Strategy avenues for breeding plants for multispecies grasslands
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To cite this version:

HAL Id: hal-02737274
https://hal.inrae.fr/hal-02737274
Submitted on 2 Jun 2020

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Strategy avenues for breeding plants for multispecies grasslands

Isabelle Litrico and Bernadette Julier

INRA – P3F Lusignan - France

EGF EUCARPIA
Zurich 24-27/06/2019
Challenge for agriculture

- Climate change
- Low inputs

Sustainable cropping systems
Production and Stability

Key role of species diversity

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://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

\[
y = 0.20x - 0.03 \\
R^2 = 0.11
\]

Perennial ryegrass – Forage yield
BUT SOME STUDIES SHOW a partial correlation

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

=> Significant implications for breeding

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
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?

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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

<table>
<thead>
<tr>
<th></th>
<th>Cultivar 1</th>
<th>Cultivar 2</th>
<th>Cultivar 3</th>
<th>Cultivar 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar 1</td>
<td>P1</td>
<td>P12</td>
<td>P13</td>
<td>P14</td>
</tr>
<tr>
<td>Cultivar 2</td>
<td>P21</td>
<td>P2</td>
<td>P23</td>
<td>P24</td>
</tr>
<tr>
<td>Cultivar 3</td>
<td>P31</td>
<td>P32</td>
<td>P3</td>
<td>P34</td>
</tr>
<tr>
<td>Cultivar 4</td>
<td>P41</td>
<td>P42</td>
<td>P43</td>
<td>P4</td>
</tr>
<tr>
<td>GMA</td>
<td>Mean P1</td>
<td>Mean P2</td>
<td>Mean P3</td>
<td>Mean P4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Species 1 Cultivar 1</th>
<th>Species 1 Cultivar 2</th>
<th>Species 1 Cultivar 3</th>
<th>Species 1 Cultivar 4</th>
<th>GMA Species 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species 2 Cultivar 1</td>
<td>P11,21</td>
<td>P12,21</td>
<td>P13,21</td>
<td>P14,21</td>
<td>Mean P21</td>
</tr>
<tr>
<td>Species 2 Cultivar 2</td>
<td>P11,22</td>
<td>P12,22</td>
<td>P13,22</td>
<td>P14,22</td>
<td>Mean P22</td>
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<td>Species 2 Cultivar 3</td>
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<td>P14,22</td>
<td>Mean P22</td>
</tr>
<tr>
<td>Species 2 Cultivar 4</td>
<td>P11,24</td>
<td>P12,24</td>
<td>P13,24</td>
<td>P14,24</td>
<td>Mean P22</td>
</tr>
<tr>
<td>GMA Species 1</td>
<td>Mean P11</td>
<td>Mean P12</td>
<td>MeanP13</td>
<td>Mean P14</td>
<td></td>
</tr>
</tbody>
</table>

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’

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucerne variety</td>
<td>37.65 ***</td>
</tr>
<tr>
<td>Lucerne genotype within variety</td>
<td>7.23 ***</td>
</tr>
<tr>
<td>Fescue genotype</td>
<td>2.90 NS</td>
</tr>
<tr>
<td>Interaction lucerne x fescue</td>
<td>1.20 NS</td>
</tr>
</tbody>
</table>

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

⇒ 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**
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

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**’

---

**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


=> **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

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
Conclusion...

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

Quantitative 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!