWUE, IWUE and ETWUE showed positive linear relationships with

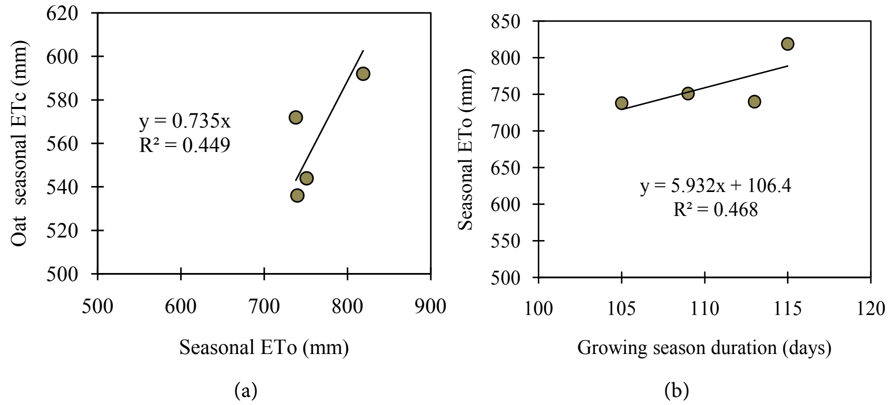

Figure 4. Relationship between (a) oat average seasonal evapotranspiration (ETc) and the seasonal reference evapotranspiration (ETo), and (b) seasonal reference evapotranspiration (ETo) and the growing season duration.

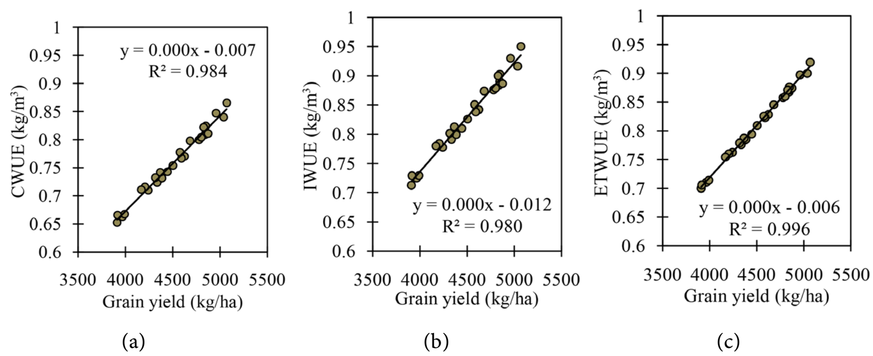

Figure 5. Relationship between average irrigation water use efficiency (IWUE)-, average crop water use efficiency (CWUE)-, average evapotranspiration water use efficiency (ETWUE) and Spring oat average grain yield.

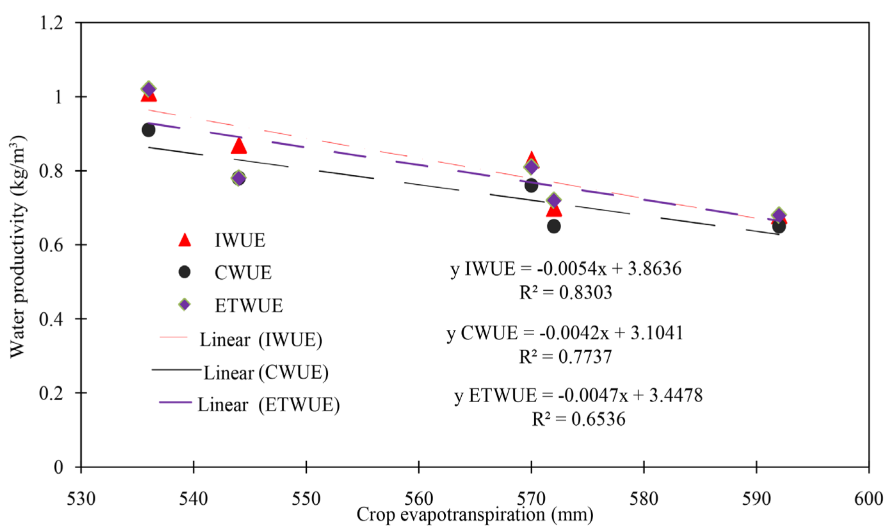

Figure 6. Relationship between oat irrigation water use efficiency (IWUE)-, crop water use efficiency (CWUE)-, evapotranspiration water use efficiency (ETWUE) and Spring oat actual evapotranspiration.

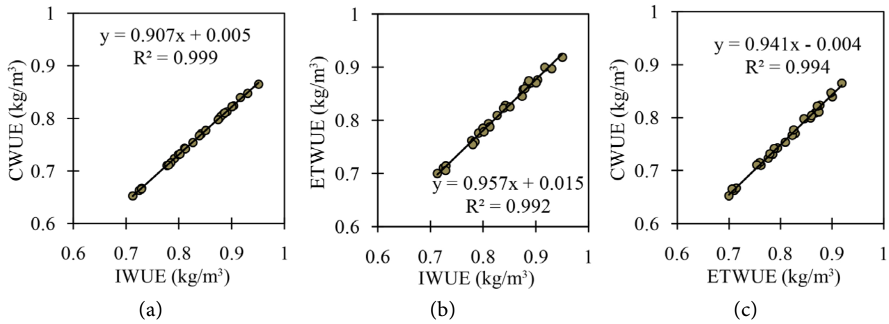

Figure 7. Relationships between average irrigation water use efficiency (IWUE)-, average crop water use efficiency (CWUE), and average evapotranspiration water use efficiency (ETWUE).

the average grain yield ($R^2 > 0.98$) (**Figure 5**) and decreased linearly with seasonal evapotranspiration ($R^2 > 0.65$) (**Figure 6**). There were strong linear relationships between CWUE, IWUE, and ETWE with R^2 close to unity (**Figure 7**). Yuan *et al.* [44] reported oat water productivity (WP) to vary from 1.1 to 1.3 kg/m^3 in China while Lin *et al.* [16] reported oat ETWUE as function of applied nitrogen fertilizer rate and ranged from 1.02 to 1.24 kg/m^3. The environment, management practices, sowing date, and the genotype might have strong effect on the variability of water use efficiency [16] [45] [46] [47].

5. Conclusion

Field experiment was conducted to evaluate the performance of twenty-eight Spring oat genotypes under irrigation conditions during four growing seasons at the NMSU Agricultural Science Center, Farmington, NM. Seasonal irrigation amount varied from 488 to 591 mm and the Spring oat seasonal evapotranspiration varied from 535.8 to 591 mm. Oat plant height significantly varied with genotypes. Oat grain yield also significantly varied with years and genotypes and ranged from 3386 to 6498 kg/ha. The best performing genotypes at Farmington and which are suitable for Farmington, New Mexico, were G1, G2, G7, G19, G20, G21 and G23 with average yield greater than 4800 kg/ha while G3, G13, G17 and G27 showed the lowest yield among the genotypes. Oat CWUE, IWUE and ETWUE varied with genotype and years and ranged from 0.53 to 1.07 kg/m^3, 0.57 to 1.20 kg/m^3, and 0.57 to 1.21 kg/m^3, and averaged 0.76, 0.83, and 0.81 kg/m^3, respectively. The results of this study demonstrate the possible incorporation of oat production into the cropping systems in the Four Corners region for grain yield or forage production. However, additional research needs to be conducted to determine the best agricultural practices on oat, the optimum water and fertilizer requirements and application timing and the optimum planning window to cope with the late Spring and the early Fall freeze that usually occurs at the high elevation in the Four Corners region.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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