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# Strategy avenues for breeding plants for multispecies grasslands

Isabelle Litrico and Bernadette Julier

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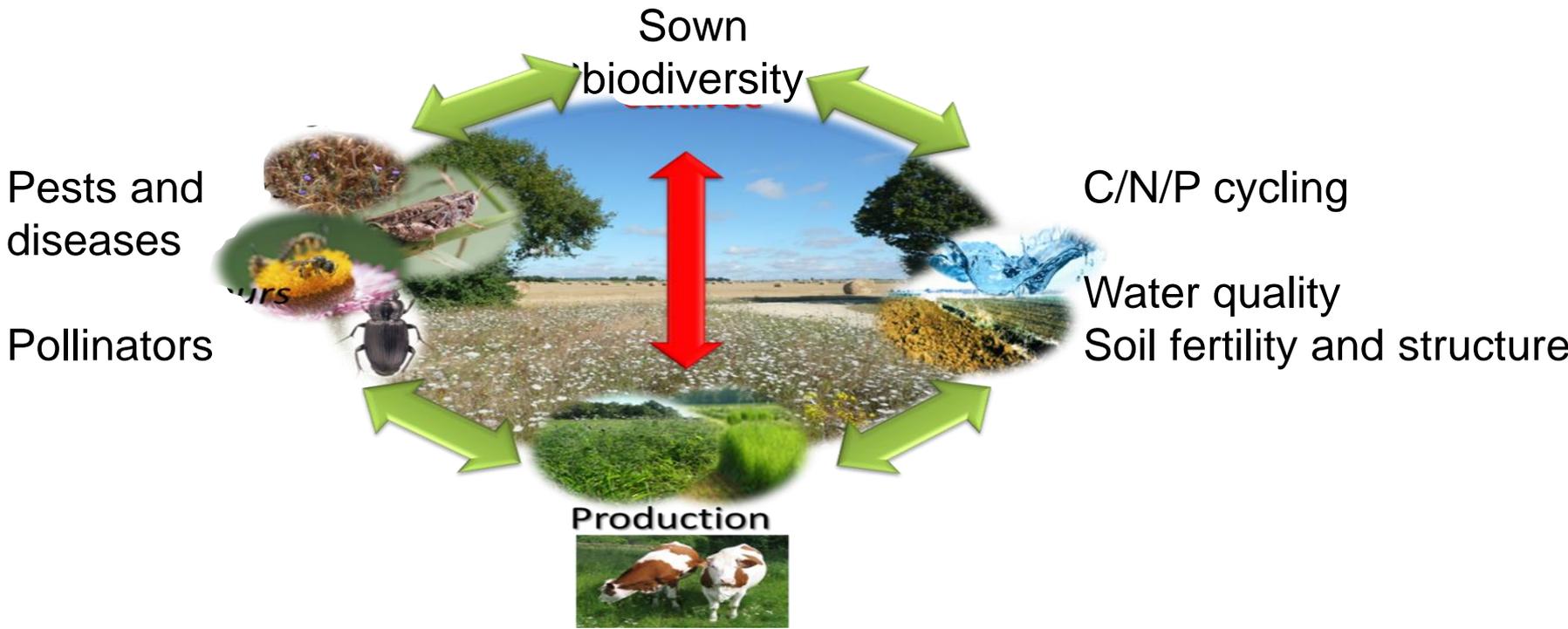


# Challenge for agriculture

Climate change  
Low inputs

Key role of species  
diversity

Sustainable cropping systems  
Production and Stability



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/Plaqueette\\_AFPF-Melanges.pdf](http://afpf-asso.fr/files/Outils/Plaqueette_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

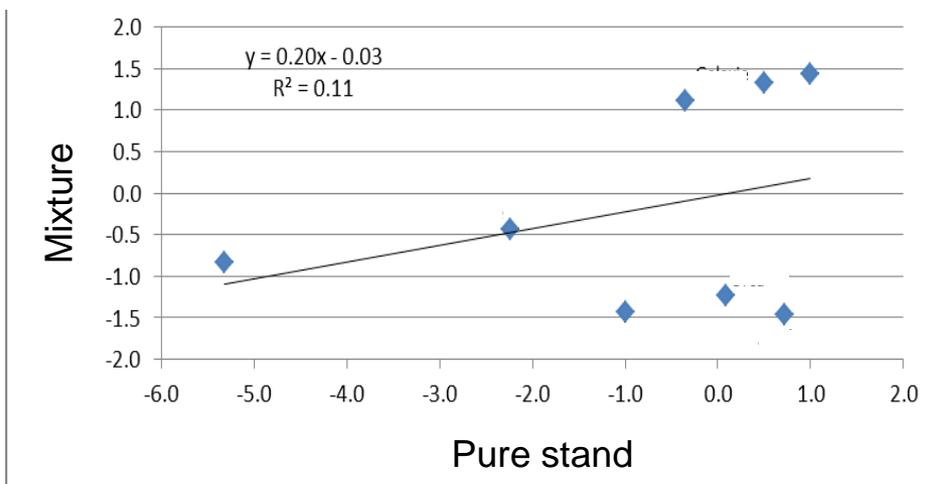
# Multispecies sown grasslands and genetic composition

Within and among species interactions : for light, nutrients, water...

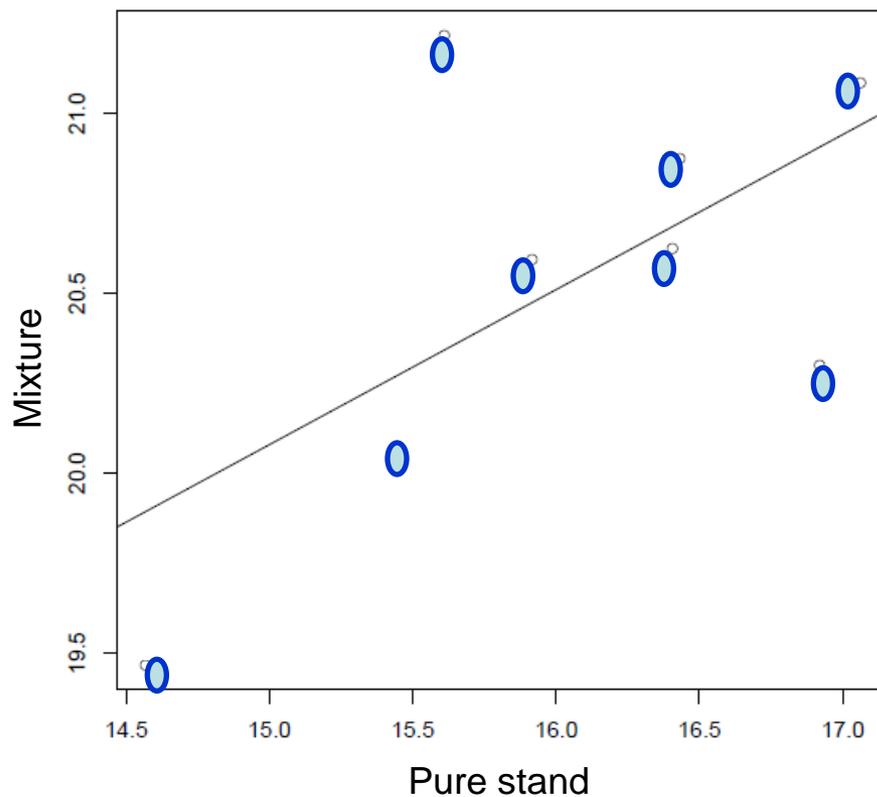
=> local selection pressures

=> 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



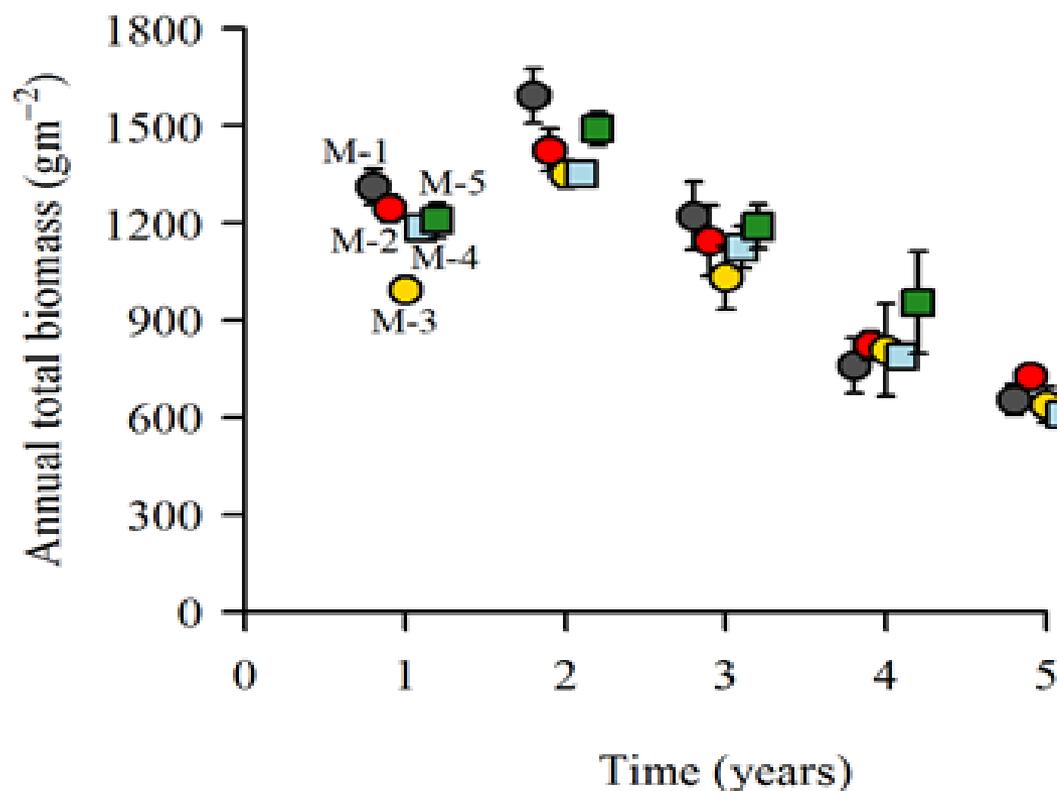
Perennial ryegrass – Forage yield





# Multispecies 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

## 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

## Do we need specific breeding for legume-based mixtures?

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- *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 =  $P12 - (\text{mean P1} + \text{mean P2})/2$

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:

⇒ the **SMA effects are small**

⇒ the progress in one target species will improve the performance of the **whole plant community**

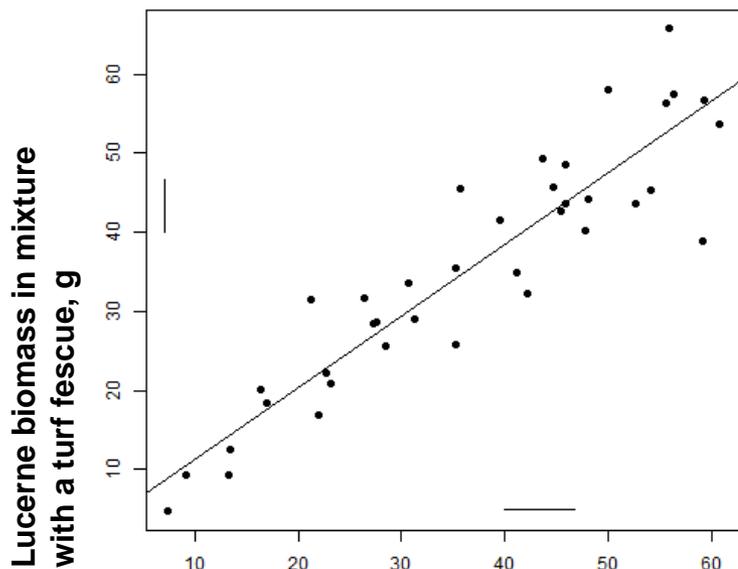
## **Limitations**

- 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										
<b>GMA Sp 1</b>	<b>P11</b>	<b>P12</b>	<b>P13</b>	<b>P14</b>	<b>P15</b>	<b>P16</b>	<b>P17</b>	<b>P18</b>	<b>P19</b>	<b>P110</b>



Lucerne biomass in mixture with a forage fescue, g

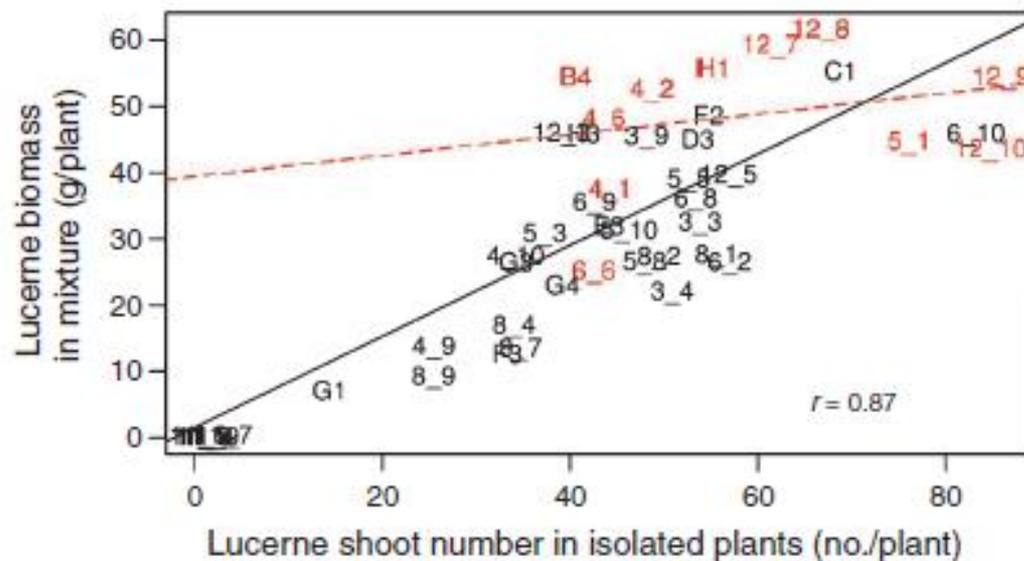
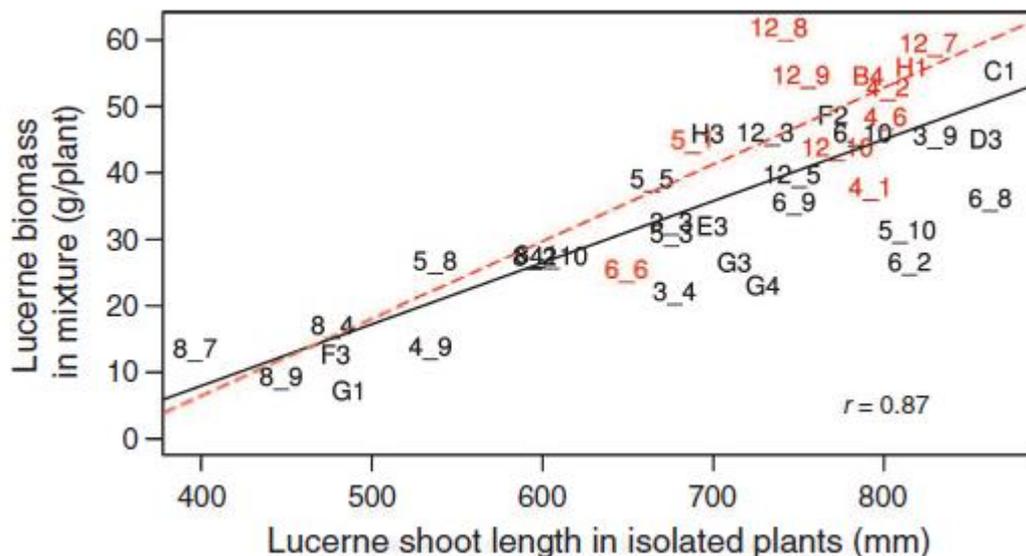
Cut 1 (May 2011)

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

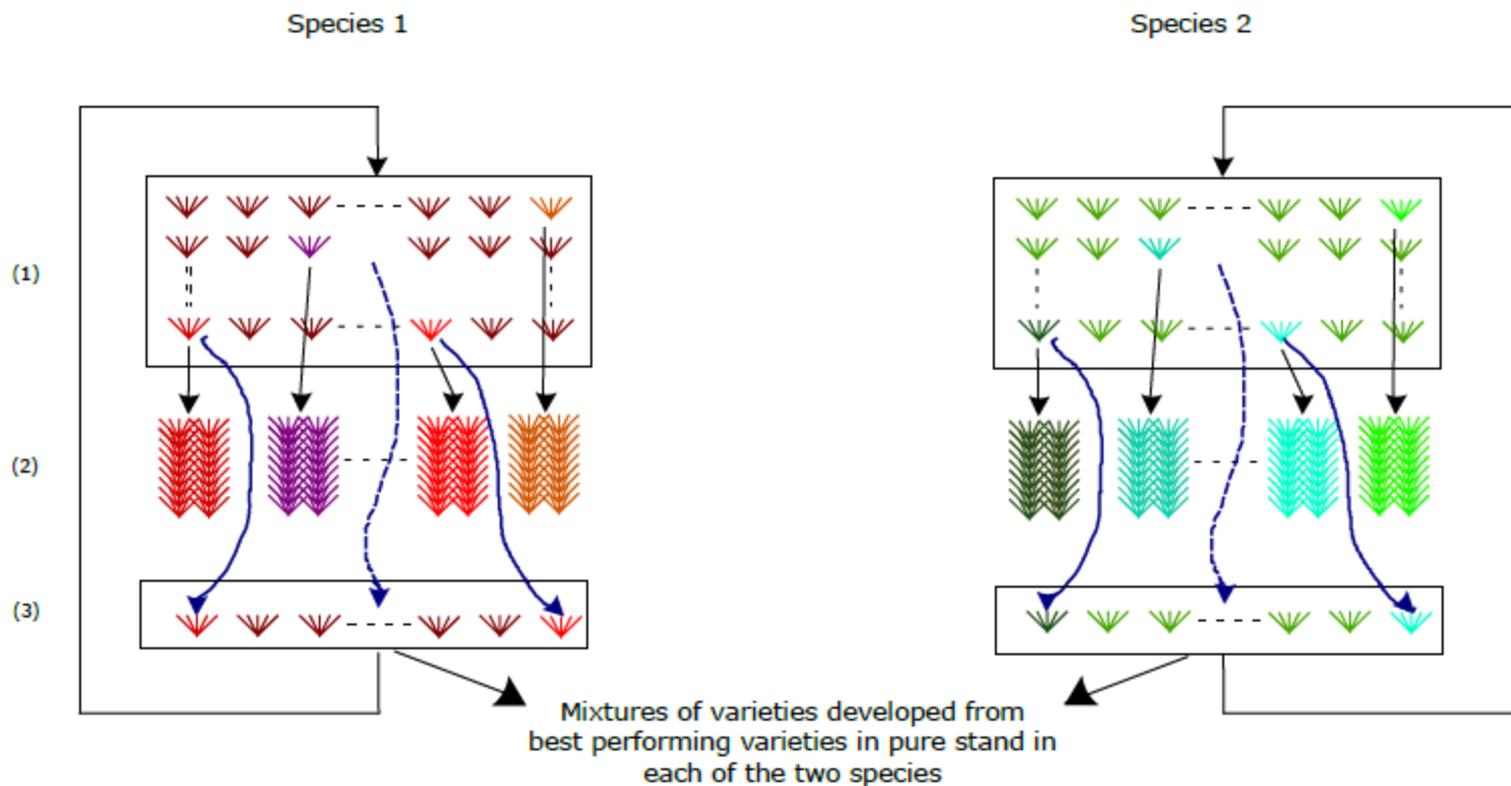


Maamouri et al 2017  
Grass Past Sci

# 'Performance in mixture' : a new breeding trait

## Comparison of 3 breeding schemes

### (1) Selections in pure stands

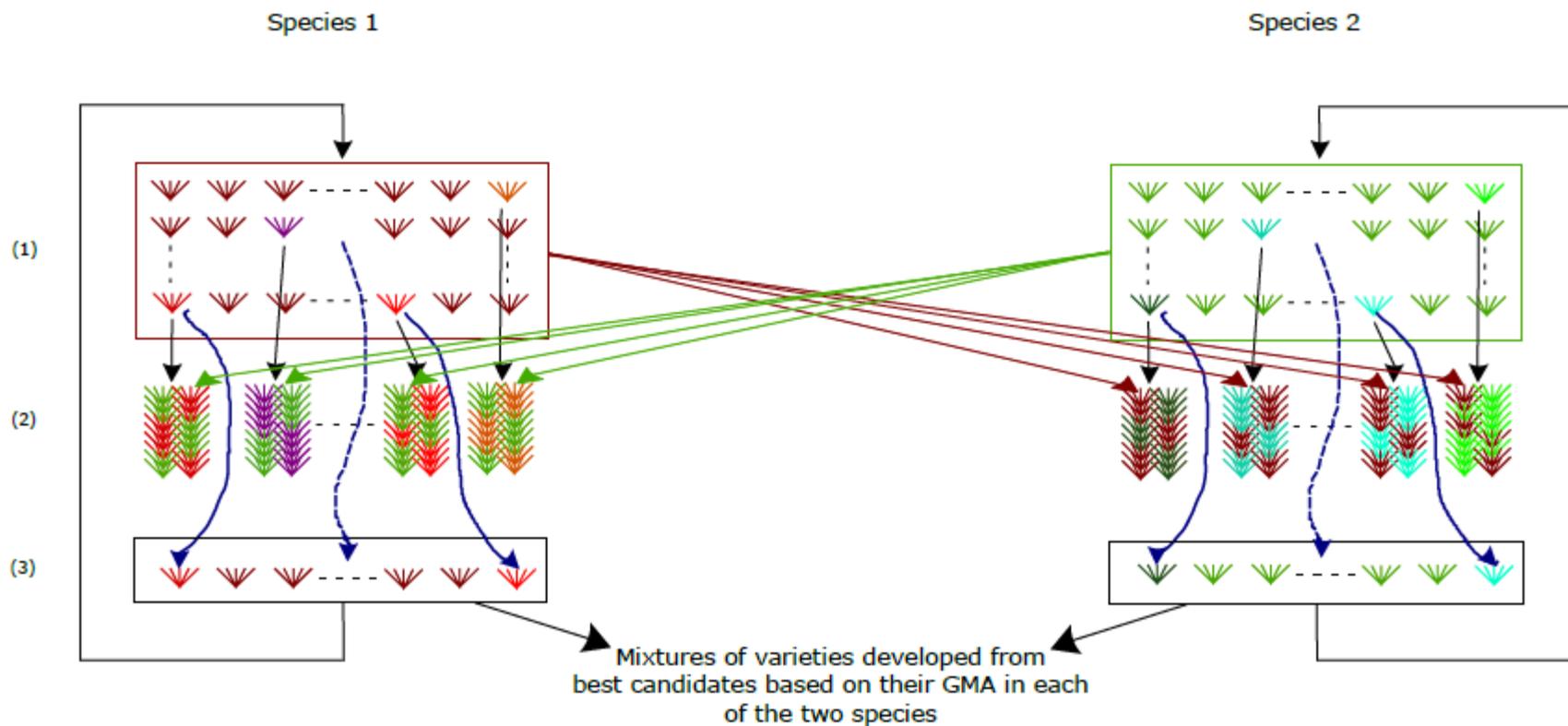


Sampoux et al,  
under review

# 'Performance in mixture' : a new breeding trait

Comparison of 3 breeding schemes

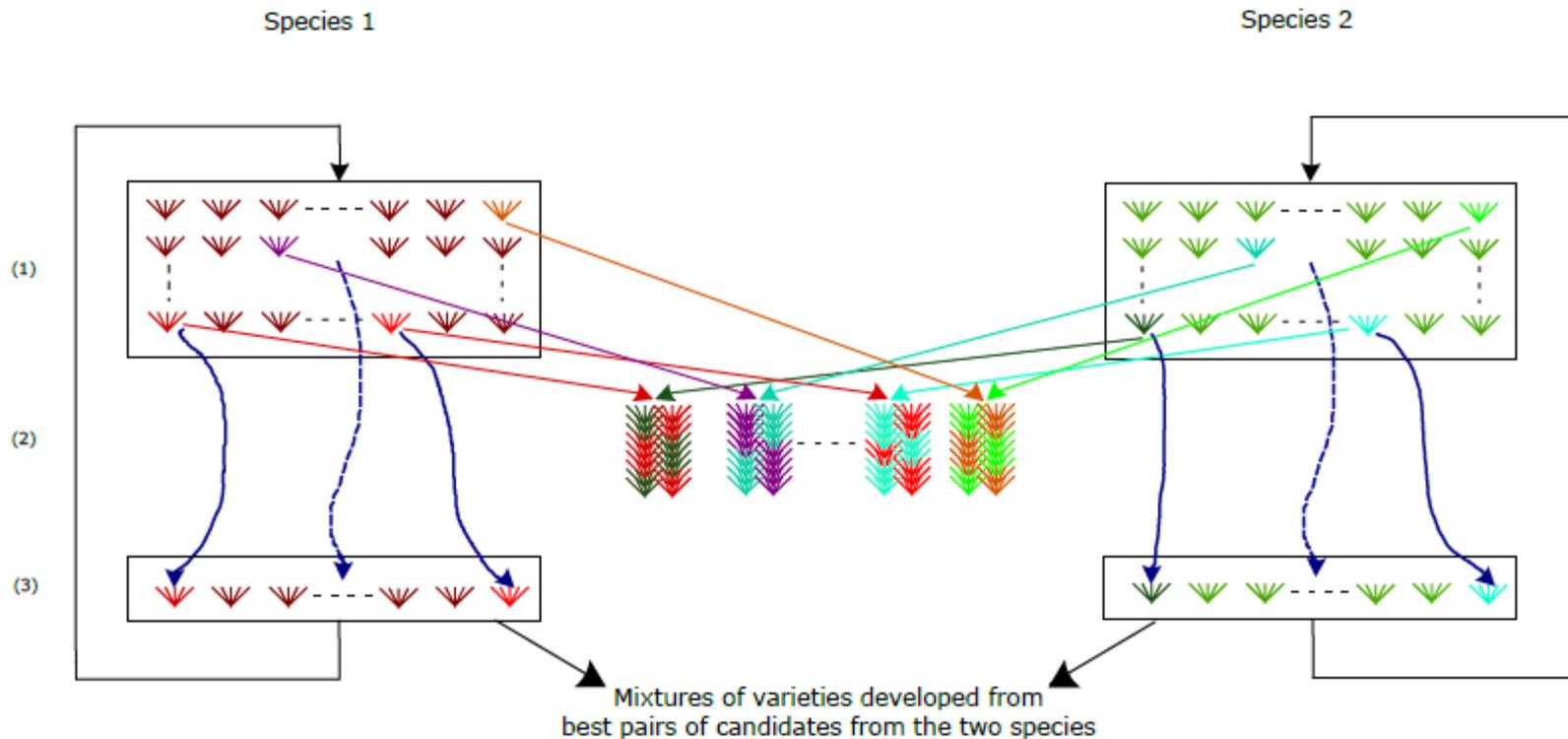
(2) Parallel selections for General Mixture Ability selection



# '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

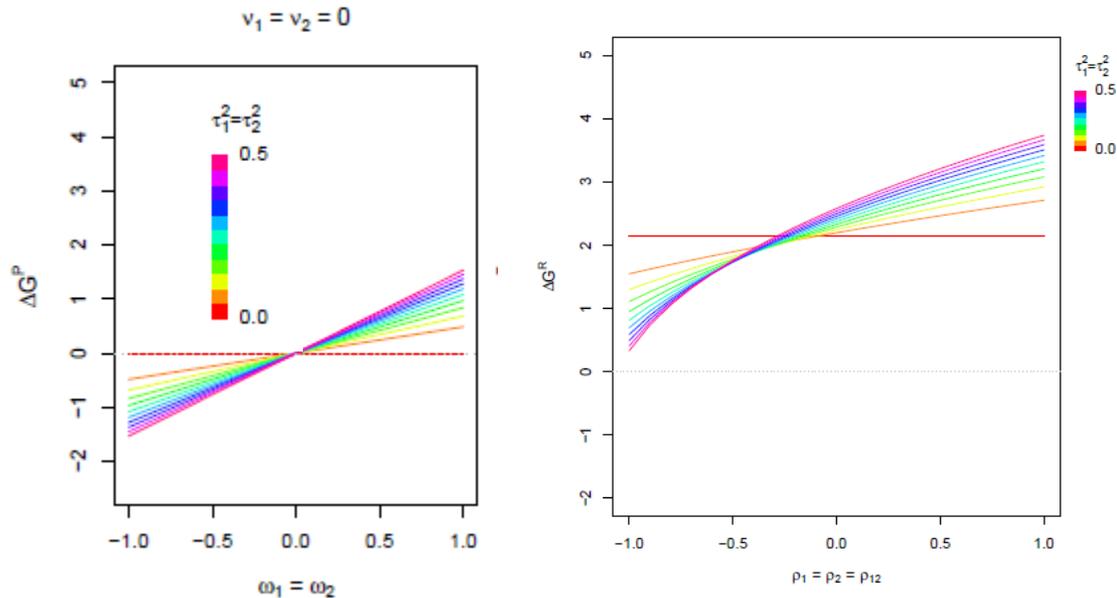
Simulation with ranges of values for:

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**

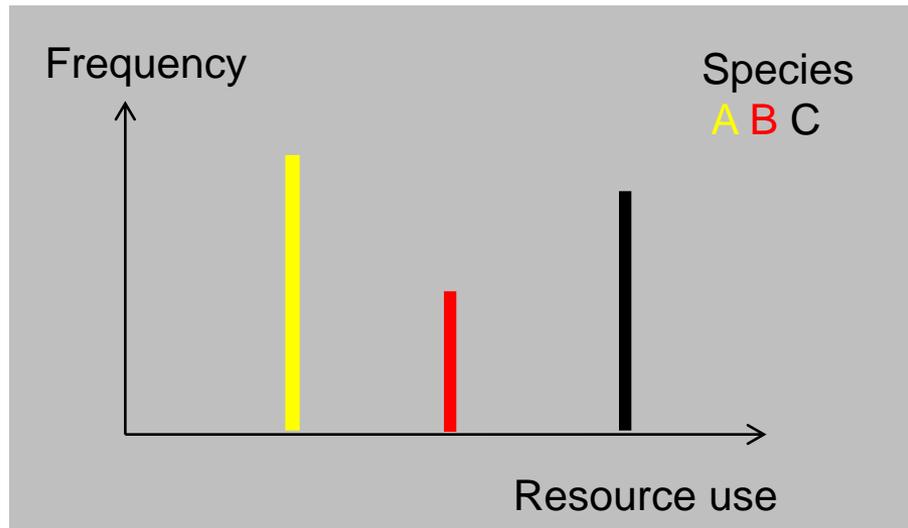


# The functional approach

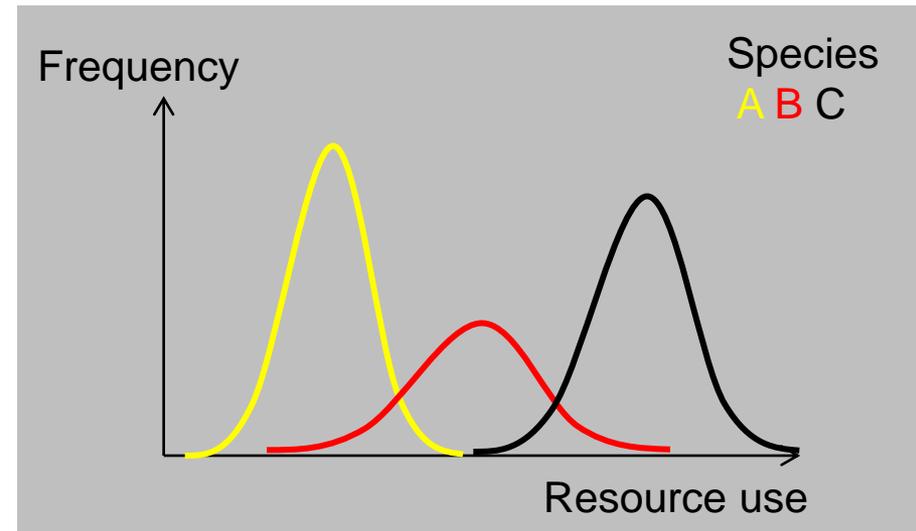
To create a more **general framework** for selection of plants to be used in **complex mixtures**

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**'

Litrice and Violle (2015)  
*Trends Plant Sci*

**Interaction traits** are related to resource acquisition:

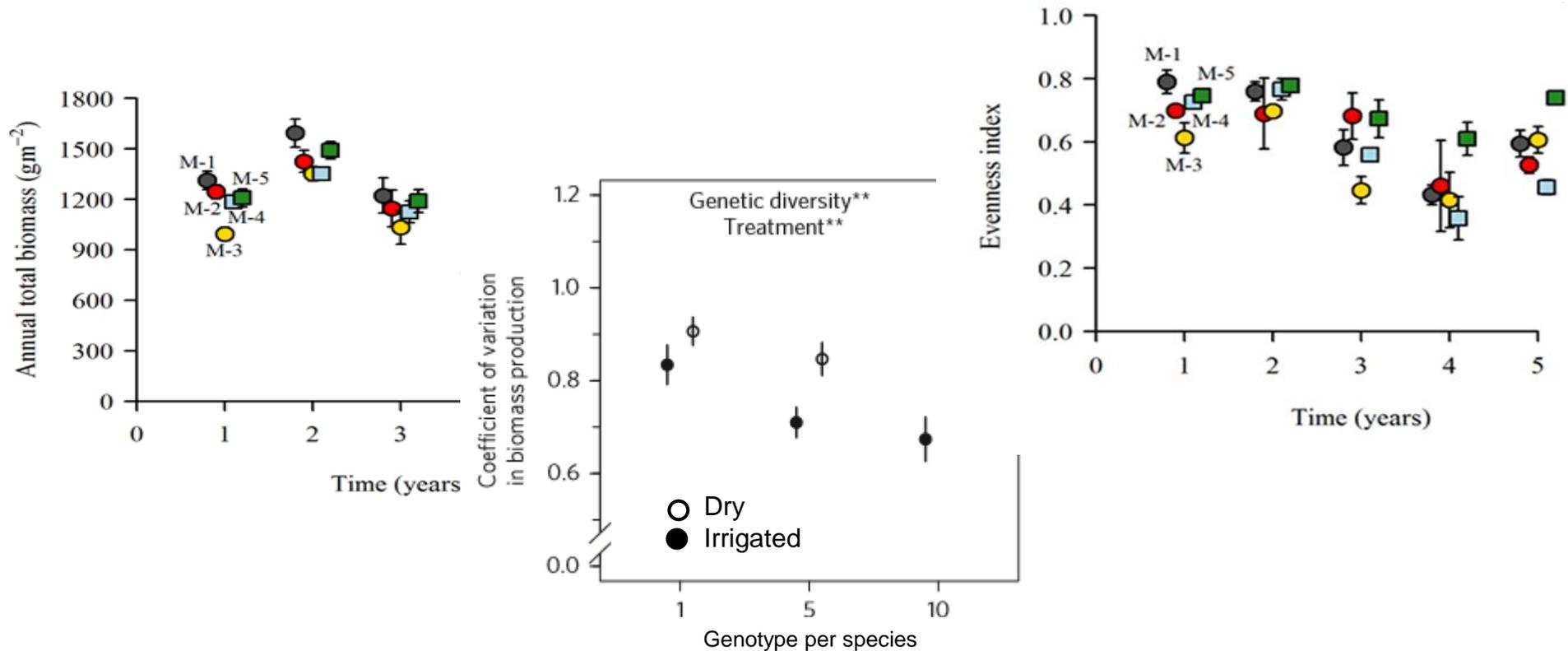
- ✓ Spatial resource-use complementarity
- ✓ Temporal resource-use complementarity → phenology
- ✓ Light partitioning and aboveground architecture

***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

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## Breeding

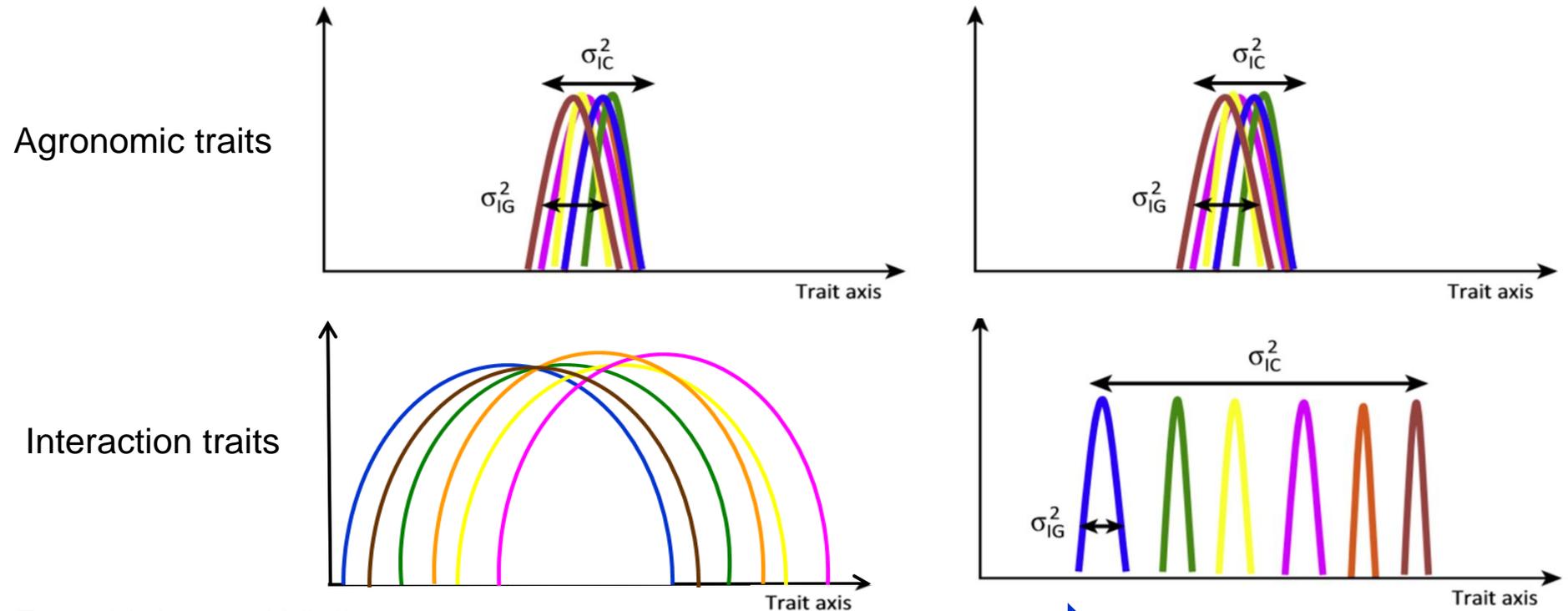
If **we know the optimal mean and variance** of the interaction traits that maximize the value of the species mixture

=> 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



From Litrico and Violle (2015)  
*Trends Plant Sci*



=> **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

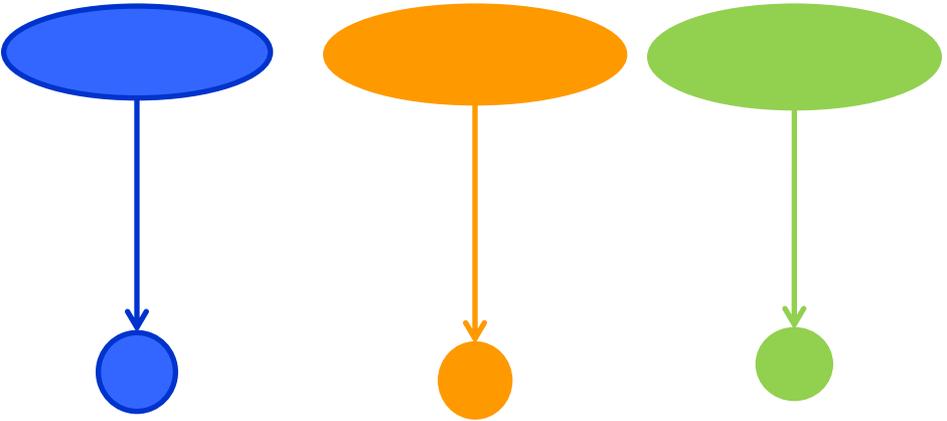
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- Efficient if a few interaction traits lead to a **major effect**
- Difficulty to determine **all** the interaction traits



# 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

Quantitative 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

Evolutionary



# 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!**