









Breeding Alfalfa Root System Architecture for changing climate

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Warming climate challenges breeding:

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The Summer of 2023 Was the Hottest in 2000 Years

Breeding crops for climate resilience with Genotype by Environment interactions (GEI)

CIMMYT, 1980-2018

What does changing climate mean for Ideal RSA?



steep, thicker, & deep" RSA

shallower dispersed lateral roots

Outline

- Objectives
- RSA Breeding history
- Breeding Progress
- Commercialization of RSA?

Root System Architecture (RSA) Breeding

• Objectives:

Develop and release germplasm/cultivars with specific RSA for different environments with changing climates.



RSA Cycle 0 (C_0): for fibrous root mass

UMN2896	UMN2494	UMN2892	UMN2893
 A composite of 9 moderately dormant cultivars and experimental populations for root system architecture (RSA) 	 A composite of 10 early nondormant cultivars and experimental populations selected for increased root <u>Nitrogen</u> concentration 	 A composite of 8 dormant experimental populations selected for disease <u>resistance</u> to <u>phytophthora</u> and <u>Aphanomyces</u> root rots and root-lesion <u>nematode</u> & <u>fibrous</u> <u>root mass</u> 	 A composite of 8 dormant experimental populations selected for differences in biological N fixation and <u>fibrous root</u> <u>mass</u>
Intermating for C_1 seed	Intermating	Intermating for C ₄ seed	Intermating for C_1 seed

RSA Cycle 1 (C_1): for fibrous root mass



Divergent selection for RSA breeding cycles



RSA Genetic gain is higher than biomass



Genetic gain of RSA by Principal Component Analysis

Panel a. PCA by cycle (2,247 gen) Panel b. PCA by architecture (2,247 gen) LF = Low fibrous HF = High fibrous T = Taproot B = Branched



Genome-wide association

Column a. All seven populations Column b. C3&C4 populations Column c. C4 populations

All, C3&C4, C4 Lat_dis, chr3.1_69669859

All, C3&C4 Tap_D, chr5.1_45250257

C3&C4, C4 Lat_num, chr8.1_72832610



Machine Learning identifies more than additive effect makers

- Machine learning algorithms like support vector machine (SVM) can be used to obtain variable importance (VI).
- VI by SVM ranks the variables (markers) from 0 to 100 according to their importance.
- Markers with high VI could agree or not with markers identified by GWAS.

Marker	_FS_	LD	LN	TD
chr5.1_3769336	100	99	60	37
chr5.1_4247500	75	100	68	37
_chr5.1_70800283_	61	_74_	100	100







Genomic selection

- Select a training population (Phen&Geno column)
- 2. Run genomic prediction model(s)
- 3. Obtain scores for the predictions
- 4. Run the best model by training and testing the population (Geno column)

Cycle	Fibrous	Arch	Рор	Phen&Geno	Geno	Total
0	0	0	UMN_2892	140	182	322
2	LF	Т	UMN_2963	133	181	314
2	HF	В	UMN_2966	146	177	323
3	HF	В	UMN_3233	182	140	322
3	LF	Т	UMN_3234	187	134	321
4	HF	В	UMN_4561	187	136	323
4	LF	Т	UMN_4563	213	109	322
			Total	1,188 (53%)	1,059 (47%)	2,247

Genomic selection

GBLUP

The model was trained with ten-fold random cross-validation

PA = Predicted ability cor(y, y_hat[GEBV]) h2 = Marker-based heritability calculated from G matrix ACC = Accuracy of the model (PA/sqrt(h2))

Tap_D	PA	h2	ACC
Lat_Num	0.16	0.13	0.45
Tap_dis	0.36	0.31	0.64
Lat_dis	0.37	0.19	0.85
Fib_score_	0.54	0.45	0.81

Panels a to d correspond to GEBV of un-phenotyped plants (testing population)



14

7/2/2024

RSA associates with yield and N fixation





N fixation

Commercializable of the root traits: --How much \$ is from each of the traits?



Summary

- 1. Alfalfa RSA was maintained across environments and heritable.
- 2. The genetic gain of RSA selection is about 12% per breeding cycle.
- 3. 14 QTLs were identified for the RSA traits
- 4. GS prediction accuracy ranged from 0.45 to 0.81
- 5. ML identified more common markers than the GWAS.



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Digital alfalfa RSA phenotyping via AI technology

Deborah A. Samac 🖾

RSA phenotyping challenges: consistency across labs and subjective





Deep Learning

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Phase 1: Use three ML: RF, SVM & GBM, found the most informative parameter to select

Phase 2: Use computer vision and deep neural network to objectively classify RSA types



Phase III: Deep layers + generative Al to generate ideal RSA



Phase IV: Alfalfa RSA prediction

Generative Al

Mobile App

Undergoing testing in 2024: Will plant density affect RSA?



Space and sward plots were planted for root plasticity study, and 2,000 roots from each of the four populations will be dug for divergent selection for Cycle # 6.