Breeding as a lever to improve seed yield of forage species

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IHSG – Angers 2023

Breeding: a lever to improve

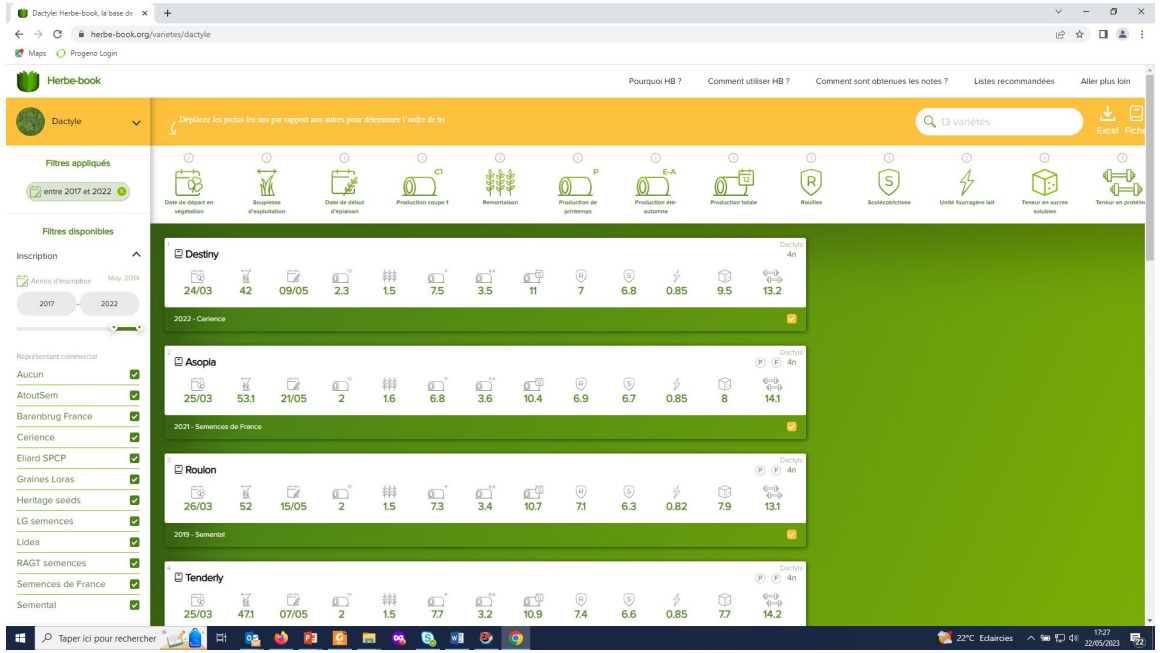
- Forage yield
- Forage quality
- Adaptation to environments, practices, usages
- Ecosystem services

But also

- Seed yield and seed yield components
- Including resistances to pests or diseases that are specific to reproductive stages

Genetic progress is achieved and described

For forage-related traits



Herbe-book.org in France

Seed yield considered as the responsibility of breeders & seed companies

2023 NAFA Leaflet, USA

	Variety	Contact for Marketing Information	Winter Survival	Bacterial Wilt	Verticillium Wilt	Fusarium Wilt	Anthracnose Race 1	Phytophthora Root Rot	Aphanomyces Race 1 Root Rot	Aphanomyces Race 2 Root Rot	Spotted Alfalfa Aphid	Pea Aphid	Blue Alfalfa Aphid	Potato Leafhopper	Stem Nematode	Southern Root Knot Nematode	Northern Root Knot Nematode	Multifoliolate Expression (H-High/M-Mod/L-Low)	Continuous Grazing Tolerance (Y-Yes)	Standability Expression (R-Resistance)	Salt Tolerance (G-Germination/F-Forage)	R-RRA; X-HarvXtra; H-75-95% Hybrid
FD 2	Foothold	BrettYoung		HR	HR	HR	HR	HR	HR	R			R		R			M			G	
	Spredor 5	Nexgrow Alfalfa	1	HR	HR	HR	HR	HR	HR	R		R									G	
	54VQ52	Pioneer		HR	HR	R	HR	HR	HR	HR	R	R			HR							

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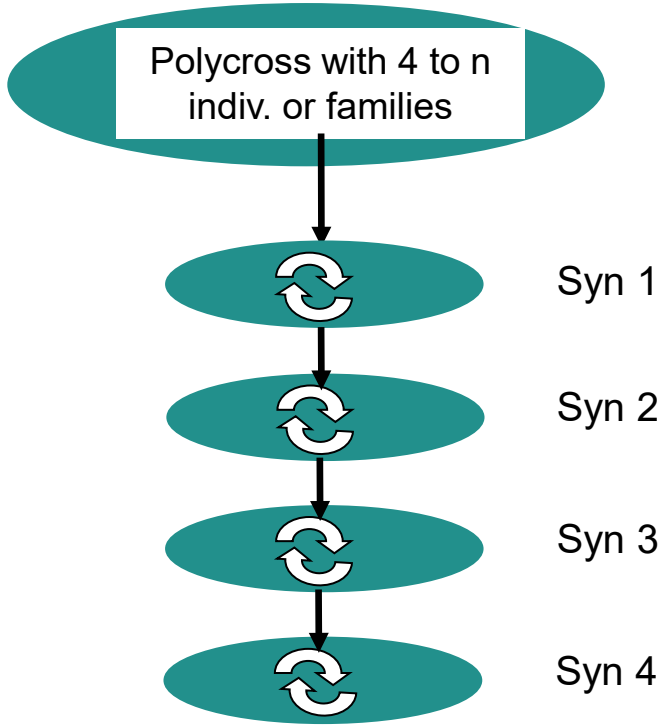
Breeding scheme in forage crops

Biological traits: allogamous, (polyploidy)

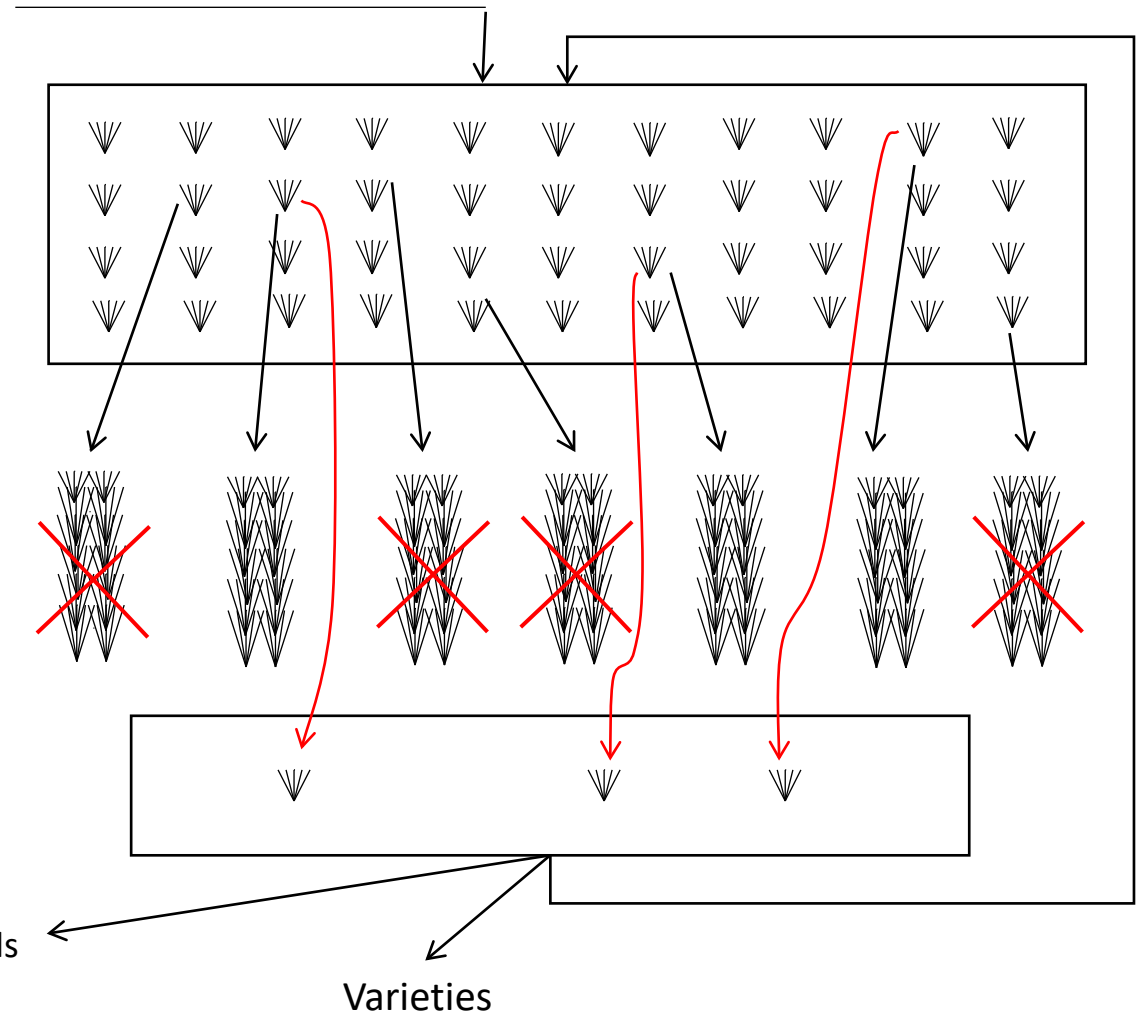
- Varieties are synthetic populations



The individuals of one variety are genetical related but all different

Breeding scheme in forage crops

A 10-15 year process



Genetic gain ΔG:

$$\Delta G = \frac{i\, h^2\, \sigma_P}{T}$$

i: selection intensity

h^2: heritability

σ_P: phenotypic variation

T: time

Breeding scheme in forage crops

What is the problem with seed yield?

- The breeding scheme is devoted to forage traits
- For forage trait evaluation, cuttings at vegetative or early reproductive steps
- Seed yield evaluation requires a parallel breeding scheme?
- And/or
  - Early evaluation with highly heritable traits
  - Post-breeding control
- And/or
  - Development of seed traits-associated markers

Breeding for seed yield

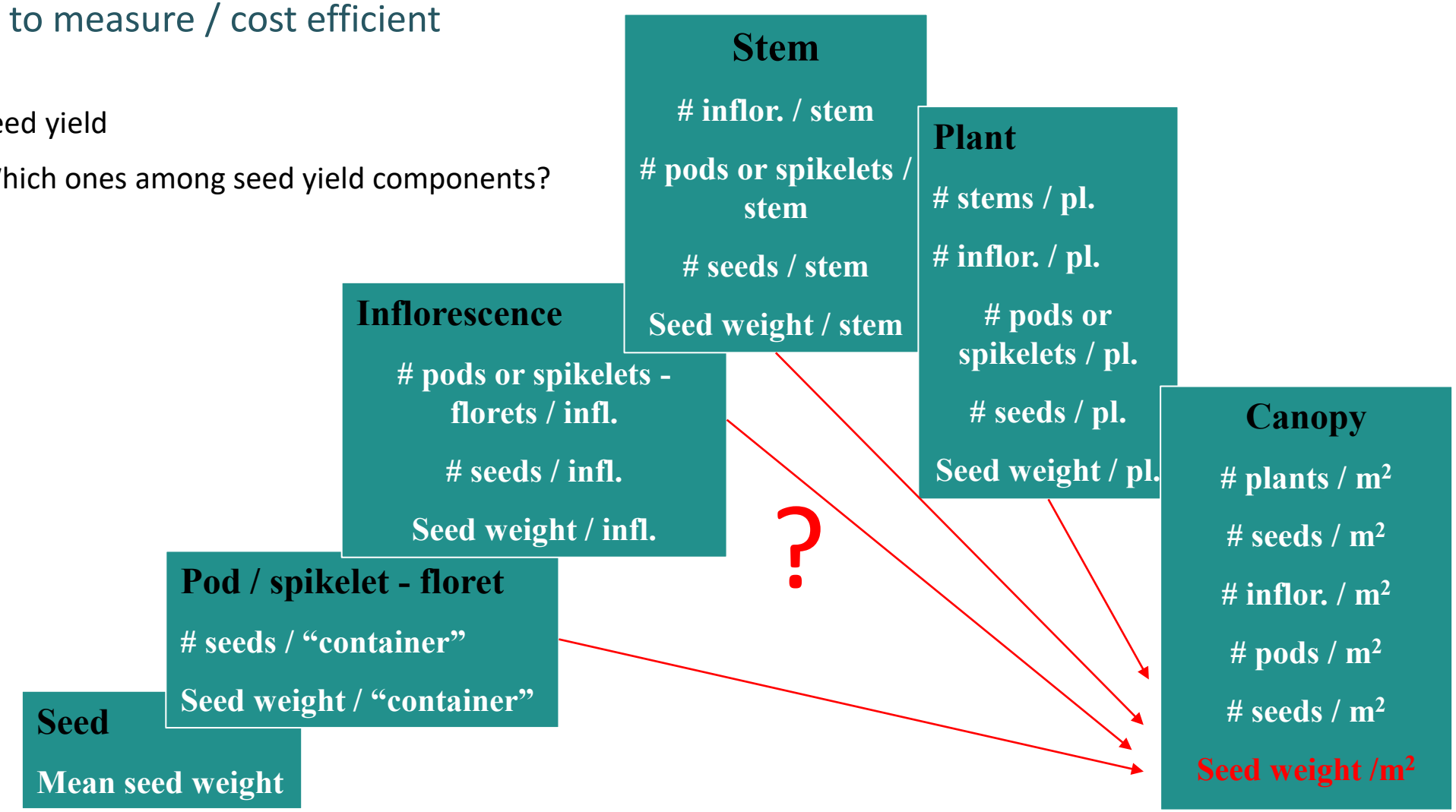
- Assessment of seed yield components
  - Reliable and easy to measure
  - Genetic diversity, heritability, correlation among components and with forage traits
  - To be included in breeding schemes
- Pest resistance
  - Identify the most harmful pests
  - Management or genetics?
  - Tests for resistance
  - Genetic diversity, heritability
  - To be included in breeding schemes
- Implementation of molecular breeding?
  - Detection of markers associated to seed yield components
  - Marker-assisted breeding schemes

Assessment of seed yield components

Seed yield components

Easy to measure / cost efficient

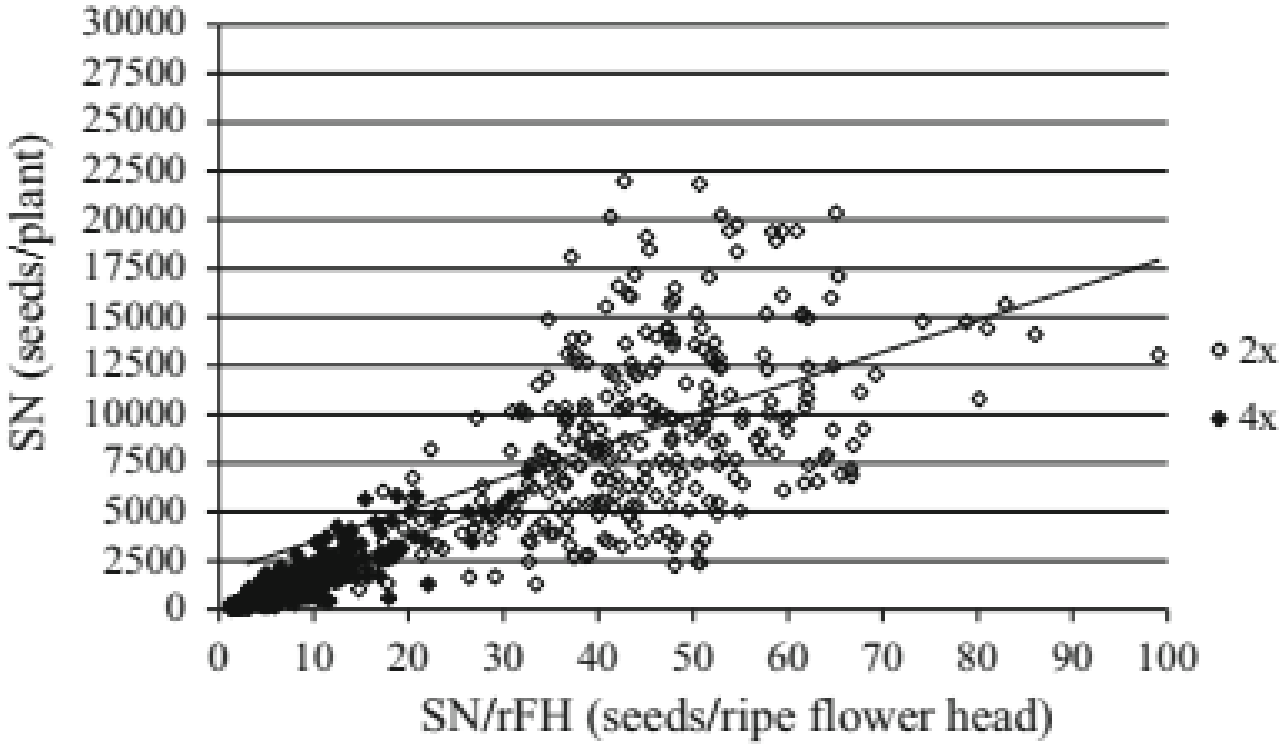
- Seed yield
- Which ones among seed yield components?



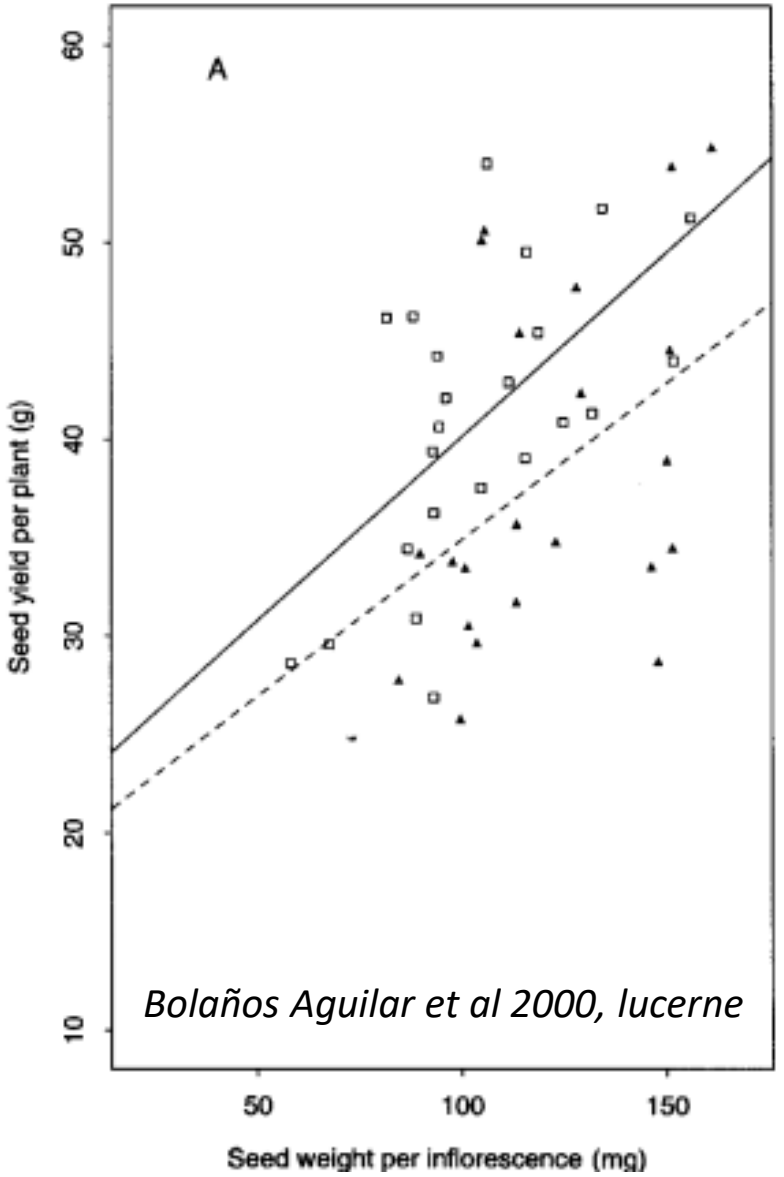
Seed yield components

Easy to measure / cost efficient

- Measurement on isolated plants (nursery)
- Correlation with seed yield in dense plots
- Inflorescence level is the most relevant



Vleugels et al 2016, red clover

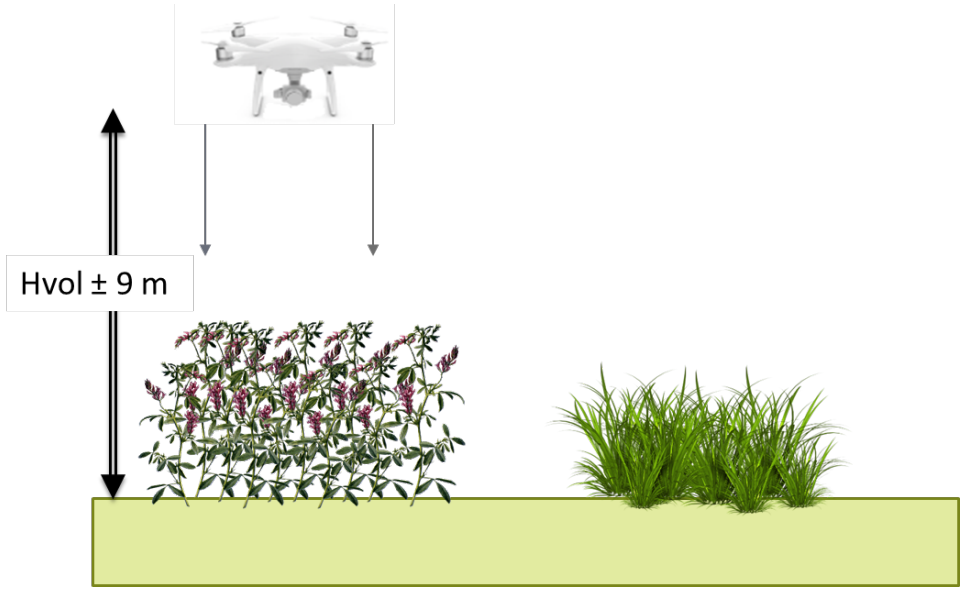


Bolaños Aguilar et al 2000, lucerne

Seed yield components

Easy to measure / cost efficient

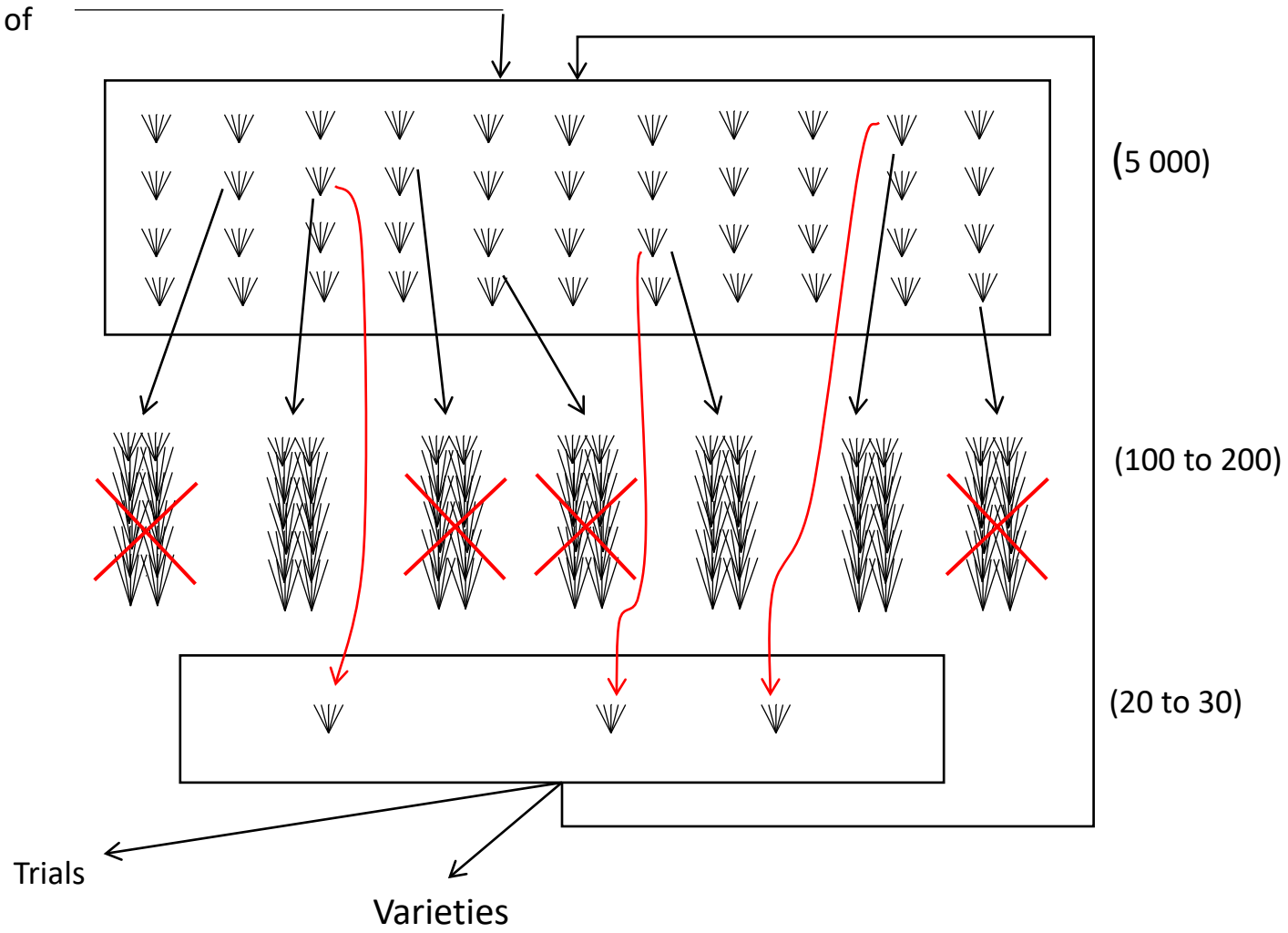
- Image analysis?



Seed yield components

To be evaluated as soon as possible in the breeding scheme

- Spaced plants
- Progenies
- Candidate varieties



Pest and disease resistance

Pests and diseases

That specifically attacks reproductive organs

Lucerne flower midge: *Contarinia medicaginis*

Alfalfa Seed Weevil: *Tychius aureolus*

Alfalfa moth: *Cydia medicaginis*

Bugs: *Lygus sp., Adelphocoris lineolatus*

Lygus sp. adulte

Adelphocoris lineolatus adulte

Larve de punaise miride

Pests and diseases

That attacks vegetative organs

Alfalfa leaf beetle: *Colaspidema barbarum*

Aphids*: Acyrthosiphon pisum* and others

Alfalfa weevil: *Hypera sp*

Curculio*: Sitona sp*

Pests and diseases

Tests?

BIOLOGICAL CRITERIA OF THE PEA APHID *Acyrthosiphon pisum* Harris AND VARIETAL RESISTANCE OF LUCERNE

Ch. Girousse, R. Bournoville,
Laboratoire de Zoologie, Institut National de la Recherche Agronomique, 86600 Lusignan – France

1994,
Eucarpia

Sitona

Empoasca fabae

Bemisia tabaci

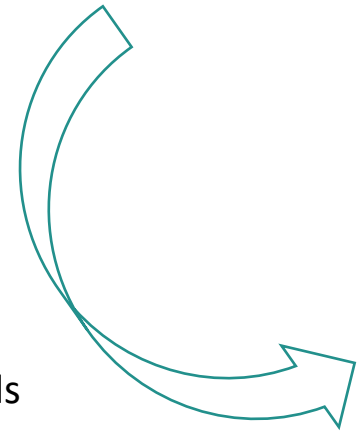
Pests and diseases

Tests? Breeding?

Ideally, biological tests in controlled conditions:

- Capture insect population(s)
- Grow and multiply the insects [to be able to test all the year long]
- Inoculate the insects to the plants
- Score damages and/or insect multiplication

High-throughput / cost effective



Genetic studies
Genetic diversity, heritability
Identification of physical barriers
Identification of biochemical compounds

Breeding

Tests

Breeding?

2023 NAFA Leaflet

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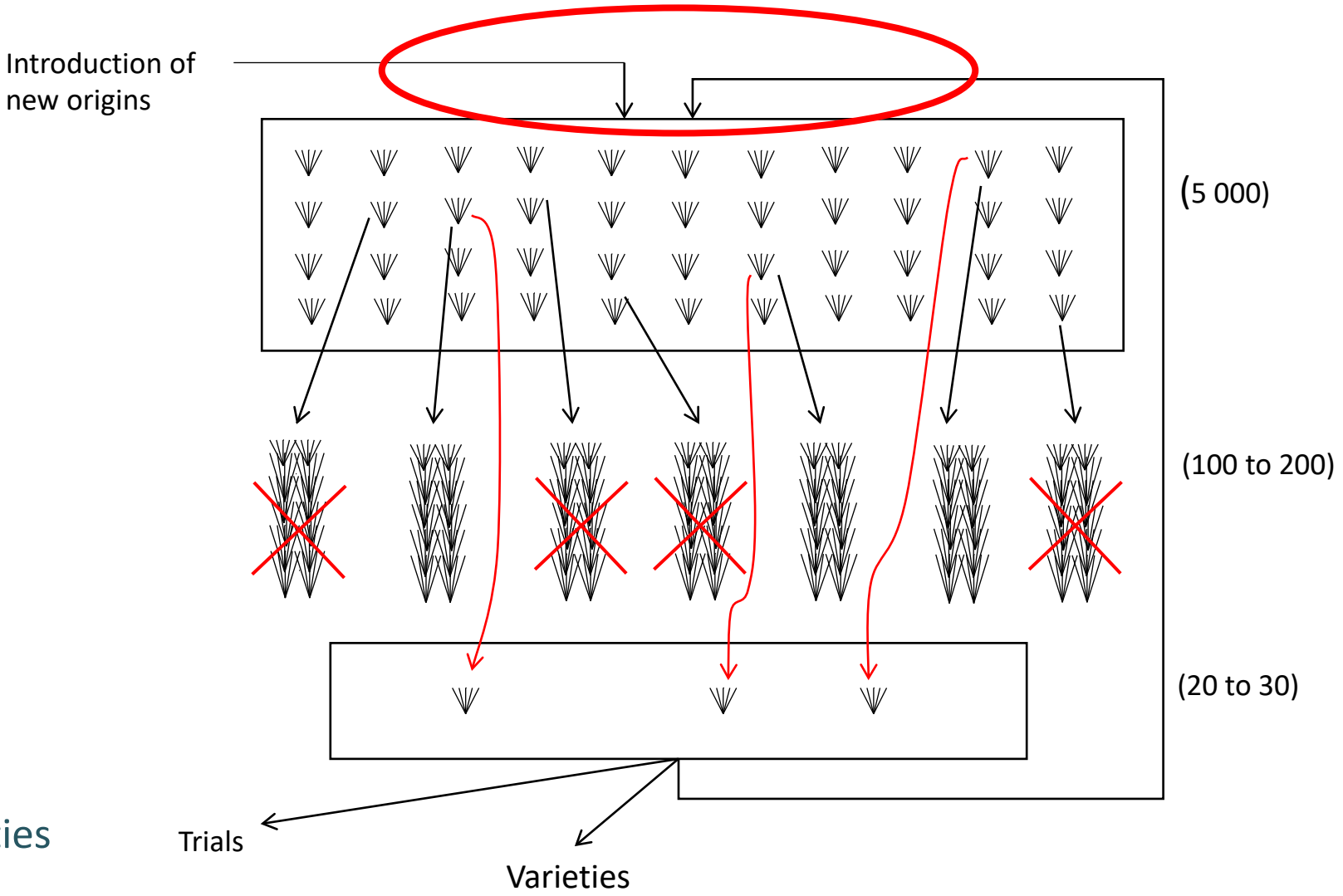
	Spredor 5	**Nexgrow Alfalfa**	**1**	**HR**	**HR**	**HR**	**HR**	**HR**	**HR**	**R**		**R**									**G**	
	54VQ52	**Pioneer**		**HR**	**HR**	**R**	**HR**	**HR**	**HR**	**HR**	**R**	**R**			**HR**							

Inclusion in breeding schemes

- Spaced plants
- Progenies
- Candidate varieties



Implementation of molecular breeding?

Molecular markers in breeding programs

Proof of concept available on plant species, implementation on maize, soybean…

Forage species lag behind

- Heterozygosity (+ auto or allo-polyploidy)
- Genome sequence
- Costs / profits

Lucerne: marker density over the genome (500 kb window size)

State of the art

Major species have been sequenced (lucerne, red clover, white clover, perennial ryegrass, (cocksfoot), …

High-throughput cost-effective genotyping methods are available: GBS (> 100 000 SNP)

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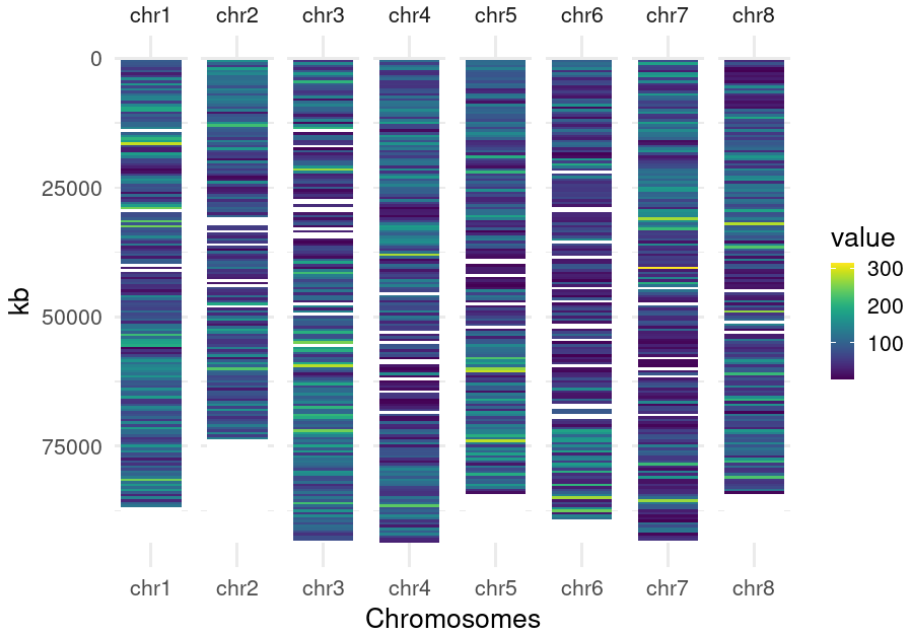

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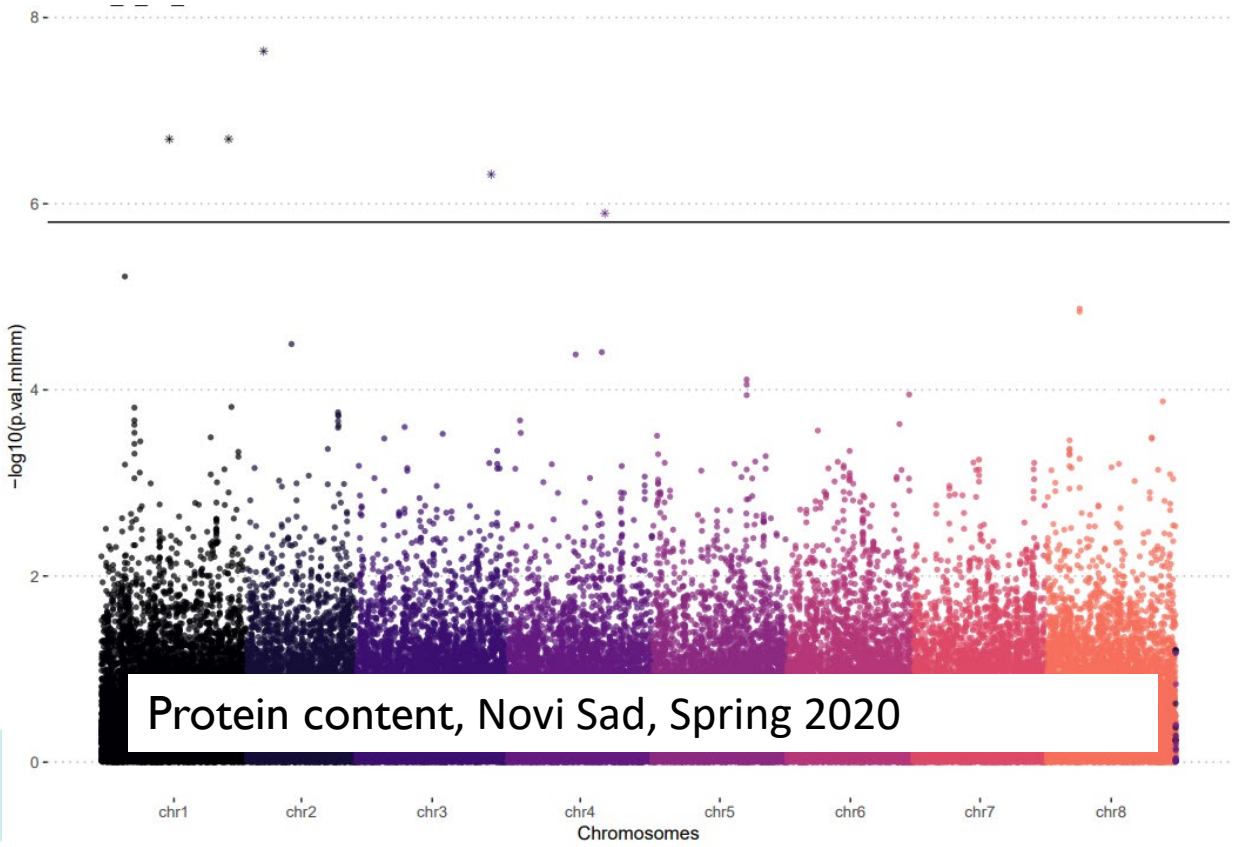
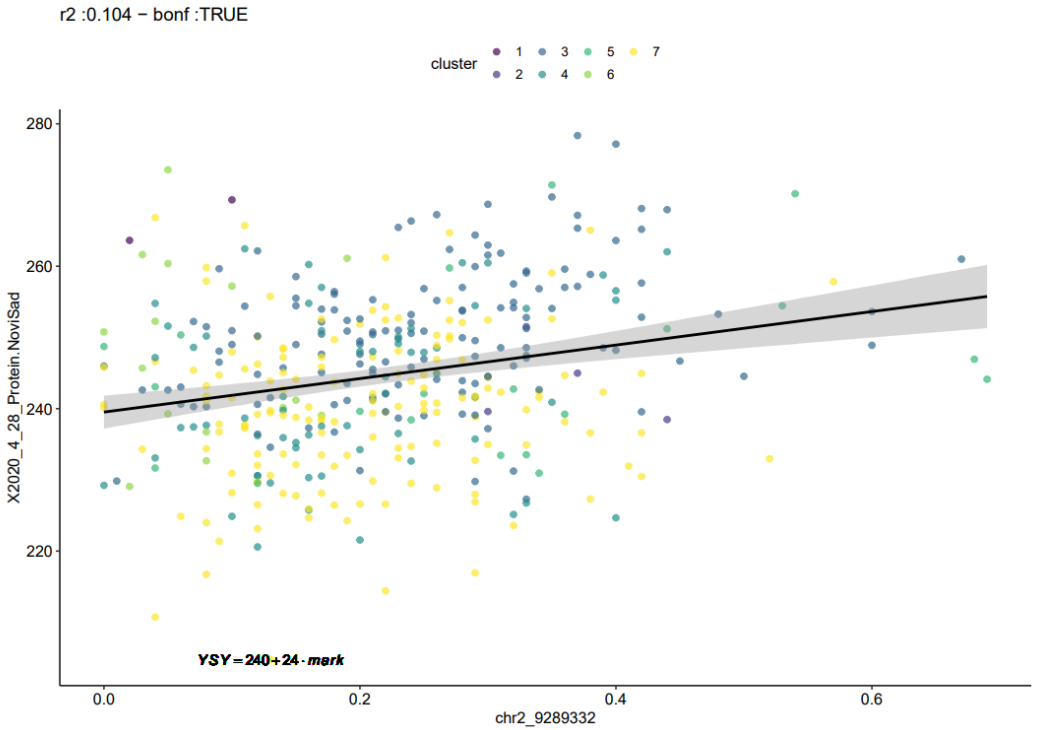
Genome-wide association studies (GWAS)



$r^2 = 0.104$



State of the art

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High-throughput cost-effective genotyping methods are available: GBS (> 100 000 SNP)

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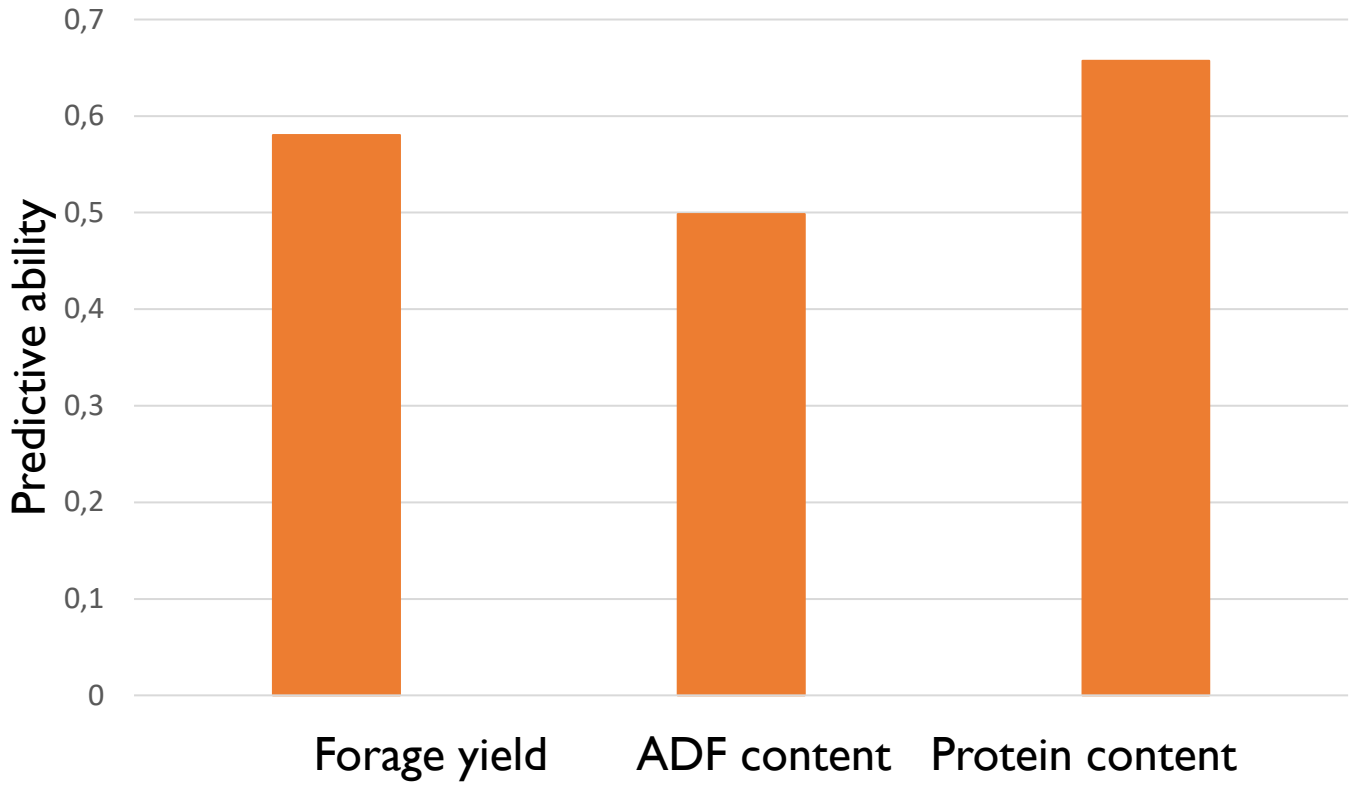
Genomic selection



Predictive ability: correlation between phenotypic values and values predicted by genomic predictive equation

Training population composed of 270 lucerne accessions studied during 3 years in 2 locations

Results for seed yield components in forage species?

Seed yield components:

Red clover: QTL in a bi-parental population (Herrmann *et al.* 2006)

Perennial ryegrass: QTL detected for spike density were explained by difference in earliness; no QTL for the other seed yield components (Keep *et al.* 2020)

Perennial ryegrass: predictive ability moderate to high (0.39 to 0.86) (Keep *et al.* 2020)

Insect resistance

Resistance genes have been identified in lucerne (Yang *et al.* 2022)

To be introduced through crossings or transgenesis (Tohidfar *et al.* 2013)

A revision of alfalfa breeding schemes

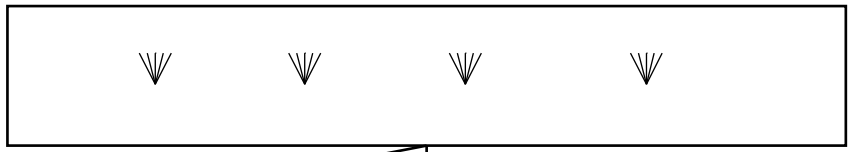
Introduction of new origins

Breeding pool

(5 000 to 15 000)

Genotyping
Analysis of diversity
Allele diversity at QTL or candidate genes
Genomic prediction
→ Choice of plants
0.5 year

Polycross of the best plants
1 year



(20 to 30)

Evaluation in multi-site trials
3 years → Varieties

Conclusion

Future progress in seed yield of herbage species?

- Seed yield components
- Insect resistance

Complex traits, limited knowledge

Phenotyping tools, genetic studies
molecular markers

- Forage traits (yield, quality)
- Disease resistances
- Abiotic stress resistances

Improved varieties

- Question: Evaluation of seed yield of candidate varieties in the registration process?

Thanks !