Alfalfa to get back into planetary boundaries

2025 world alfalfa congress
FRANCE REIMS-CHÂLONS

High yield alfalfa for low carbon livestock in stressful climate

Brummer C. & Odorizzi A.

Plenary session 6

FROM 03 › TO 06
nov. 2025

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2025 world alfalfa congress FRANCE REIMS - CHÂLONS

Breeding alfalfa for adaptation to the changing climate

Annicchiarico P., Nazzicari N., Laouar M., Franguelli N., Pecetti L.

crea Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

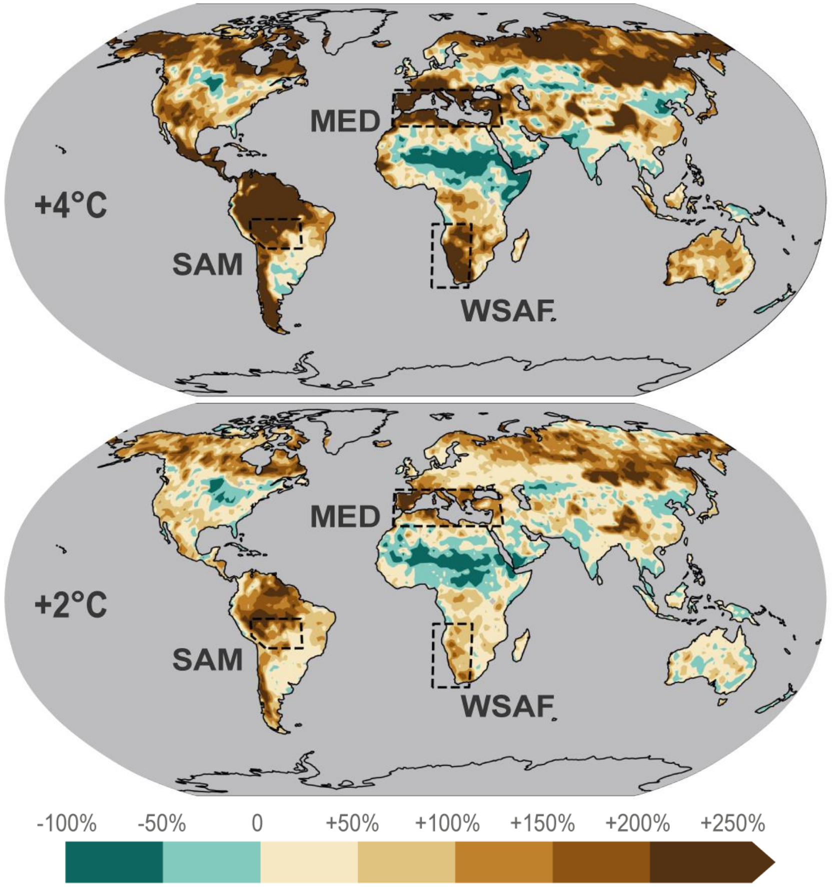
ECOLE NATIONALE SUPERIEURE AGRONOMIQUE

FROM 03 › TO 06 nov. 2025

Drought is the main stress - and is bound to increase

Increasing frequency and severity due to climate change and less irrigation water

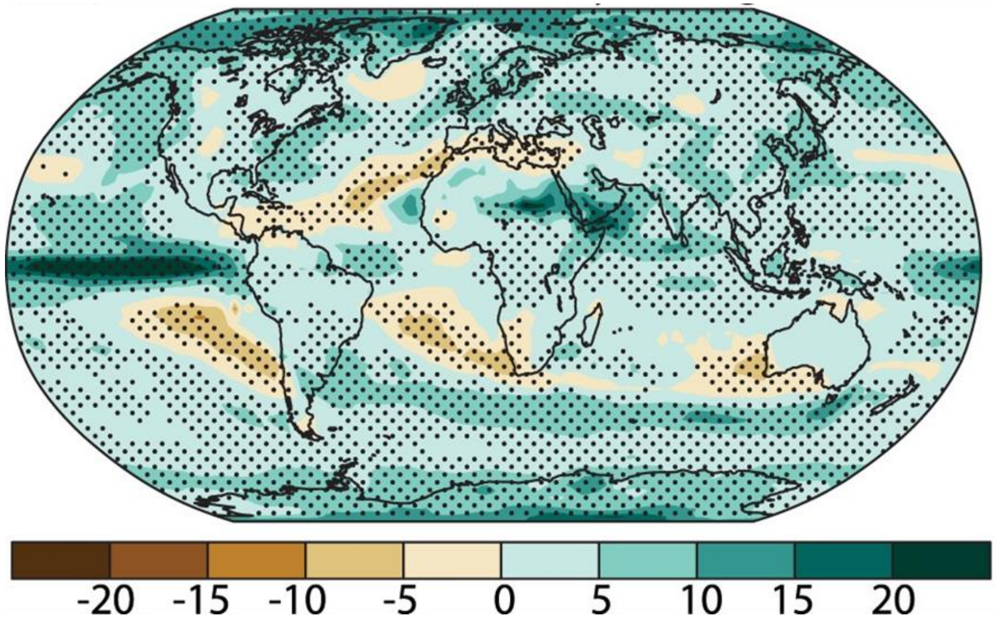
Predicted changes in the likelihood of an extreme single-year drought event for different climate change scenarios



Caretta et al. (2022) In: Climate Change 2022: Impacts, adaptation, and vulnerability. Cambridge Univ. Press, pp 551-712

Increasing year-to-year climate variability

Predicted change in rainfall seasonal standard deviation for the period 2071-2100 compared to 1976-2005 (in %)



Pendergrass et al. (2017) Sci. Rep. 7: 17966

Alfalfa may out-yield annual legume crops even under extreme drought

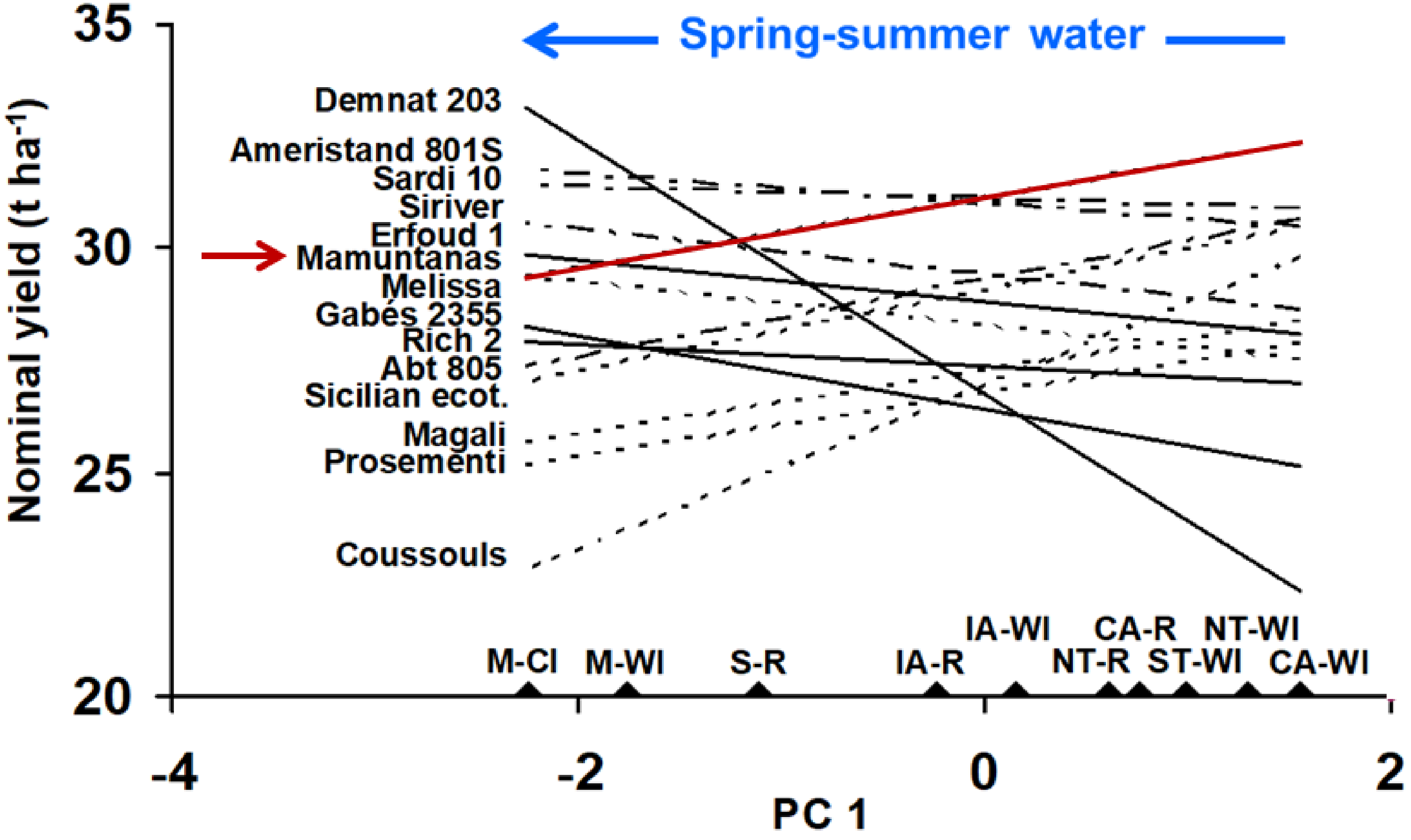
Average annual dry biomass yield of alfalfa-based, pea-based and vetch-based crops in regions with moderate (Sardinia) or extreme (inland Morocco) drought stress

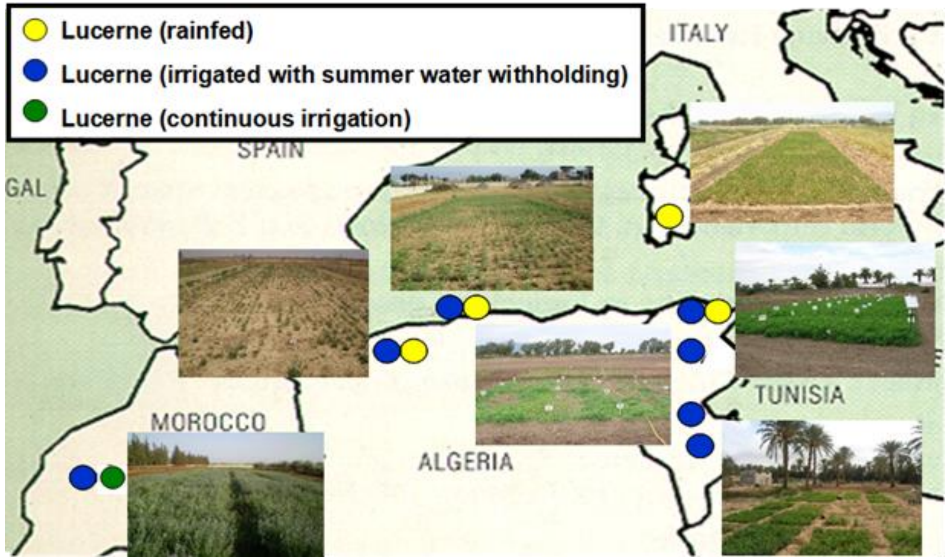
Crops	Sardinia (rainfall: 512 mm)		Morocco (rainfall: 256 mm)	
	Biomass yield (t/ha)	Legume proportion	Biomass yield (t/ha)	Legume proportion
Alfalfa (Mamuntanas) pure stand	10.08	–	6.45	–
Pea (Kaspa) pure stand	5.62	–	4.43	–
Common vetch (Barril) pure stand	5.68	–	2.86	–
Alfalfa-grass (tall fescue or cocksfoot) binary mixtures	11.15	0.65	6.19	0.80
Pea-cereal (oat or triticale) binary mixtures	7.00	0.31	4.61	0.40
Common vetch-cereal (oat or triticale) binary mixtures	7.07	0.42	4.43	0.31
LSD ($P < 0.05$) for individual crops	1.54	0.13	0.94	0.13

Data averaged across three cropping years; Melis et al., unpublished (submitted to Eur. J. Agron.)

Identikit of a drought tolerant cultivar (Mamuntanas): adaptation pattern

AMMI-1 modelled biomass yield of alfalfa cultivars across sites of the Mediterranean basin





Annicchiarico et al. (2011) Field Crops Res. 120: 283-291

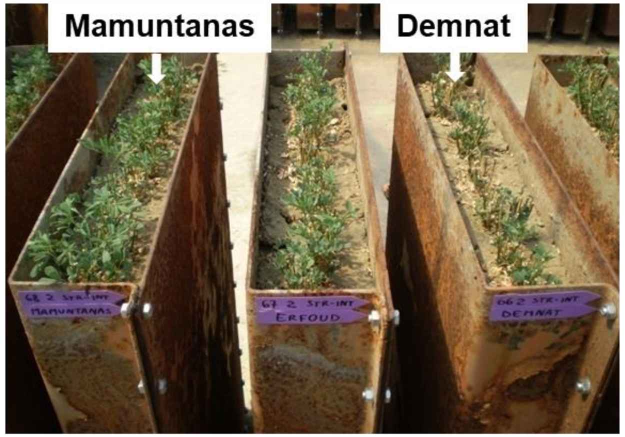
Identikit of a drought tolerant cultivar (Mamuntanas): adaptive traits

Featuring traits mainly related to dehydration tolerance and a water saving strategy

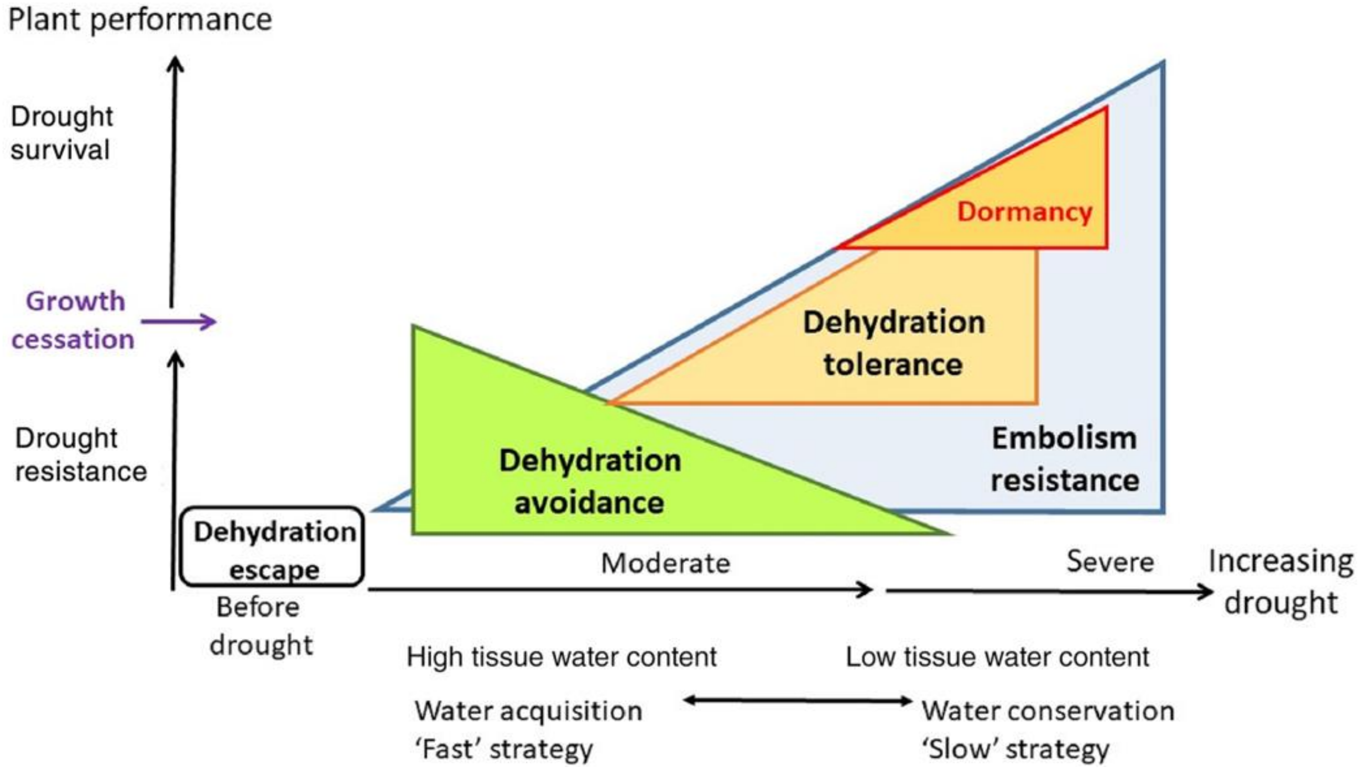
- **slow early shoot and root growth**
- **small leaves**
- **low leaf stomata density**
- **high accumulation of amino acids**
- **high water-soluble carbohydrate content in storage organs under stress**
- **delayed leaf senescence under stress**
- **high leaf tolerance to dessication**

Annicchiarico et al. (2013) Ann. Appl. Biol. 162: 27-40

Kang et al. (2023) J. Agron. Crop Sci. 209: 132-143



Mamuntanas and Demnat under drought stress



Drought adaptation strategies of perennial forage crops

Lüscher et al. (2022) Grass Forage Sci. 77: 235-246

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Breeding for various drought-prone regions is hindered by GE interaction

Genetic correlations for biomass yield of 127 alfalfa half-sib progenies across four regions with different extent and pattern of drought stress

Region	South Morocco	Italy	North-East Argentina
North Algeria (rainfed with moderate summer drought + heat)	−0.19 NS	−0.06 NS	0.00 NS
South Morocco (suspended summer irrigation + heat)	−	−0.29 +	−0.22 NS
Italy (simulated rainfed with moderate summer drought)		−	0.39 **
North-East Argentina (rainfed with cool-season drought)			−

Material sorted out of a Mediterranean reference population issued by intercrossing of 3 cultivars (Mamuntanas; Sardi 10; Erfoud 1). +, ** = different from zero at *P* < 0.10, and *P* < 0.01, respectively; NS, not significant. All correlations are different from unity at *P* < 0.01

Annicchiarico et al. (2022) Plant Genome 16: e20264

For the same material, the genetic correlation between Italy summer irrigated and South Tunisia continuously irrigated (two favorable environments) was 0.58 **

Annicchiarico et al., unpublished data

Promising genomic selection for biomass yield

Intra-population predictive ability mostly in the range of 0.10-0.35, tendentially lower under increasing drought stress

Annicchiarico et al. (2015) *BMC Genomics* 16, 1020
Medina et al. (2021) *Cells* 10, 3372
Andrade et al. (2022) *The Plant Genome* 15, e20235
Annicchiarico et al. (2022) *The Plant Genome* 16, e20264
Pégard et al. (2023) *Frontiers in Plant Science* 14, 1196134

Even values as low as 0.15 may indicate greater predicted gain per unit time and unit cost for genomic selection than phenotypic selection, owing to low narrow-sense heritability

Annicchiarico et al. (2021) In: Yu & Kole (eds) The Alfalfa Genome, Springer, pp. 191-210

High value of a variety genomically selected for Northern Algeria

Biomass yield of genomic and phenotypic selections issued from the same genetic base

Material	Alfalfa yield in pure stand	Alfalfa yield in mixed stand with tall fescue[a]
Genomic selection (GS)[b]	22.31	5.60
Phenotypic selection (PS)[c]	20.51	4.50
Genetic base (Mediterranean reference population)	19.27	4.46
Speed (elite control variety)	21.07	4.33
LSD ($P < 0.05$)	1.92	0.90

Annicchiarico et al., unpublished data.

[a] No significant difference for total (alfalfa + grass) biomass yield.

[b] Max. GS predictive ability = 0.22 (Annicchiarico et al., 2022); GS of 15 plants out of 564 random ones from the genetic base.

[c] PS of 60 plants by selection of 15 top-yielding half-sib progenies out of 150 and within-progeny visual selection of four best surviving plants per progeny.

High value of a variety genomically selected for Northern Italy

Biomass yield of genomic and phenotypic selections issued from the same genetic base

Material	Yield (t/ha)
Genomic selection based on rrBLUP model[a]	10.38
Genomic selection based on Support Vector Regression[a]	9.17
Genomic selection based on 150 markers with odd score > 1.5 in a GWAS[a]	9.64
Phenotypic selection[b]	8.40
Genetic base (Po Valley reference population)	8.97
Alfitalia (elite control variety)	9.13
LSD ($P < 0.05$)	1.07

Annicchiarico et al., unpublished data.

[a] Max. genomic selection predictive ability = 0.32 (Annicchiarico et al., 2015). Genomic selection of 18 plants out of 1536 that derived from one-year mass selection.

[b] Two-stage phenotypic selection of 18 plants based on two-year stratified mass selection of 74 plants out of 1776 followed by three-year clonal selection applied onto the 74 plants.

Moderate scope for cross-population genome-enabled prediction

Predictive ability (PA) loss passing from intra-population to cross-population prediction of multi-year biomass yield (based on phenotyped half-sib progenies of GBS-genotyped parent plants), for three genetically unrelated reference populations

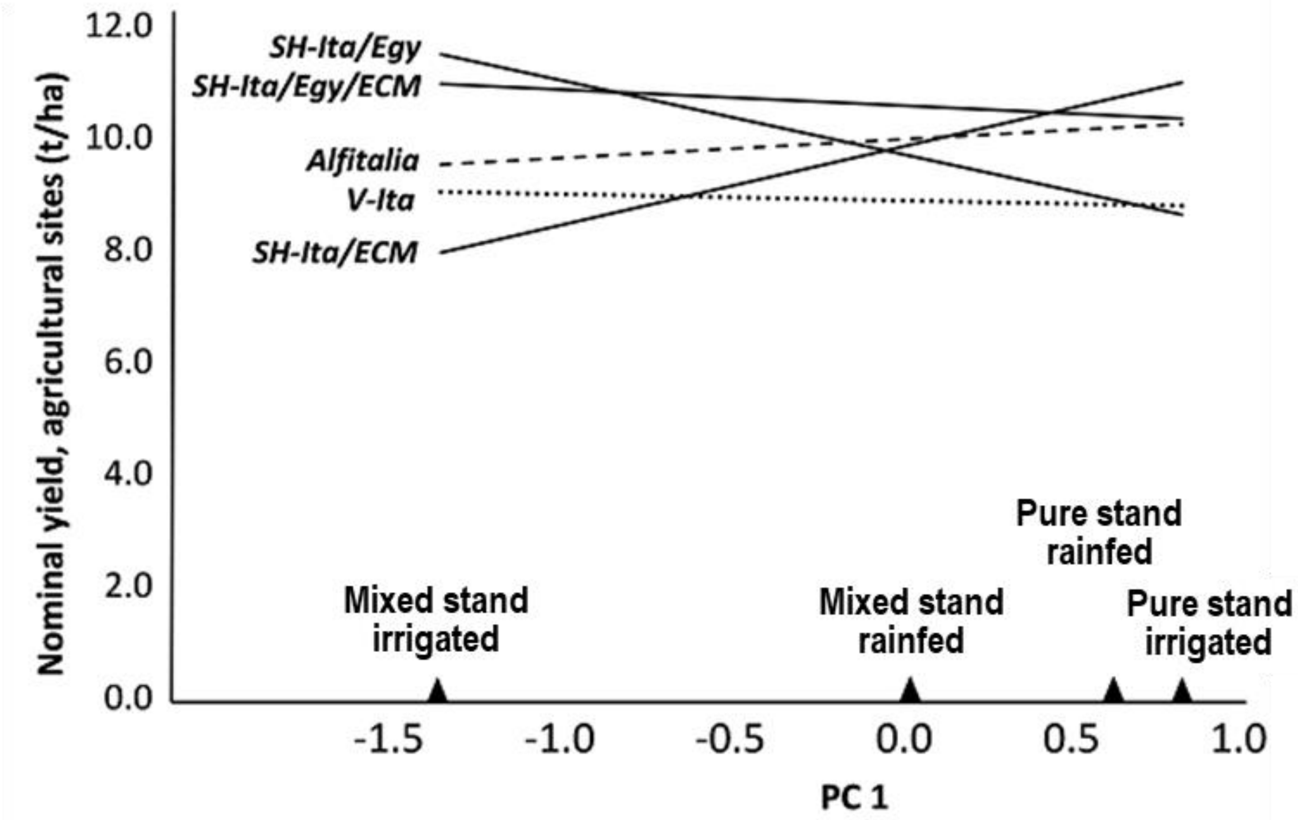
Prediction scenario	Crop condition	Model construction	Model validation	PA	PA decrease
Intra-population[a]	Water- favorable	Mediterranean	Mediterranean	0.28	43%
Cross-population[a]	Water- favorable	Po Valley	Mediterranean	0.16	
Intra-population[a]	Water- favorable	Po Valley	Po Valley	0.36	39%
Cross-population[a]	Water- favorable	Mediterranean	Po Valley	0.22	
Intra-population[b]	Drought stress	Mediterranean	Mediterranean	0.17	24%
Cross-population[b]	Drought stress	European semi-dormant	Mediterranean	0.13	
Intra-population[b]	Drought stress	European semi-dormant	European semi-dormant	0.14	nil
Cross-population[b]	Drought stress	Mediterranean	European semi-dormant	0.16	

[a] rrBLUP model based on diploid-like SNP calling; 154 genotypes for the Mediterranean population and 124 for Po Valley; Annicchiarico et al. 2015).

[b] rrBLUP modelling based on tetraploid SNP calling; 127 genotypes for the Mediterranean population and 143 for the European one (unpublished data).

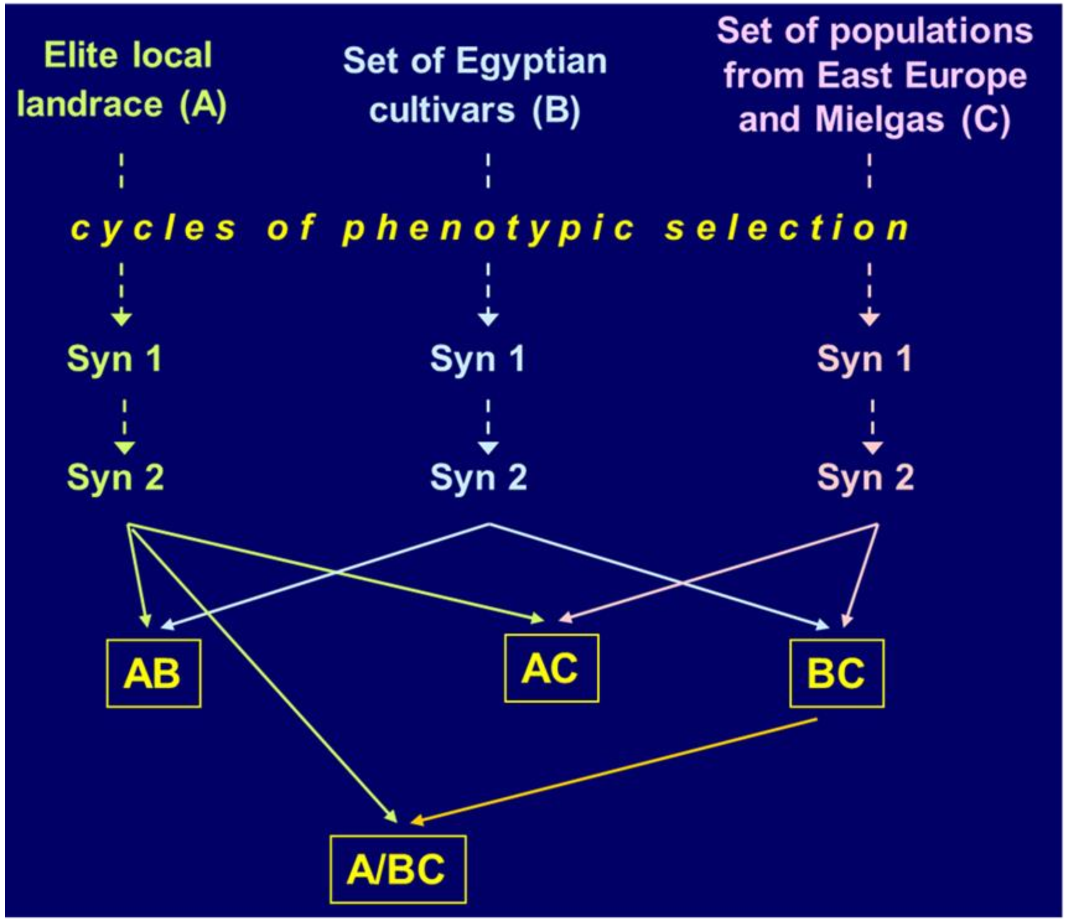
Semi-hybrids may rise the crop yielding ability and adaptability

AMMI-1 modelled biomass yield of 2- and 3-way semi-hybrids (SH) issued from three selected heterotic populations and the Italian selected population (V-Ita, benchmark)



Annicchiarico et al. (2024) Crop Science 65, e21425

For responses across eight managed environments see: Annicchiarico & Pecetti (2022) Field Crops Res. 283: 108522



Projects that generated these result

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Thank you for your attention!