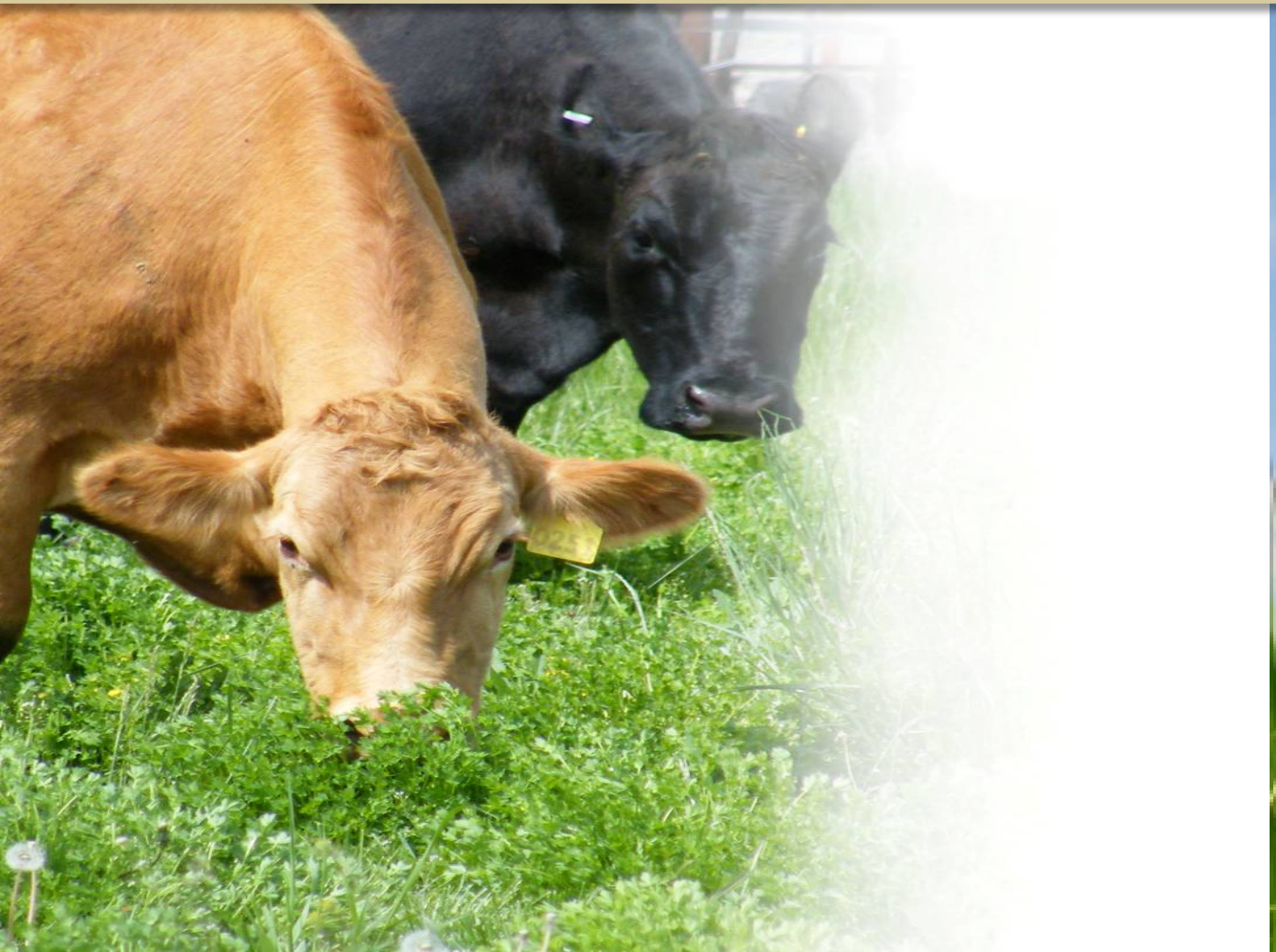
HERITABILITY OF RESILIENCE TO DEFICIT IRRIGATION IN TALL FESCUE

Forage and Range Research Laboratory



Blair L Waldron

USDA-ARS Forage and Range Research
Logan, UT, USA

Valentin D Picasso

University of Wisconsin
Madison, WI, USA

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"RESILIENCE"

What is 'Resilience'?

- Resilience is perhaps one of the predominate 'Buzz' words of the decade – often associated with climate change
  - Appeared 22 times in USDA-ARS Forage and Range Research 5-year plan (2019-2024)
- "Resilience in forage and grazingland systems is difficult to quantify." Tracy et al., 2018. Crop Science.
- "Resilience is the ability to withstand a short-term crisis, perturbation, or shock, like drought . . ." Picasso et al., 2019. Crop Science.
- In order to study resilience, an operational measure of resilience is needed. Picasso et al., 2019. Crop Science.

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RESEARCH

Resilience, Stability, and Productivity of Alfalfa Cultivars in Rainfed Regions of North America

Valentin D. Picasso,* Michael D. Casler, and Dan Undersander

Published in Crop Sci. 59:800–810 (2019).
doi: 10.2135/cropsci2018.06.0372

- Proposed Productivity, Stability, and Resilience variable operational definitions.
  - e.g., a metric that would enable examining differences in resilience among alfalfa cultivars
- Based upon identifying a crisis event/year/environment from forage yield trials/ datasets.

- Is Resilience a heritable trait?
- Can we breed for improved resilience per se in a forage species?
- Could we use a line-source sprinkler experiment to simulate a 'crisis' drought environment?

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Materials and Methods

Studied these questions using a line-source sprinkler irrigation – tall fescue forage mass data set.

- Plant Materials and Plots:
  - 30 Tall fescue (*Schendonorus arundinaceus* [Schreb.] Dumort, nom. Cons.) half-sib families (HSF).
    - HSF developed by 2-cycles of selection for soft leaves and vegetative vigor in non-competitive spaced-plant nurseries.
  - Sward plots were established in a line-source sprinkler experiment.
    - Irrigation gradient established such that there were five 2-m ranges with the range closest to the sprinkler received 110% of evapotranspiration (ET) replacement and each successive distal range experiencing greater deficit irrigation.
    - **i.e., five ranges that received 110, 88, 62, 43, and 20% growing season ET replacement, respectively**.
  - Plots were mechanically harvested five times per growing season, and yearly forage mass determined for three consecutive years (2001, 2002, 2003).

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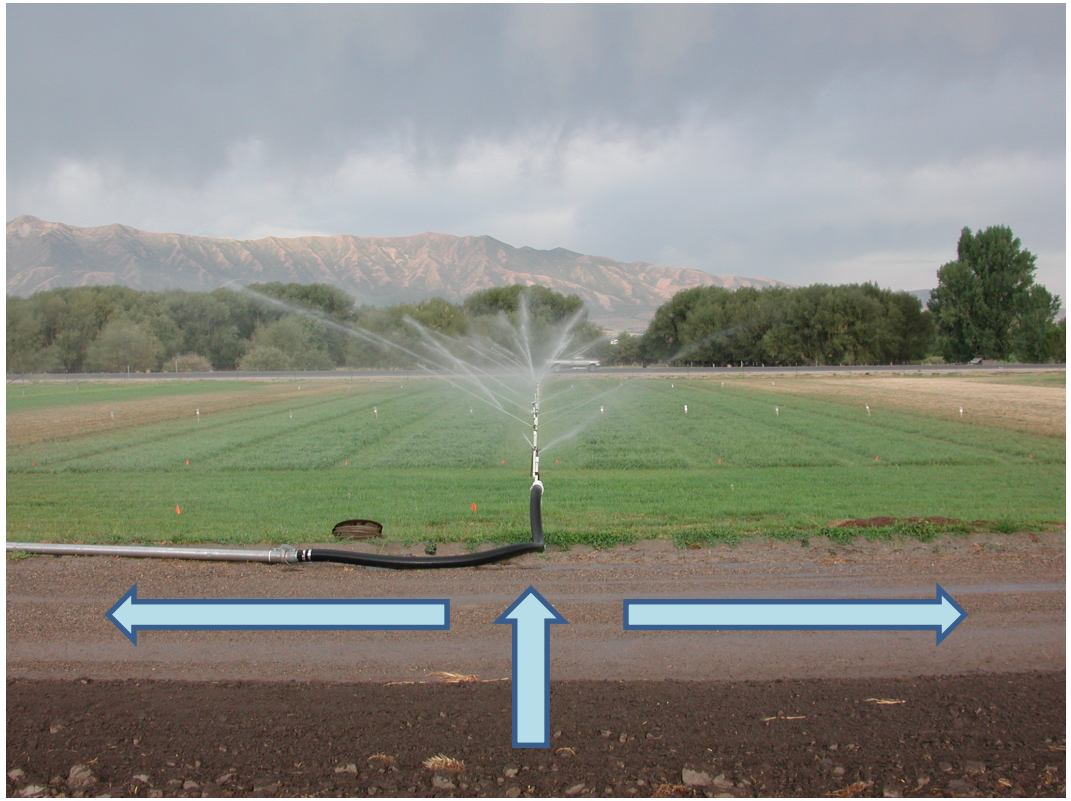
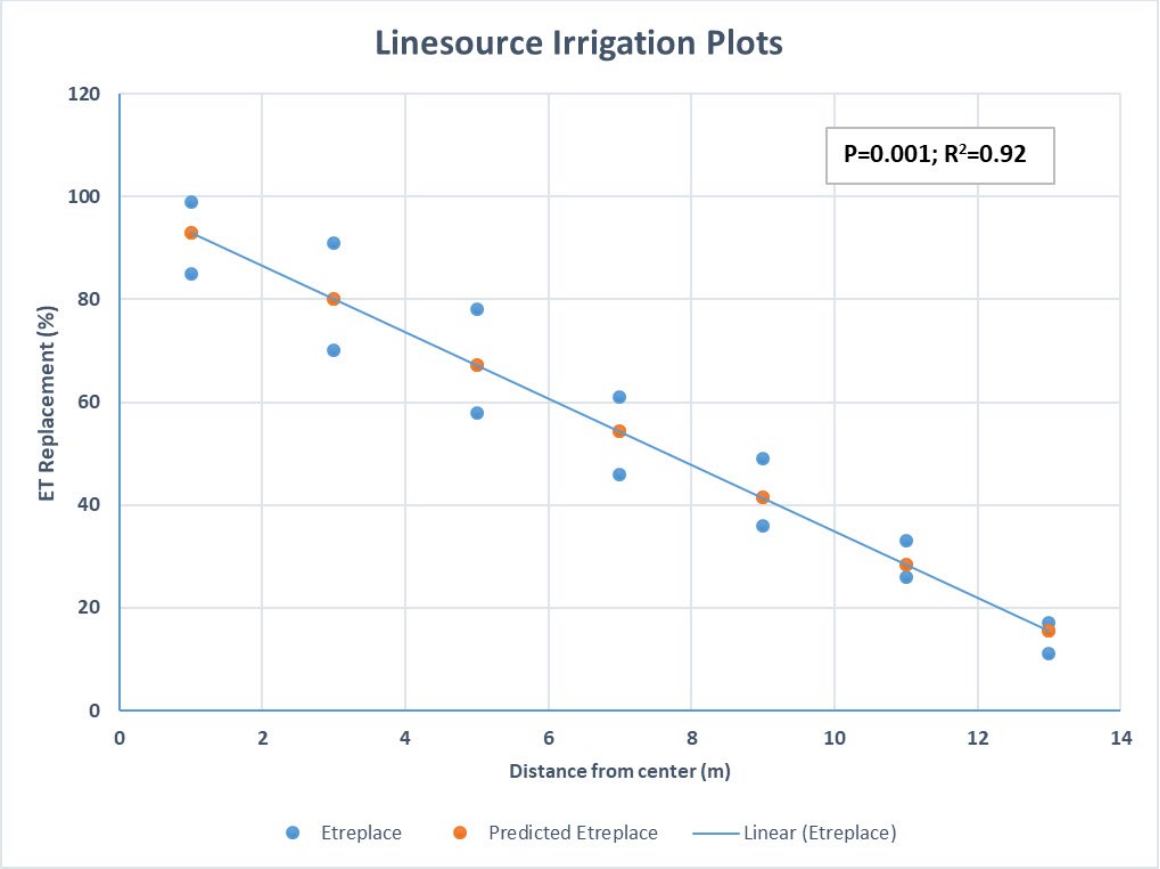
Line-source Sprinkler Irrigation: Linear water gradient





WL5 (20% ET replacement) receives
~ 0 supplemental irrigation.

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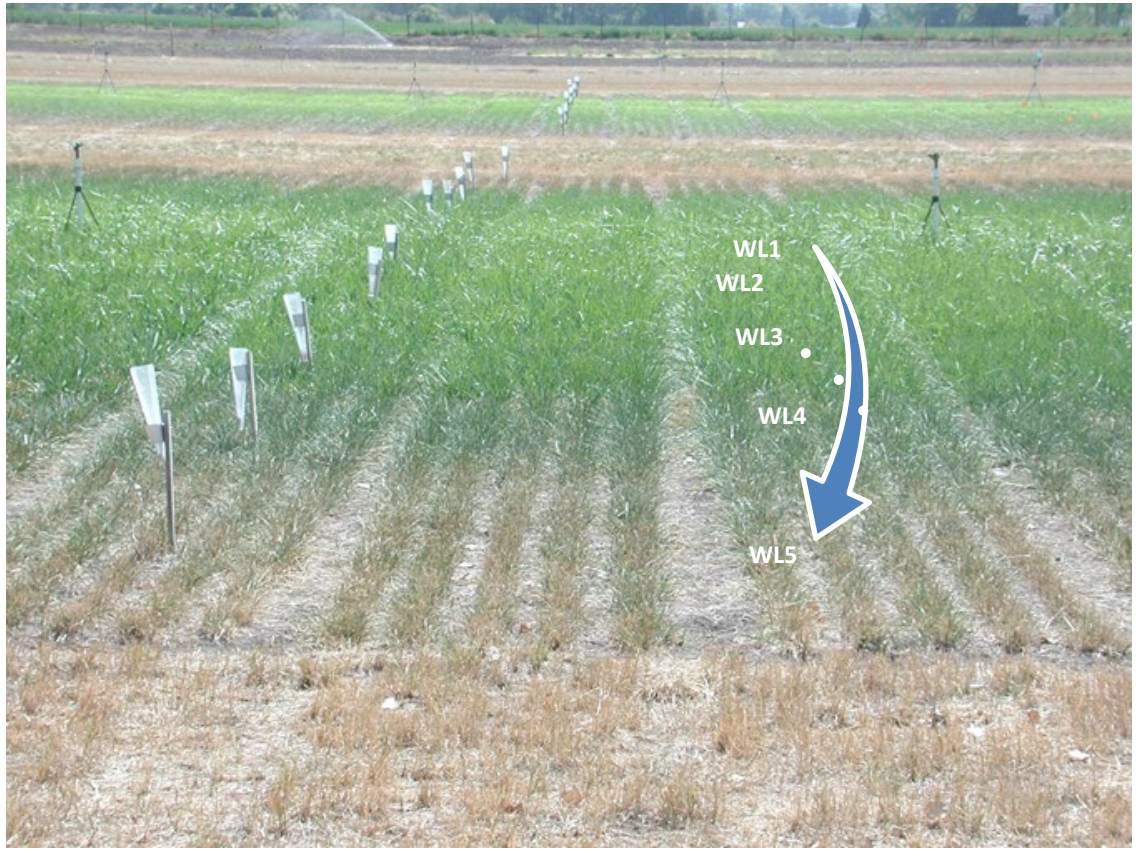
Line-source Irrigation: Seasonal growth gradient



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Materials and Methods: Harvesting

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Materials and Methods: Variable definitions

- "Variable Operational Definitions":
  - Productivity, Stability, and Resilience estimated for each HSF.
    - Picasso et al. 2019. Crop Sci. 59:800-810.
    - Considering each irrigation level a different environment.
    - Considering the lowest irrigation level (20% ET replacement) as the crisis environment.
    - Calculated within years and reps.

$$P_{jl} = \frac{\sum_{i}^{n-1} Y_{ijl}}{n-1} \qquad S_{jl} = \frac{P_{jl}}{\mathrm{SE}\left(P_{jl}\right)} \qquad R_{jl} = \frac{\mathrm{Yc}_{jl}}{P_{jl}}$$

  - Where P_{jl} is Productivity and Y_{ijl} is yield of HSF *j* in replication *i* for irrigation environment *l;* (i.e., mean forage mass over non-crisis environments).
  - Where S_{jl} is Stability and $SE(P_{jl})$ is the standard error of the productivity.
  - Where R_{jl} is Resilience and Yc_{jl} is yield of HSF *j* in the crisis irrigation environment *l;* (i.e., ratio of crisis to non-crisis productivity).

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Materials and Methods: Genetic correlations

- Genetic Analysis:
  - Narrow-sense heritabilities (h^2) estimated for forage Productivity, Stability, and Resilience and at each irrigation level; and
  - Genetic correlations (r_G) estimated between Productivity, Stability, and Resilience and each irrigation level.
    - Genetic correlation is based upon resemblance between relatives (e.g. variance between HSF = ¼ genetic variance).
    - "The genetic correlation expresses the extent to which two measurements reflect what is genetically the same character." (Falconer, 1989)
    - Can be extended to the genetic correlation between 'selection environments'.
    - $r_G = cov_{xy}/sqrt\ var_x\ var_y$
    - ". . . the magnitude and even the sign of the genetic correlation cannot be determined from phenotypic correlation alone" because r_P includes environmental correlation (Falconer, 1989).

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Materials and Methods: Correlated response

- Genetic Analysis continued:
  - Predicted response of direct selection, and correlated response and relative efficiency (RE) of indirect selection estimated for 1-cycle of selection on a HSF mean basis.
    - Bernardo. 2002. Breeding for Quantitative Traits in Plants, Stemma Press; Falconer. 1989. Quantitative Genetics, Wiley and Sons.
    - Response: $R_x = k_p\, h_x\, \sigma_{G(x)}$;
    - Correlated Response: $CR_x = k_p\, h_x\, r_G\, \sigma_{G(y)}$;
    - RE: $CR_x/R_x = r_G\, h_y/h_x$;
    - If RE > 1.0 then indirect selection more efficient.
    - Assumed a selection intensity of 15% such that the standardized selection differential (k_p) = 1.446.

Mike Casler: "Progress = (intensity X accuracy X variation) ÷ time"

So we are predicting progress from breeding for increased Resilience:

= (selection intensity X genetic correlation X heritability) ÷ 1-cycle of selection

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RESULTS & DISCUSSION

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Results: Forage mass

Table 1. Average forage mass of 30 tall fescue half-sib families (HSF) growing in varying deficit irrigation environments.

Irrigation Level	ET Replacement	Forage Mass	P-value (among HSF)
	%	- Mg ha^{-1} -	
WL 1	110	12.9	0.0441
WL 2	88	11.7	0.0249
WL 3	62	8.8	0.1093
WL 4	43	6.7	0.0283
WL 5	20	4.9	0.0001

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Results: Productivity, Stability, and Resilience estimates

Table 2. Value and significance of average Productivity, Stability, and Resilience variables for forage mass of tall fescue half-sib families growing in varying deficit irrigation environments.

Crisis environment	Variable	Mean Value	P-value (among HSF)
Included in calculation			
	Productivity(1)	**8.989**	**0.0017**
	Stability(1)	**2.677**	**0.6673**
	Resilience(1)	**5.427**	**0.0669**
Not included in calculation			
	Productivity(2)	**10.011**	**0.0094**
	S[illegible]	[illegible]	[illegible]
	Resilience(2)	**4.896**	**0.0617**

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Results: h^2, r_G, and RE of indirect selection for deficit irrigation using Productivity an Resilience estimates

Table 3. Heritabilities, genetic correlations (r_G), and relative efficiencies of indirect selection for forage mass of tall fescue under deficit irrigation

Variable/Environment	h^2	$r_{G(Productivity, WL)}$	$RE_{indirect}$	$r_{G(Resilience, WL)}$	$RE_{indirect}$
Productivity	0.65 ± 0.10				
Resilience	0.44 ± 0.16				
WL1, 110%ET	0.62 ± 0.11	0.91 ± 0.07	0.93	0.29 ± 0.43	0.24
WL2, 88%ET	0.61 ± 0.11	0.87 ± 0.09	0.90	0.04 ± 0.40	0.03
WL3, 62%ET	0.46 ± 0.15	0.89 ± 0.10	1.06	0.17 ± 0.48	0.17
WL4, 43%ET	0.56 ± 0.15	0.96 ± 0.11	1.04	-0.20 ± 0.41	-0.18
WL5, 20%ET	0.62 ± 0.13	0.74 ± 0.20	0.76	0.73 ± 0.17	0.62

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Productivity	**0.65 ± 0.10**				
Resilience	**0.44 ± 0.16**				
WL1, 110%ET	**0.62 ± 0.11**	**0.91 ± 0.07**	**0.93**	*~0*	*N/A*
WL2, 88%ET	**0.61 ± 0.11**	**0.87 ± 0.09**	**0.90**	*~0*	*N/A*
WL3, 62%ET	**0.46 ± 0.15**	**0.89 ± 0.10**	**1.06**	*~0*	*N/A*
WL4, 43%ET	**0.56 ± 0.15**	**0.96 ± 0.11**	**1.04**	*~0*	*N/A*
WL5, 20%ET	**0.62 ± 0.13**	**0.74 ± 0.20**	**0.76**	**0.73 ± 0.17**	**0.62**

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h^2, r_G, and predicted RE of indirect selection between irrigation levels

Table 2. Heritability, genetic correlation estimates (r_G), and relative efficiency of indirect selection for forage mass of tall fescue under deficit irrigation

	h^2	$r_{G(WL5, WLi)}$	$RE_{indirect}$	$r_{G(WL1, WLi)}$	$RE_{indirect}$
WL1, 110%ET	**0.62 ± 0.11**	**0.82 ± 0.23**	**0.82**	**- - -**	**- - -**
WL2, 88%ET	**0.61 ± 0.11**	**0.61 ± 0.25**	**0.61**	**0.66 ± 0.20**	**0.66**
WL3, 62%ET	**0.46 ± 0.15**	**0.72 ± 0.30**	**0.72**	***0.17 ± 0.48***	***0.17***
WL4, 43%ET	**0.56 ± 0.15**	**0.53 ± 0.27**	**0.53**	***-0.20 ± 0.41***	***-0.18***
WL5, 20%ET	**0.62 ± 0.13**	**- - -**	**- - -**	**0.73 ± 0.17**	**0.62**

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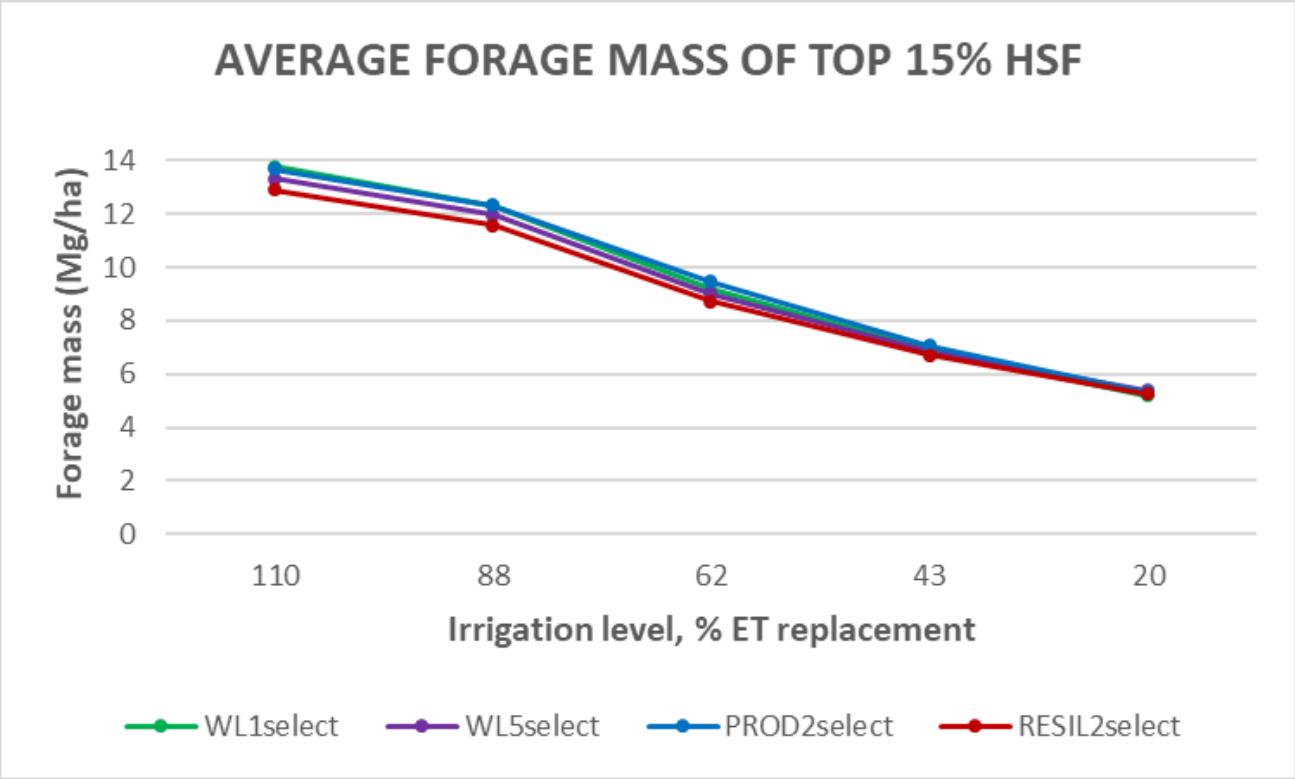
Top 15% HSF: Mean forage mass and Spearman's rank correlation from direct and Indirect selection



	WL1RANK	*WL5RANK*	*PROD2RANK*	*RESIL2RANK*
WL1RANK	1			
WL5RANK	0.51	1		
PROD2RANK	0.83	0.58	1	
RESIL2RANK	-0.04	0.71	-0.05	1

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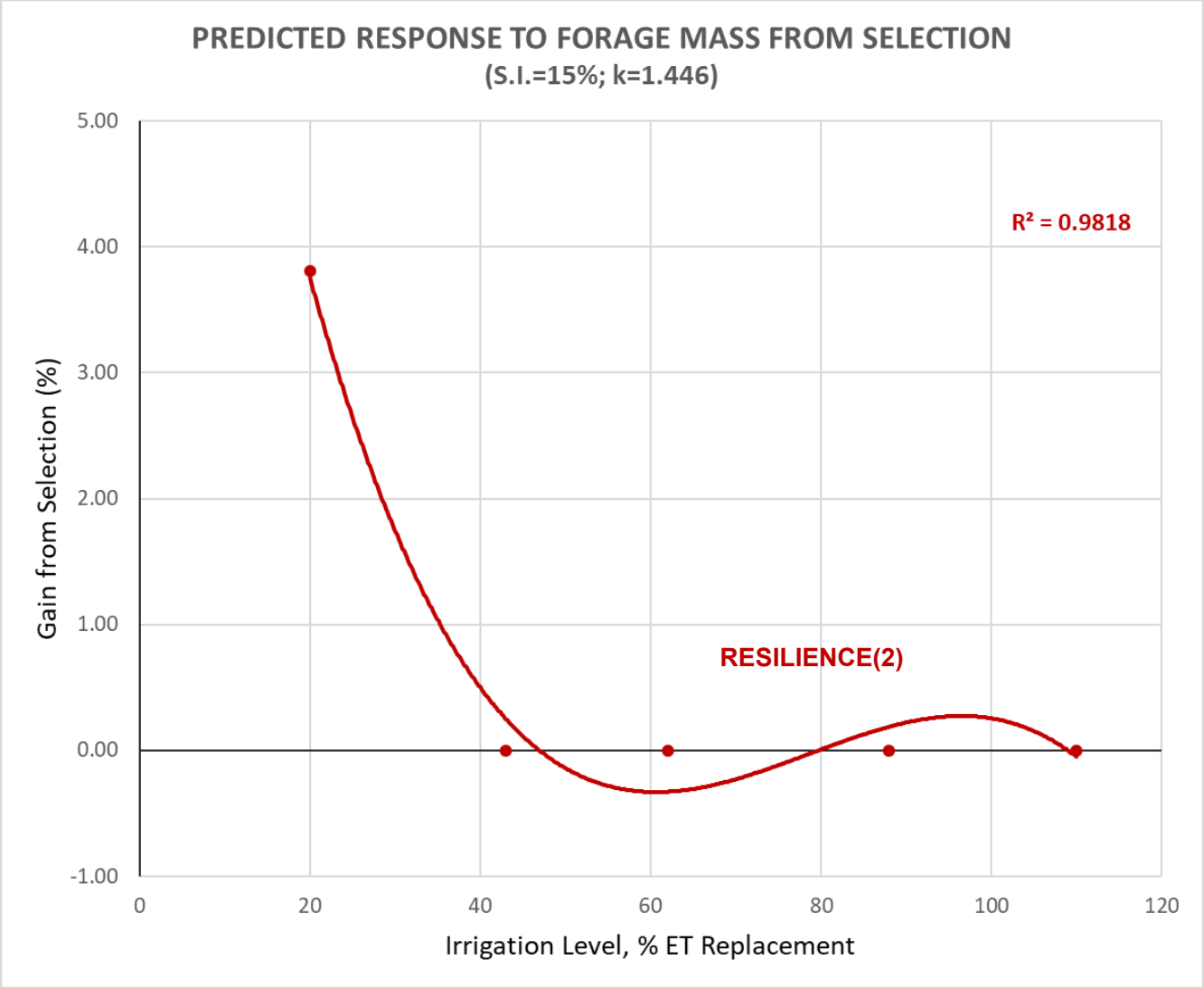
Predicted response to selection for increased RESILIENCE



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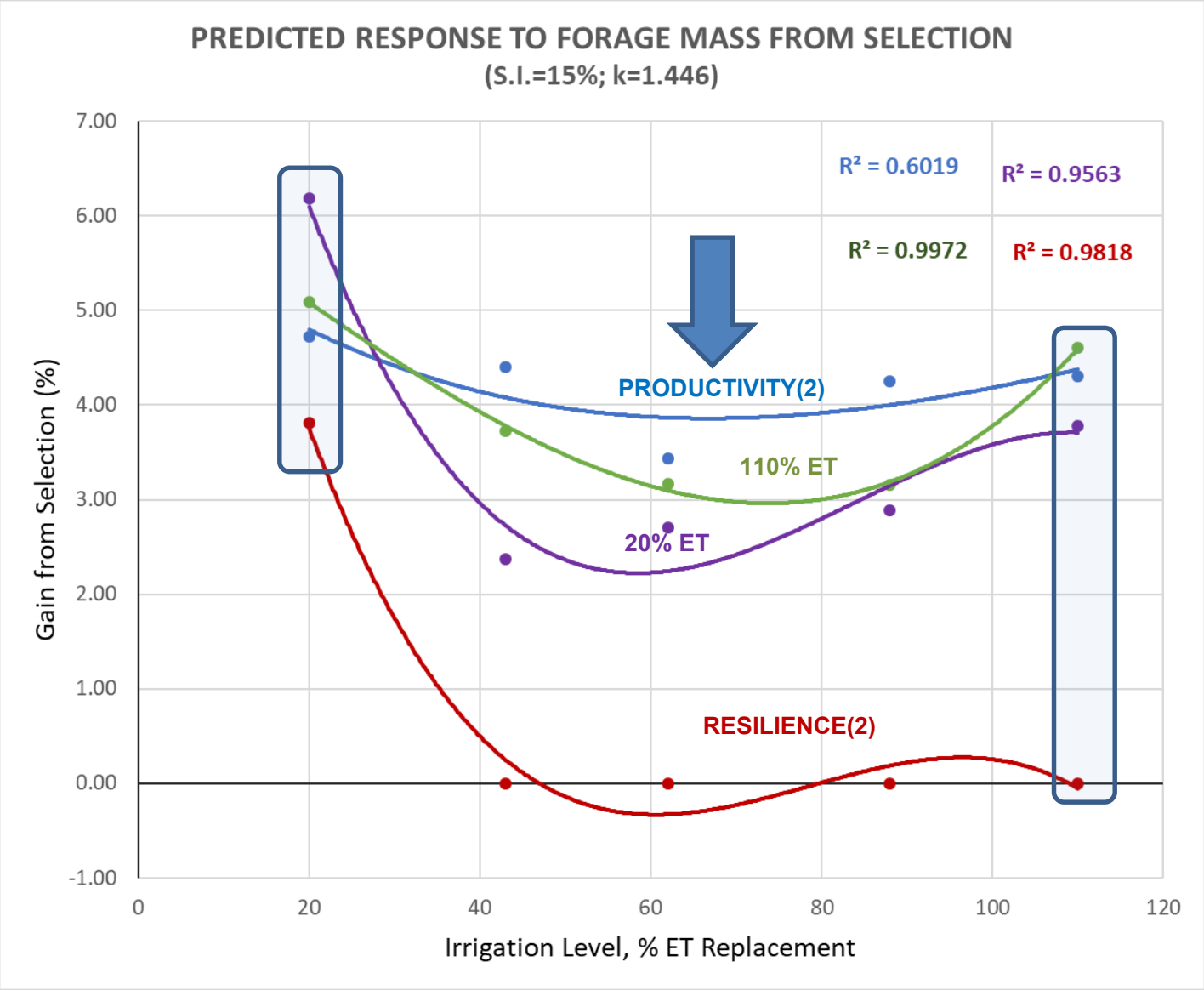
Predicted response to selection for increased PRODUCTIVITY, RESILIENCE, or forage mass at 110 and 20% ET



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Indirect Selection/Correlated Response

- Univ. of Minnesota 1993, Dr. Don Rasmusson's Plant Breeding Class:
  - In many instances, selection in a highly-productive, non-target environment is best because it has lower plot variability and higher heritability -----
  - AND translates to higher yield in the stress environment.

Euphytica **64:** 49-58, 1992.

Relationship between barley grain yield measured in low- and high-yielding environments

Salvatore Ceccarelli, Stefania Grando & John Hamblin
The International Center for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 5466, Aleppo, Syria

Received 7 May 1992; accepted 17 September 1992

Euphytica **44:** 137-142, 1989.

Predicting the relative effectiveness of direct versus indirect selection for oat yield in three types of stress environments

Gary N. Atlin[1] and Kenneth J. Frey
Dept. of Agronomy, Iowa State Univ., Ames, IA 50011; USA; [1]present address: Biotechnica Canada Inc.170, 6815-8 Street N.E., Calgary, Alberta 12E 7H7 Canada

Received 14 June 1988; accepted in revised form 6 October 1988

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Conclusions

- Resilience to deficit irrigation can be measured and is a heritable trait – thus resilience can be improved per se by plant breeding.
- Resilience to deficit irrigation was not correlated with productivity in 'non-crisis' environments.
- Assuming the 'crisis' environment can be predicted/simulated, then direct selection within that environment was more effective to improve performance (in this population of tall fescue).
- Selection for increased 'Productivity' was predicted to improve performance across both crisis and non-crisis irrigation environments.
- What if only examined the immediate recovery after the crisis (e.g., first harvest each year) or used a different irrigation level (e.g., 43% ET replacement) as the 'crisis' environment?

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Questions