Strategy avenues for breeding plants for multispecies grasslands

Isabelle Litrico, Bernadette Julier

INRA
SCIENCE & IMPACT

Strategy avenues for breeding plants for multispecies grasslands

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INRA – P3F Lusignan - France

PRAISE

ReMIX
Species mixtures for redesigning European cropping systems

Expoleg-AV

EGF EUCARPIA
Zurich 24-27/06/2019

Challenge for agriculture

Climate change
Low inputs

Key role of species diversity

Sustainable cropping systems
Production and Stability

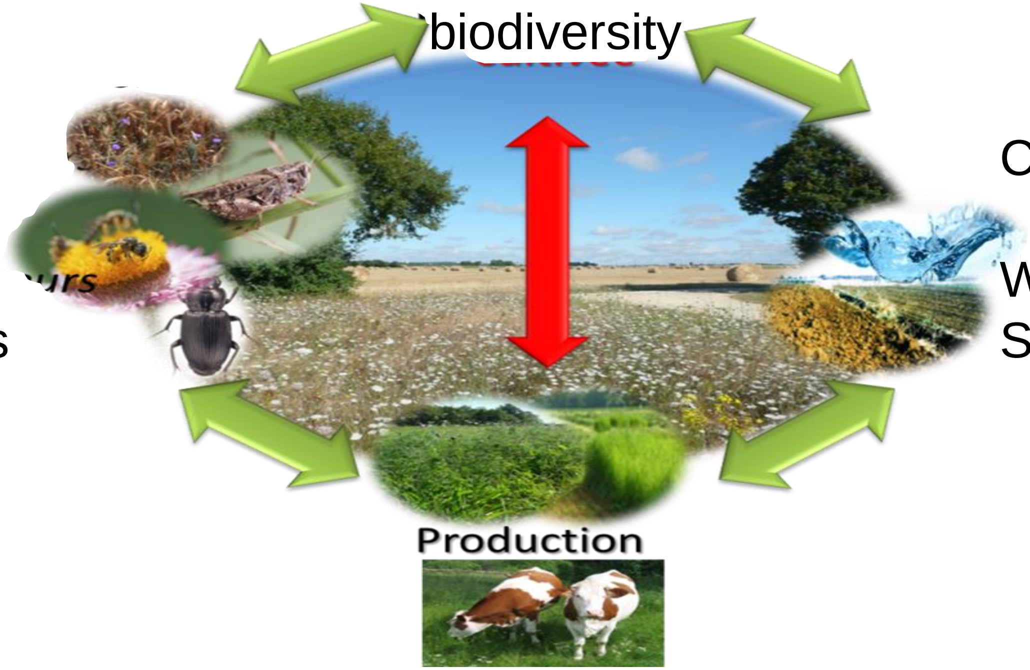
Sown biodiversity

Pests and diseases

Pollinators

C/N/P cycling

Water quality
Soil fertility and structure



Multispecies sown grasslands for sustainable production

Choice of species and varieties in the mixtures

To consider the intrinsic qualities of the species
mowing / pasture, frost, drought, feeding value, depending on the needs of the animals and growing conditions

To consider the possibilities of facilitation and complementarity between species :
legume / grass (N), rooting depth (water),
Limitation of competition for light interception (plant height)

Rules for species assembling are quite well established :
http://afpf-asso.fr/files/Outils/Plaquette_AFPF-Melanges.pdf
http://www.prairies-gnis.org/pages/melanges.htm
Standard mixtures in Switzerland
…

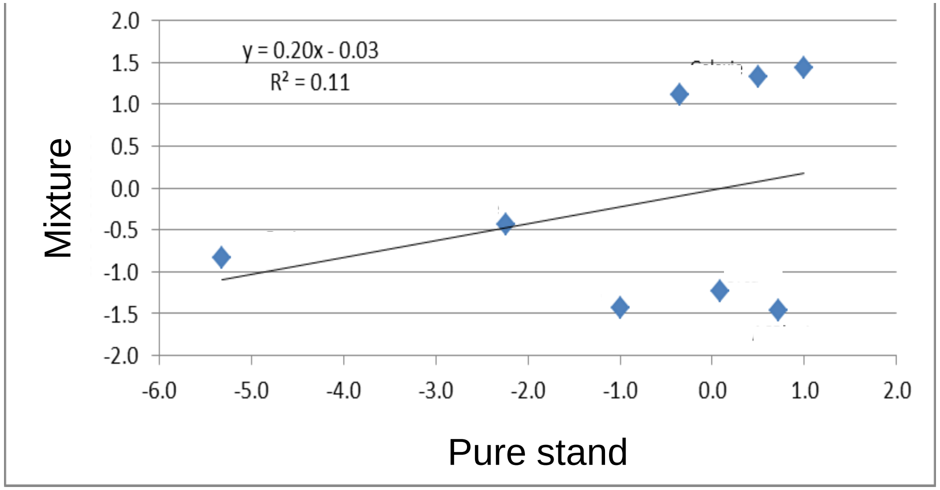
But choice of varieties is less documented :
varieties are bred and registered for pure stands … except white clover
Intrinsic quality of varieties is considered

Multispecies sown grasslands and genetic composition

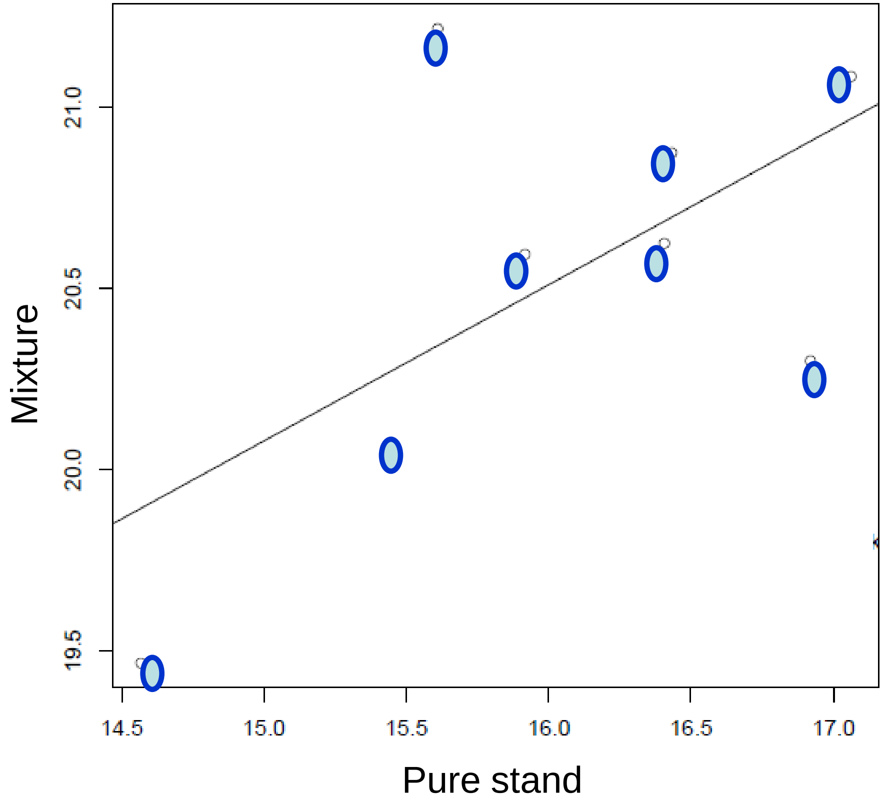
Within and among species interactions : for light, nutrients, water…
=> local selection pressures

=> Performance of a cultivar in a pure stand could be a poor indicator of its performance in a species mixture

Lucerne - Combined index of protein and ADF

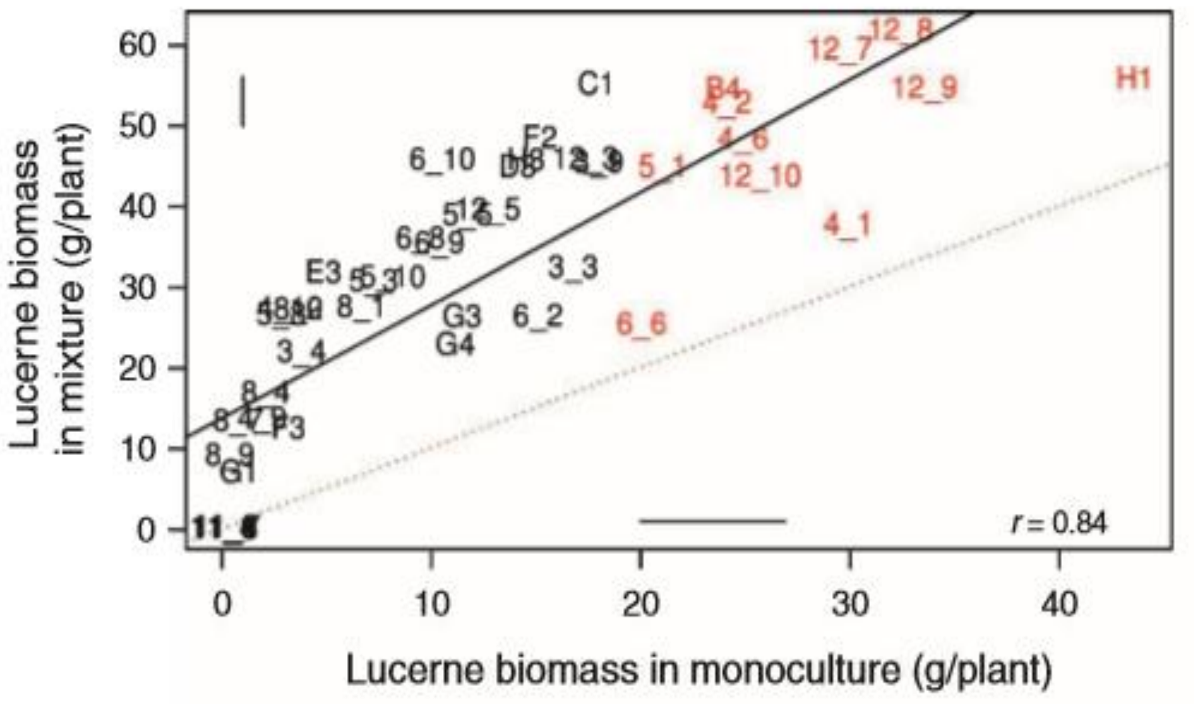


Perennial ryegrass – Forage yield



Multispecies and pure sown grasslands

BUT SOME STUDIES SHOW a partial correlation

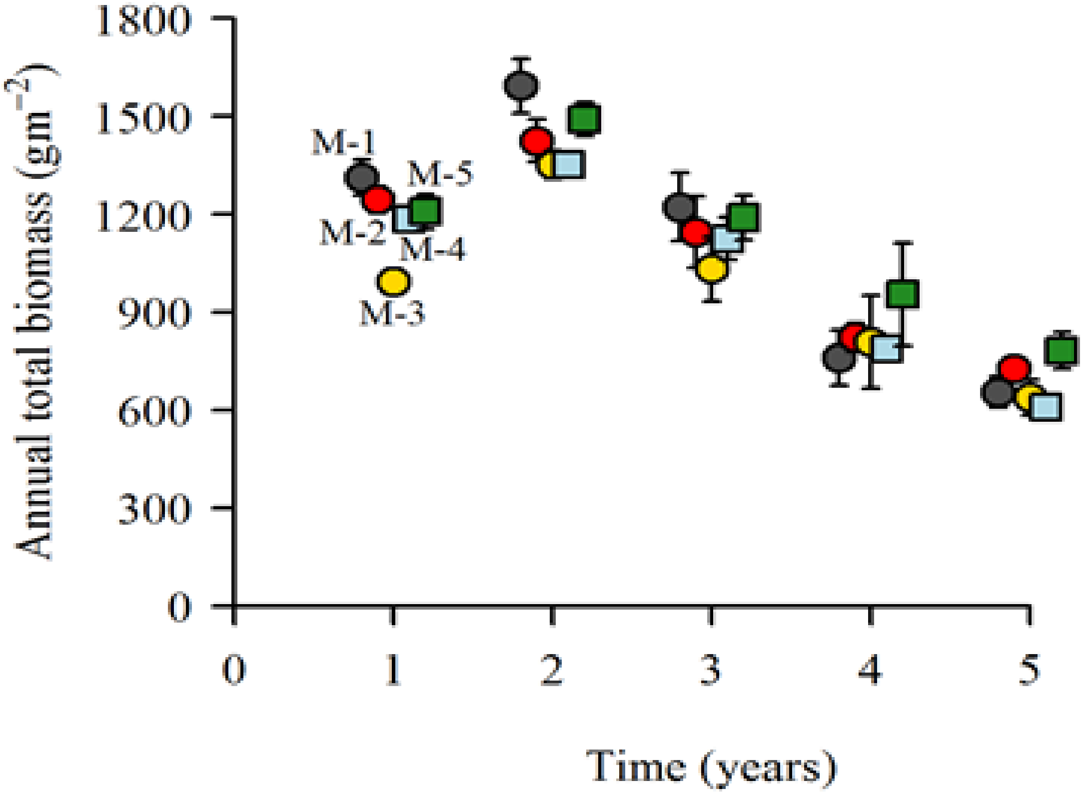


Maamouri et al (2017)
Crop Pasture Sci

Interactions modify the relative performance and this modification depends on the genotype

Multispecies sown grasslands and genetic composition

Importance of genetic composition of the species employed in a mixture



7 species mixtures
M-1, M-2, M-3: 1 variety / sp
M-4: 2-3 varieties / sp
M-5: 6 varieties /sp

Meilhac et al. (2019)
Annals of Botany

=> Significant implications for breeding

Multispecies sown grasslands and breeding

Empirical tests of varieties

Comparison of varieties for the performance in mixture: yield, species proportion, survival

Mainly in binary mixtures containing one legume and one grass species

No selection for performance in mixture
With exceptions

Multispecies sown grasslands and breeding

Do we need specific breeding for legume-based mixtures?

Paolo Annicchiarico[a,*], Rosemary P. Collins[b], Antonio M. De Ron[c], Cyril Firmat[d], Isabelle Litrico[d], Henrik Hauggaard-Nielsen[e]

[a] Council for Agricultural Research and Economics, Research Centre for Animal Production and Aquaculture, Lodi, Italy
[b] Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, Gogerddan, Aberystwyth, Wales, United Kingdom
[c] Misión Biológica de Galicia, National Spanish Research Council, Pontevedra, Spain
[d] Institut National de la Recherche Agronomique, Unité de Recherche Pluridisciplinaire Prairies et Plantes Fourragères, Lusignan, France
[e] Roskilde University, Department of People and Technology, Roskilde, Denmark
* Corresponding author: *Email address:* paolo.annicchiarico@crea.gov.it (P. Annicchiarico)

- ***On average, selection in pure stand was 40 % less efficient than selection in mixed stand***
- ***Specific breeding for intercropping is a key point for species undergoing severe competition***

Annicchiarico et al (2019)

Advances in Agronomy

We need a specific breeding…

⇒ **'Performance in mixture' seen as a new breeding trait**
⇒ **Evolutionary plant breeding**
⇒ **'Functional' approach**

'Performance in mixture' : a new breeding trait

GMA/SMA: General/Specific Mixing Ability approach

Evaluation of biomass or other traits of each mixture

	Cultivar 1	Cultivar 2	Cultivar 3	Cultivar 4
Cultivar 1	P1	P12	P13	P14
Cultivar 2	P21	P2	P23	P24
Cultivar 3	P31	P32	P3	P34
Cultivar 4	P41	P42	P43	P4
GMA	Mean P1	Mean P2	Mean P3	Mean P4

GMA: mean value of a cultivar in mixture
SMA of 1+2 = P12 – (mean P1 + mean P2)/2

Initially used to design mixtures of varieties (1970 →)

‘Performance in mixture’ : a new breeding trait

GMA can also be used with species mixtures

	Species 1 Cultivar 1	Species 1 Cultivar 2	Species 1 Cultivar 3	Species 1 Cultivar 4	GMA Species 1
Species 2 Cultivar 1	P11,21	P12,21	P13,21	P14,21	Mean P21
Species 2 Cultivar 2	P11,22	P12,22	P13,22	P14,22	Mean P22
Species 2 Cultivar 3	P11,23	P12,23	P13,23	P14,22	Mean P22
Species 2 Cultivar 4	P11,24	P12,24	P13,24	P14,24	Mean P22
GMA Species 1	Mean P11	Mean P12	MeanP13	Mean P14	

GMA for the biomass of each species or any other trait

Direct effect on the target species

Indirect effect on the companion species

‘Performance in mixture’ : a new breeding trait

A high GMA means that the variety has a high performance on average with any variety of the companion species

The **efficiency of this GMA approach** assumes that:

$\Rightarrow$ the **SMA effects are small**

$\Rightarrow$ the progress in one target species will improve the performance of the **whole plant community**

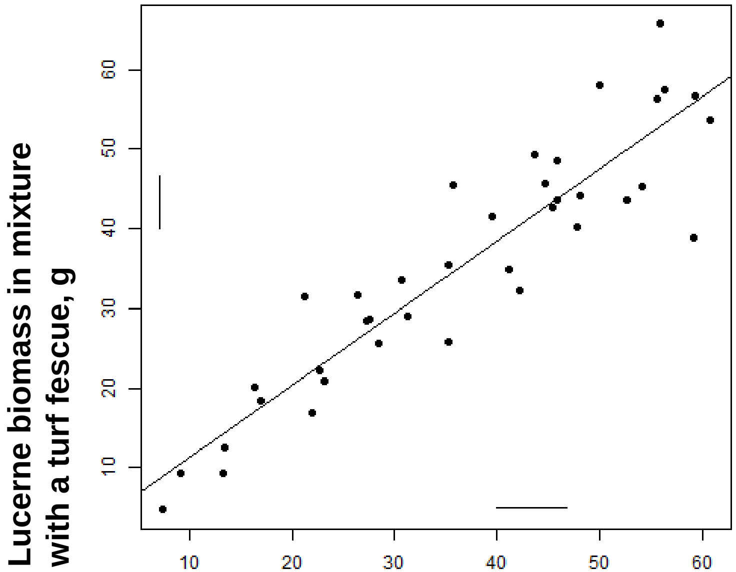
Limitations

- GMA estimation could not be transferred beyond the specific tested material
- Large number of possible combinations to be tested

‘Performance in mixture’ : a new breeding trait

=> Limit the number of combinations with the concept of ‘tester’

	Sp1 Cult1	Sp1 Cult2	Sp1 Cult3	Sp1 Cult4	Sp1 Cult5	Sp1 Cult6	Sp1 Cult7	Sp1 Cult8	Sp1 Cult9	Sp1 Cult10
Sp 2 Tester 1										
Sp 2 Tester 2										
GMA Sp 1	**P11**	**P12**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P110**



Lucerne biomass in mixture with a forage fescue, g

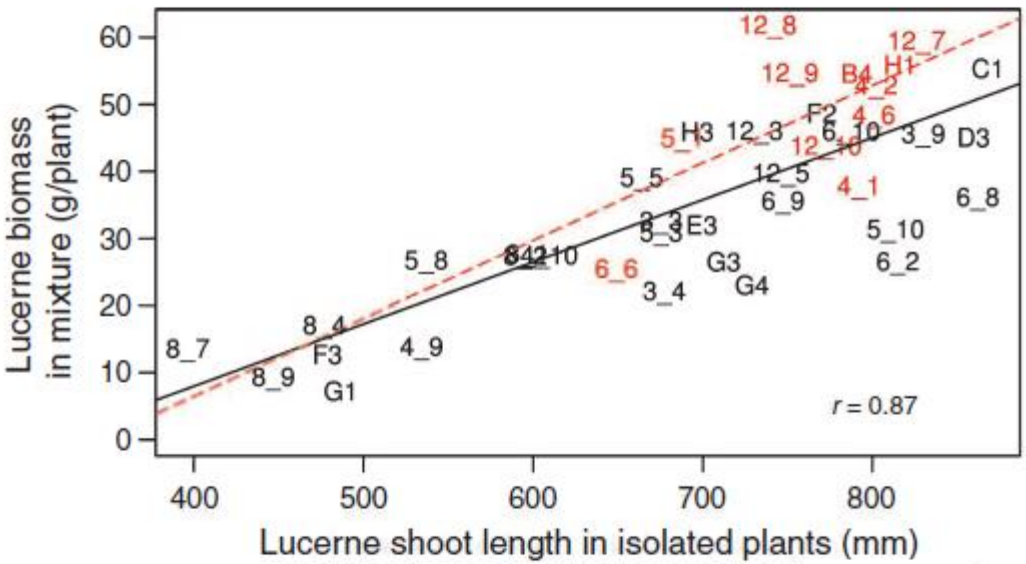
Cut 1 (May 2011)

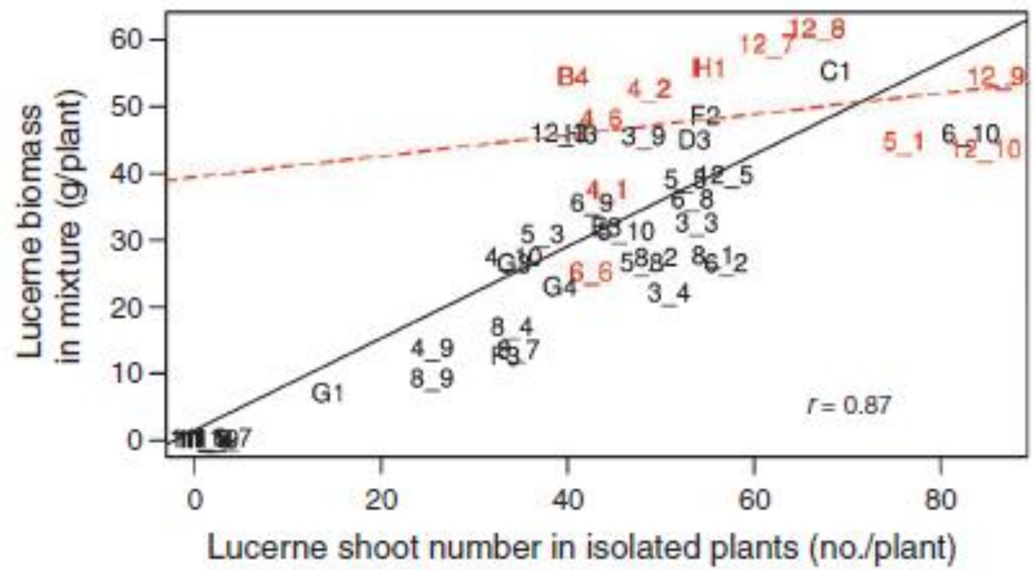
Source of variation	**Biomass**
Lucerne variety	37.65 ***
Lucerne genotype within variety	7.23 ***
Fescue genotype	2.90 NS
Interaction lucerne x fescue	1.20 NS

Maamouri et al 2015
Grass Past Sci

‘Performance in mixture’ : a new breeding trait

⇒ Select cultivar for traits that are correlated to GMA



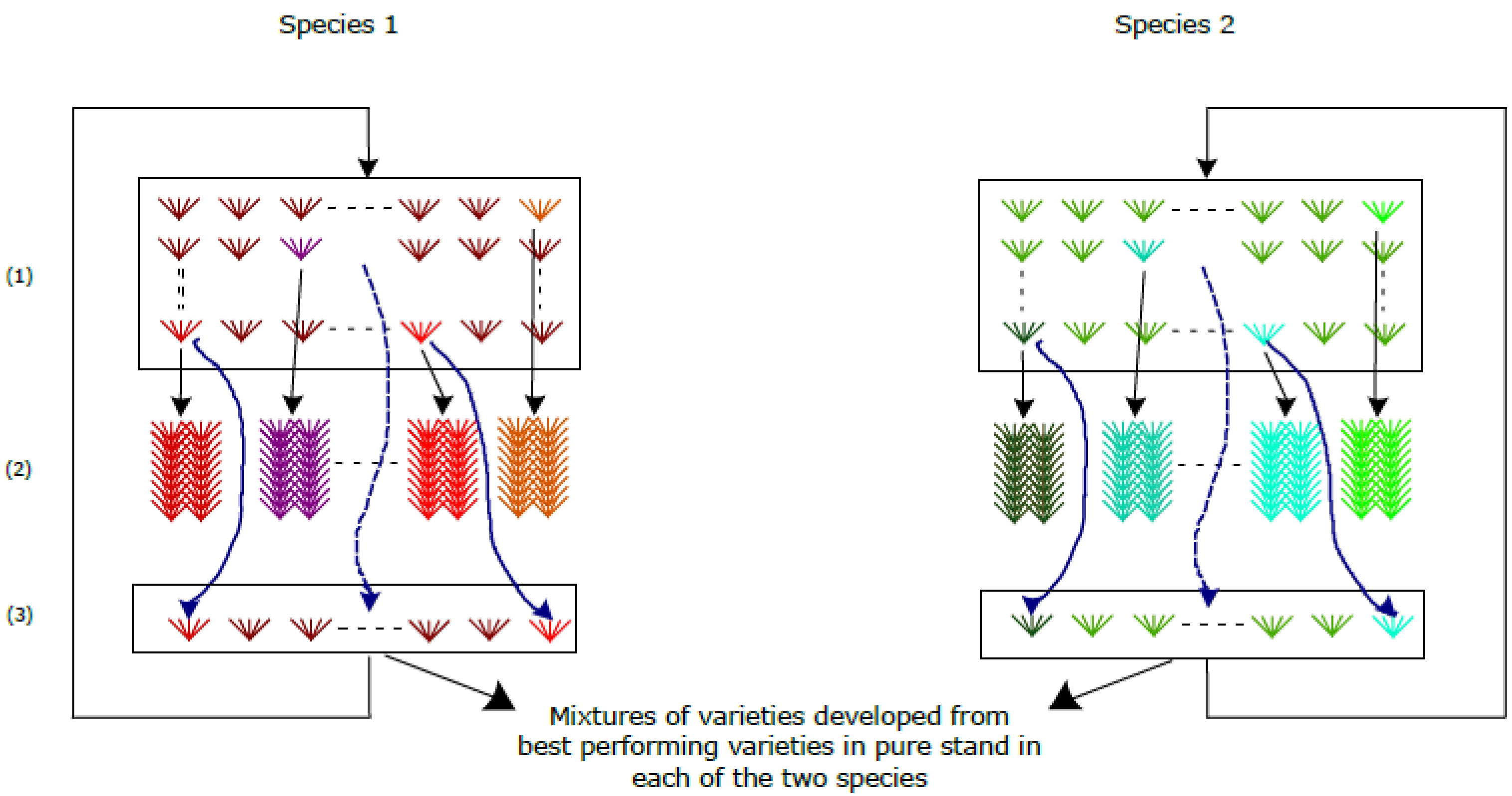


Maamouri et al 2017
Grass Past Sci

‘Performance in mixture’ : a new breeding trait

Comparison of 3 breeding schemes

(1) Selections in pure stands

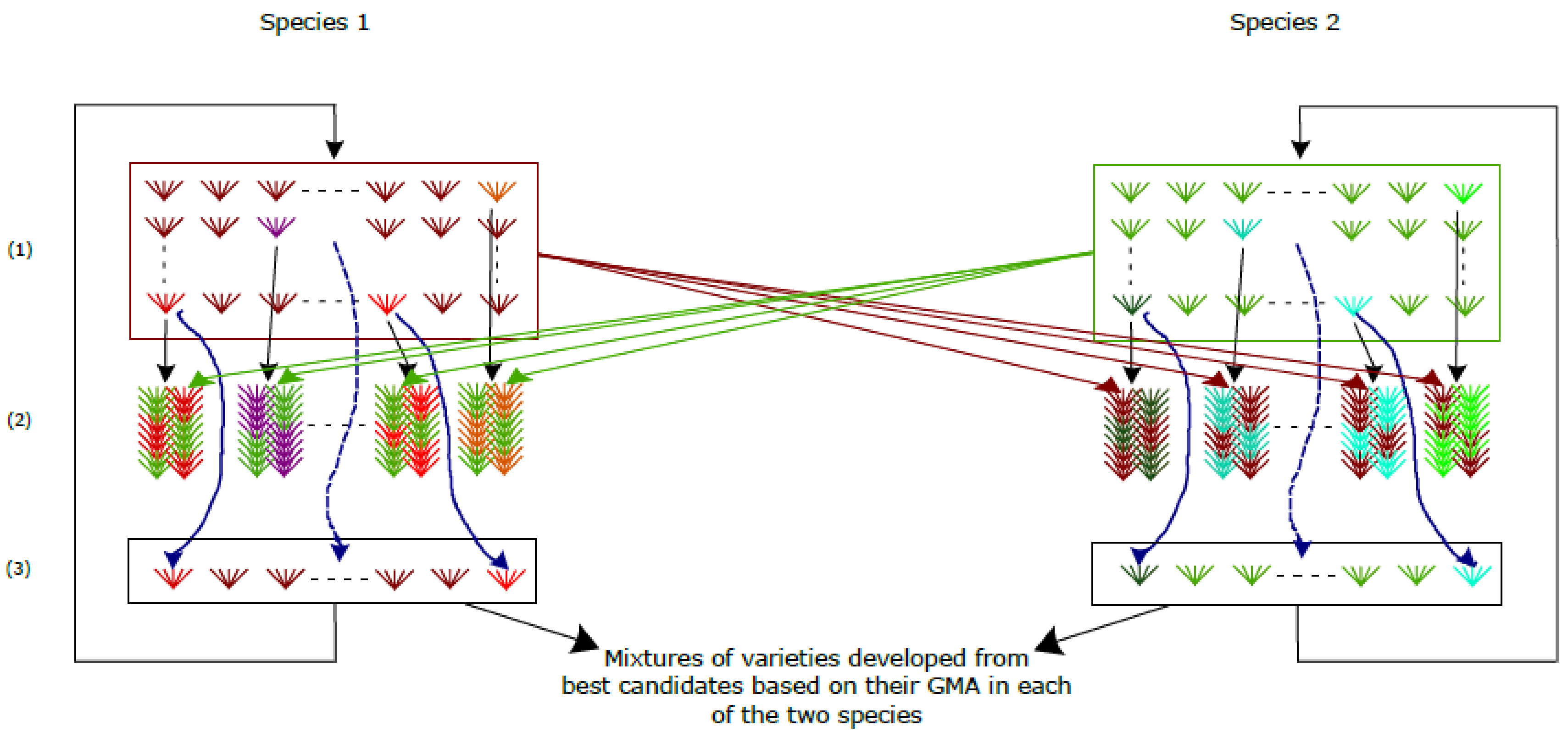


Sampoux et al, under review

'Performance in mixture' : a new breeding trait

Comparison of 3 breeding schemes

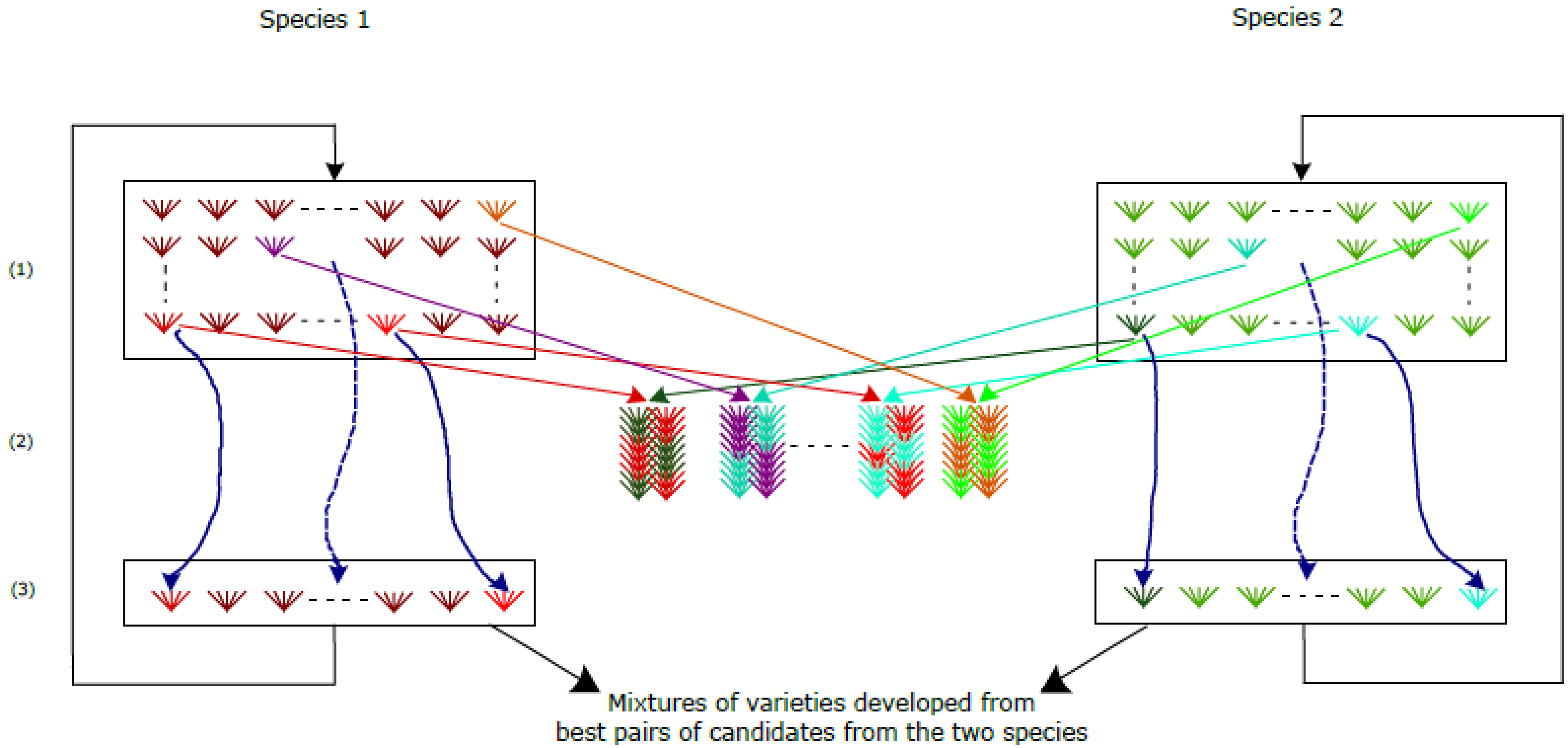
(2) Parallel selections for General Mixture Ability selection



‘Performance in mixture’ : a new breeding trait

Comparison of 3 breeding schemes

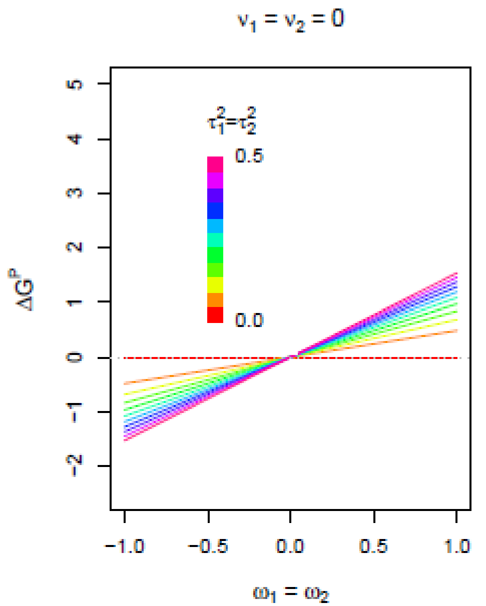
(3) Reciprocal selection for General Mixture Ability selection

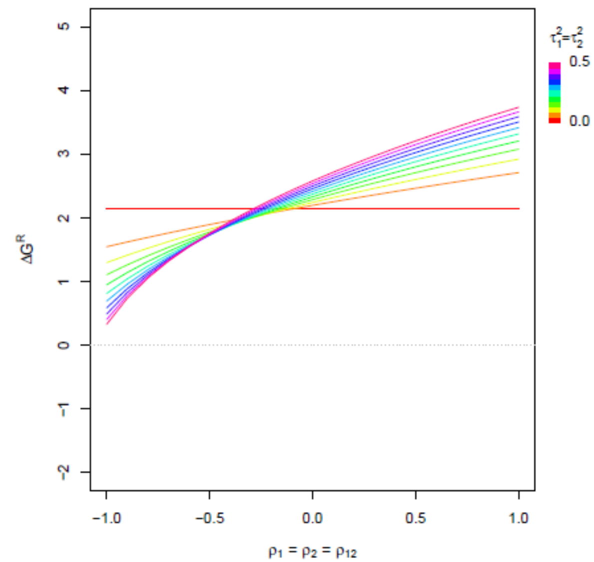


‘Performance in mixture’ : a new breeding trait

Comparison of 3 breeding schemes

Simulation with ranges of values for:
- Selection intensity
- Variances of direct and indirect effects
- Covariances
- …





Sampoux et al, under review

⇒ Parallel selection for General Mixture Ability is usually the most efficient scheme

Evolutionary Plant Breeding

'Evolutionary plant breeding' method (Suneson, 1956)

Selection of individuals after several years (fitness)

Initially in multiline mixtures (barley, wheat)

Also for grassland species

Select plants have experienced the interactions within the cover

In multispecies mixtures context

=> can allow the simultaneous selection of several species.

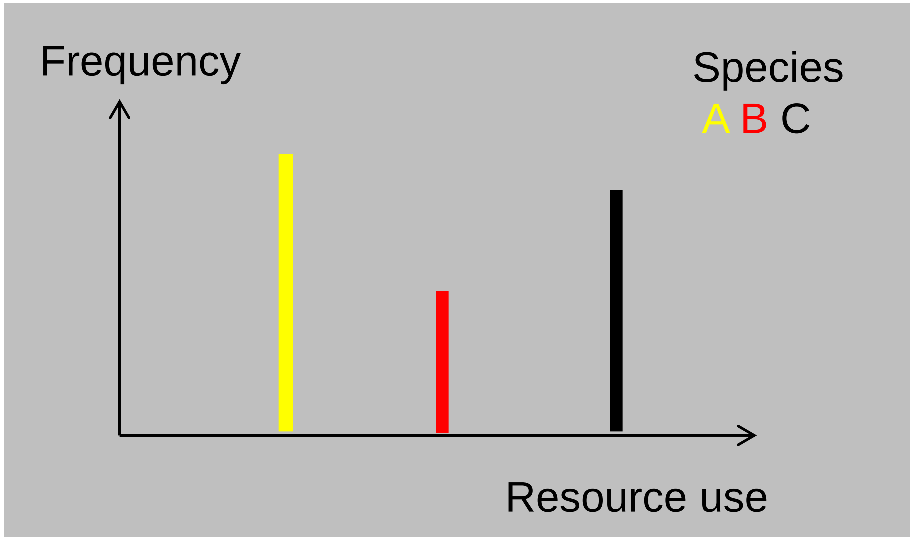
BUT the efficiency depends on the **correlation between fitness and agronomic value**

The functional approach

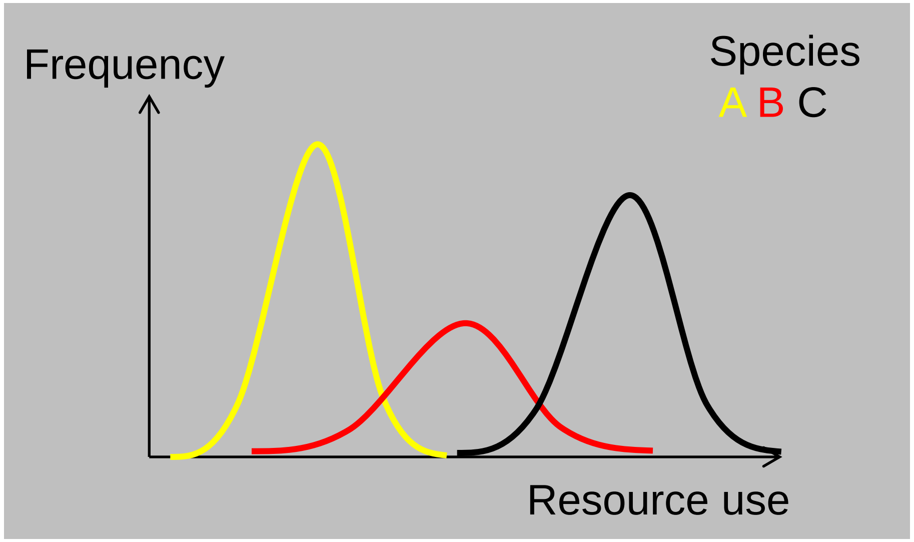
To create a more **general framework** for selection of plants to be used in **complex mixtures**

Based on the concepts and theories of community and functional ecology
=> **Complementarity** for resource use and acquisition

Mean



Distribution



Resource-use complementarity is being assessed in plant ecology *via* measurements of particular traits

The functional approach

=> **Rules** based on cultivar traits of each species **for assembling cultivars in multispecies mixtures**

=> Selection based on these '**interaction traits**'

Litrico and Violle (2015)
Trends Plant Sci

Interaction traits are related to resource acquisition:

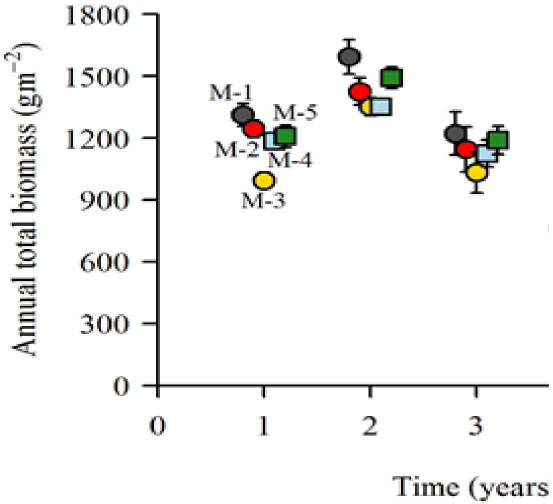
- ✓ Spatial resource-use complementarity
- ✓ Temporal resource-use complementarity → phenology
- ✓ Light partitioning and aboveground architecture

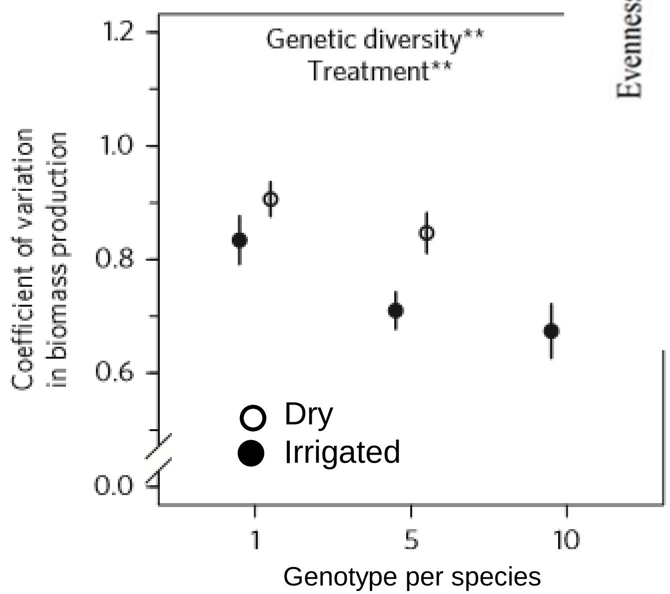
Effect of variance of these traits to be studied

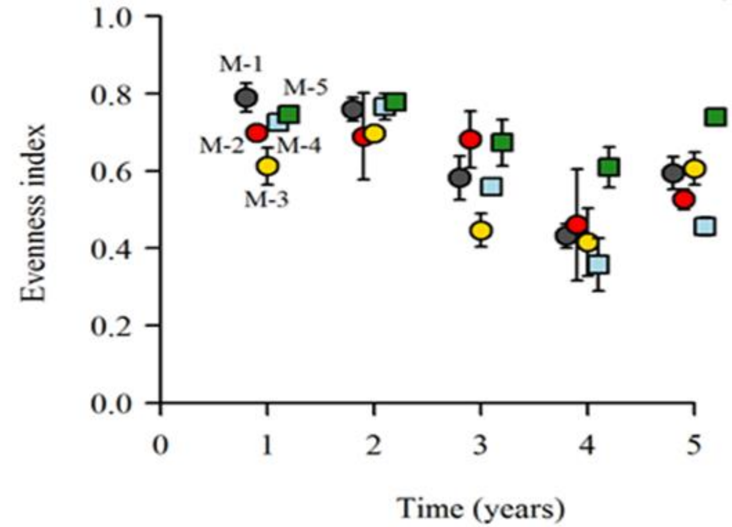
The functional approach

Genetic diversity within grassland species in mixture improves:

- ➢ Biomass production (Meilhac et al. 2019 Annals Botany)
- ➢ Biomass stability (Prieto et al. 2015 Nature Plants; Meilhac et al 2019 Annals Botany)
- ➢ Equilibrium of species abundance (Meilhac et al. 2019 Annals Botany)







=> Intra-species variance of interaction traits could be required

The functional approach

Breeding

If **we known the optimal mean and variance** of the interaction traits that maximize the value of the species mixture

=> the usual scheme of **recurrent selection can be applied** for each species separately

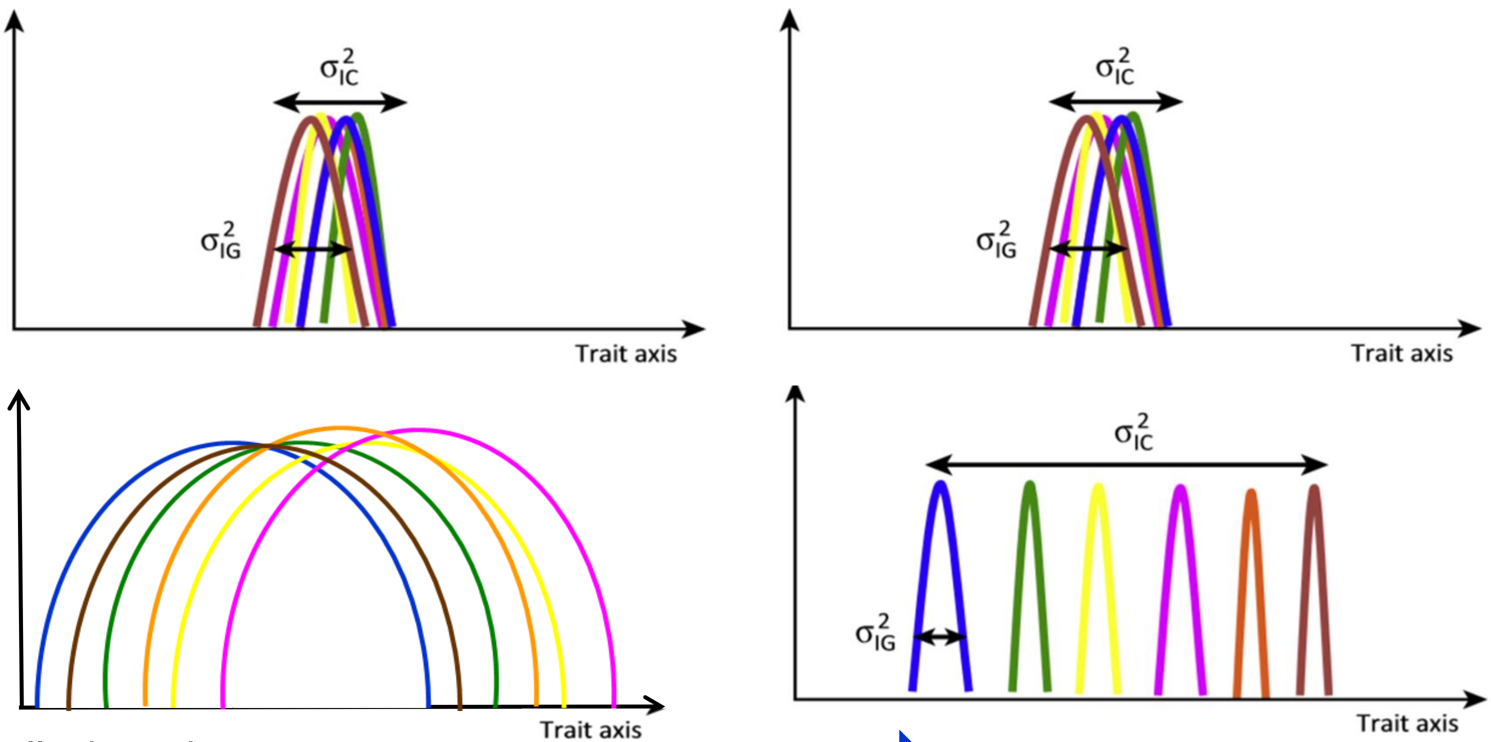
To obtain a certain variance for the interaction traits:

- pooling a number of cultivars, each with low variance for interaction traits but with contrasting means of these traits
- selecting a cultivar with a large variance for the interaction traits

The functional approach

Agronomic traits

Interaction traits



From Litrico and Violle (2015)
Trends Plant Sci

Selection

=> **Correlations** between interaction traits and agronomic traits

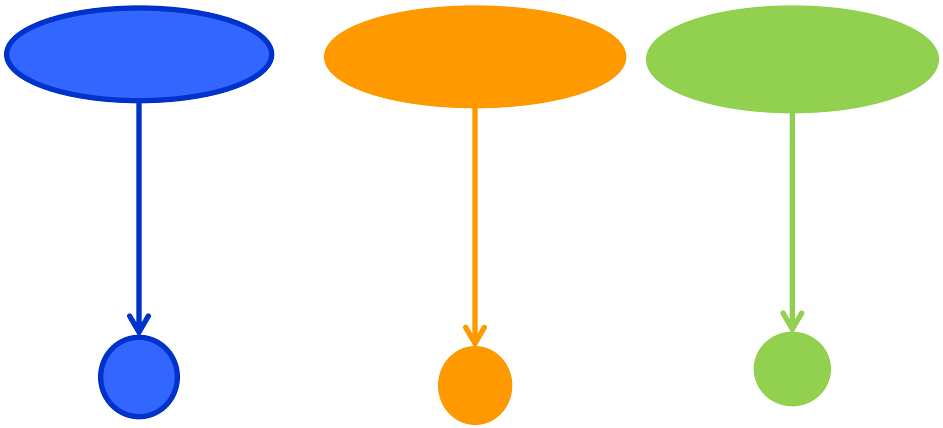
=> **Selection indices** to simultaneously control the means and variances of the interaction traits and the means of the agronomic traits

The functional approach

- Efficient if a few interaction traits lead to a **major effect**
- Difficulty to determine **all** the interaction traits

Combined approaches

=> Efficient selection schemes to improve **complex mixtures**



Selection of candidate genotypes from each species on the basis of

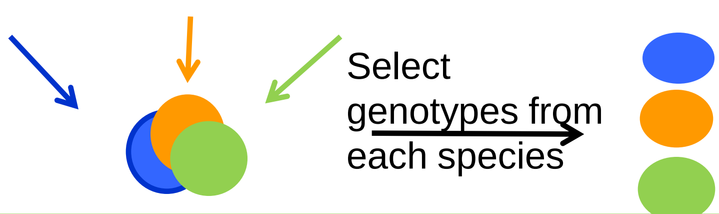
- the mean and variance values of the interaction traits
- the mean value of agronomic traits

optimize the trade-off between traits through selection indices if needed

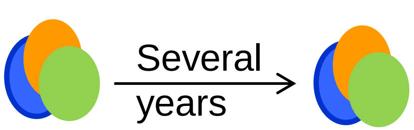
Functional approach

Quantiative genetics

1) Fitness and performance values are not or negatively correlated
→ Parallel selections for General Mixture Ability



2) Fitness and performance values are correlated
→ Evolutionary plant breeding



Evolutionnary

Conclusion…

Several approaches to improve multispecies grasslands
Choice of the method depends on the expected level of performance
yield, species composition, …

Quantative genetics and functional analyses to improve the multispecies grasslands

⇒ Need to **increase our knowledge** on all species used in grasslands and their interactions within a multispecies composition

⇒ **Screening of** the current **genetic resources of grassland species**
to estimate the variability of interaction traits and the genetic correlations between the interaction traits and the agronomic traits

⇒ Need to develop **proofs of concept**
with experimental selections

Thank you for your attention!