Genotype by Irrigation Management Interactions in Elite Alfalfa Germplasm

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Introduction

Alfalfa (*Medicago sativa L.)* is the most economically important forage crop in the U.S., and 48% of the nation's alfalfa hay is produced under irrigated conditions in the West. However, rapidly diminishing surface and ground water resources threaten hay production throughout much of this region. Identifying elite germplasm with high yield potential in variable soil moisture environments can help optimize alfalfa forage production and sustainability while conserving water. Superior germplasm can subsequently be utilized in plant breeding programs to further improve alfalfa's yield potential in water-limited environments.

Objectives

- Determine the productivity of 24 elite alfalfa populations developed by conventional and DNA marker assisted breeding methods under three flood irrigation management regimes.
- Identify germplasms that are productive under highly variable soil moisture conditions.
- To assess the magnitude and significance of genotype by environment interactions.

Materials & Methods

Plant material

24 alfalfa elite populations including:

- Nine commercial cultivars and two industry breeding lines
- Three NMSU cultivars and 10 breeding lines developed by DNA marker assisted selection (MAS) and/or phenotypic recurrent selection for improved drought resilience.

Location

Leyendecker Plant Science Research Center, near Las Cruces, NM (32^{0}11' 45.83" N, 106^0 44' 25.28" W)

Flood Irrigation Treatments (Figure 1)

- Control (**C**): 14-day irrigation interval during growing season. Seasonal irrigation allotment ~1300 mm.
- Early Termination (**ET**): Same as control during February to June, followed by no irrigation during July to January. Seasonal irrigation allotment ~760 mm.
- Deficit (**D**): 28-day irrigation interval during growing season. Seasonal irrigation allotment ~700 mm.

Experimental design:

- Randomized Complete Block Design with four replicates nested within each irritation treatment.
- Field plots of the 'NuMex Bill Melton' cultivar were planted at regularly spaced intervals to provide a covariate to adjust for effects of soil texture variability on soil water-holding capacity.

Data collection

- D and C irrigation treatments: six and five forage harvests collected in 2015 and 2016, respectively.
- ET irrigation treatment: three forage harvests collected each year.
- Leaf relative water content measurements taken from 'NuMex Bill Melton' cultivar 24 hours prior to each harvest for all treatments .

Statistical Analysis

Forage yield data were analyzed in PROC GLM and PROC MIXED (SAS version 9.3 & 9.4). Entries, irrigation treatments and years were fixed effects, and replicates were random effects.

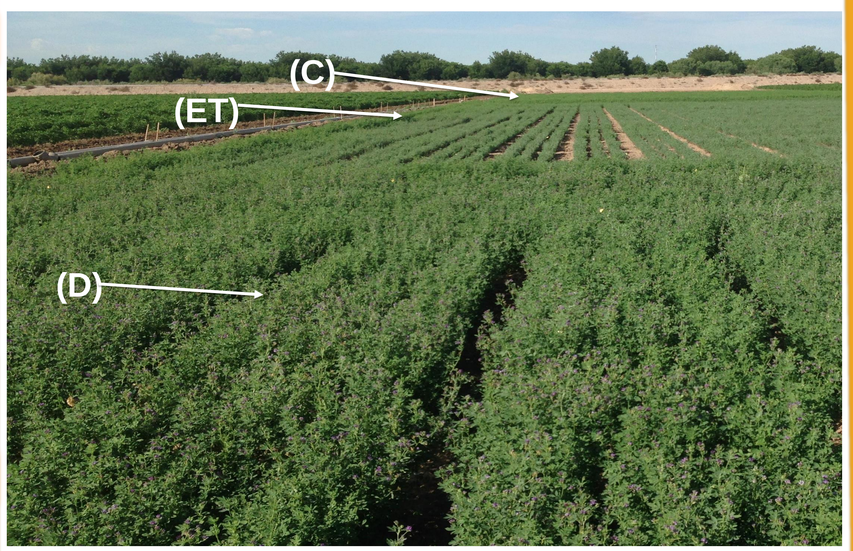

Figure 1. June 2016 alfalfa forage regrowth (10 days after irrigation) for three irrigation treatments: (D) Deficit, prior to on-set of stress; (ET) Early termination, final regrowth cycle prior to termination of irrigation; (C) Control.

Results

Table 1. Climate information for study site in 2015 & 2016†

	Temperature (^{0}C)						
Year	Max	Min	Avg. Max	Avg. Min	No. Days Max Temp >37.8^{0}C‡	No. Days Min Temp <10.0^{0}C‡	Precipitation (mm)
2015	39.5	-4.9	30.1	12.9	9	83	186
2016	41.8	-2.0	30.7	12.3	27	100	131

† March 1 to October 28
‡ 37.8^{0}C=100^{0}F; 10.0^{0}C=50^{0}F

Table 2. Leaf relative water content, NuMex Bill Melton Cultivar

	2015			2016		
Harvest	D	ET	N	D	ET	N
April	-	-	-	55.4	76.1	75.3
May	69.3	83.4	82.3	58.9	64.6	68.1
June	62.9	82.1	79.8	60.0	67.4	67.3
July	58.3		69.1	62.8		76.1
September	58.6		76.9	65.8		79.6
October	65.4		78.4	NA		NA
Mean	62.9	82.7	77.3	60.6	69.4	73.3

† D, Deficit; ET, Early Termination; C, Control irrigation treatments (see Materials & Methods)
‡ NA, Not available. Six harvests completed in 2015; five harvests completed in 2016, with October harvest pending.

Table 3. Dry matter yield (Mg ha^{-1}) mean squares of 24 elite alfalfa germplasms under three irrigation treatments in 2015 & 2016.

Source	df	2015	2016	df	Across Years
Treatment (**T**)	2	259.91**	360.92**	2	605.48**
Rep$_{[T]}$	9	21.27**	2.19**	9	17.31**
Genotype (**G**)	23	2.00**	0.51**	23	2.04**
G×T	46	0.56*	0.17	46	0.53
G×Rep$_{[T]}$	206	0.39	0.18	207	0.43**
Year (**Y**)				1	6.12**
T×Y				2	0.09
G×Y				23	0.60**
T×G×Y				46	0.27
Residual				215	0.25
CV (%)		8.7	10.2		8.9

Table 4. Dry matter yield summary statistics associated with 24 elite alfalfa germplasms under three irrigation treatments in 2015 & 2016.

Summary statistics	2015			2016‡		
	D†	ET†	C†	D	ET	C
Mean all entries	14.2	13.7	20.3	6.0	7.8	14.3
Range all entries	11.9 - 16.6	11.7 - 15.2	17.8 - 22.7	4.8 - 6.8	7.1 - 8.4	12.8 - 16.0
LSD$_{(0.05)}$	2.4	0.9	1.8	1.1	NS	NS
CV (%)	12.1	4.6	6.3	12.6	9.6	8.9

† D, Deficit; ET, Early Termination; C, Control irrigation treatments (see Materials & Methods)
‡Six harvests completed in 2015; five harvests completed in 2016, with final (i.e. sixth) harvest pending.

Results Summary

- **Table 1**. Relative to 2015, 2016 was drier with greater temperature variation, and three-fold more days with extreme high temperatures
- **Table 2**. Leaf relative water contents were similar in the C and ET treatments, and consistently greater than those of the D treatment.
- **Table 3**. Significant variation detected among genotypes over the three irrigation treatments within and across years.
  - G × T interaction not detected in 2016 nor "Across-Years".
  - G × T interaction detected in 2015, where three harvests for the ET and six harvests for the D and C treatments were analyzed. Reanalysis of D, C, and ET data based only on the first three harvests in 2015 detected no G × T interaction (P=0.2).
  - G × Y interaction detected. Reanalysis within each treatment detected significant G × Y for the ET, but not C or D treatments.
- **Table 4.** Relative to 2015, observed 2016 yield reductions for all irrigation treatments were attributed to one less harvest (pending data collection) and less favorable climatic conditions in 2016.
  - Significant variation among genotypes was not detected in the C and ET treatments in 2016.

Conclusions

- Nonsignificant variation among genotypes in the C and ET treatments in 2016 compromised the ability to detect genotype by irrigation treatment interactions in 2016 and across years.
- A significant G × T interaction in 2015 appeared to result from genotype performance based on three harvests for the ET treatment, as compared to six harvests for the C and D treatments.
- A significant G × Y interaction in the ET treatment was primarily attributed to termination of irrigation during the second half of the 2015 growing season, which impacted the relative performance of genotypes in 2016 (post-stress) as compared to 2015 (pre-stress).
- Collection of third and fourth production year data are planned to monitor the long-term impact of these irrigation treatments on genotype productivity.
- Performance of genotypes across irrigation treatments and years, identified two commercial cultivars and four NMSU breeding lines that performed well over all environments.

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