Multi-environment QTL mixed models for dissecting N use efficiency and tolerance to low N in wheat

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Nitrogen (N) fertilizer in the wheat production system

> impact on grain yield (GY) and grain protein content (GPC)
> economic issues
  > about 30% of operational cost
  > about 66% of energetic cost
> environmental issues
  > water pollution
  > greenhouse effect

⇒ Agronomical solutions
⇒ Need to breed for wheat varieties that
  > have a high N use efficiency (NUE)
Lower genetic progress at low N

Ortiz-Monasterio et al, 1997

Foulkes et al, 1998

Brancourt et al, 2003
**Traits and definitions**

- **NUE** = Grain Yield / Available N
  - N uptake efficiency (NUpE) = Plant N / Available N
  - N utilization efficiency (NUtE) = Grain Yield / Plant N

  Available N = Soil N + Fertilizer N
  Supposed to be the same for all genotypes

- **NNI** = Nitrogen Nutrition Index
  - Based on the N critical curve (Justes et al 1994)
  - Indicates N stress level
    - Environment: indicator of the overall level of N stress
    - Genotype: a component of the resistance to N stress

  ![Graph showing N Critical curve equation: \( N_{%c} = 5.35 \times DM^{-0.442} \) when DM > 1 t/ha]
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![Diagram showing NNI curve and N stress levels for different genotypes (G1, G2, G3).]
Genetic variability for response to N stress

(Le Gouis et al 2000, Devienne-Barret et al unpublished)
## Populations and Trials

<table>
<thead>
<tr>
<th>Traits</th>
<th>Arche x Récital (F)</th>
<th>Apache x Ornicar (F)</th>
<th>Seri x Babax (Au)</th>
<th>Cranbrook x Halberd (Au)</th>
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<tbody>
<tr>
<td>Size</td>
<td>198</td>
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<tr>
<td>Traits</td>
<td>Biomass / N%</td>
<td>Biomass / N%</td>
<td>Biomass / N%</td>
<td>Biomass / N%</td>
</tr>
<tr>
<td></td>
<td>Flo-Mat</td>
<td>Flo-Mat</td>
<td>Flo</td>
<td>Flo+180°Cd</td>
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</tbody>
</table>

NUE, NUtE, NUpE, NNI
Range of variation

Grain Yield (g/m²)

NUE = 27 kg GY / kg Na

NUtE = 45 kg GY / kg Nt

NUpE = 63%
QTL detection - mixed linear QxE model

1. Estimate means (BLUEs)
2. Choose Var/Cov Model
3. Estimate genetic predictors
4. SIM QTLwin= 30cM
5. CIM CofWin= 50cM
6. Backward selection
7. Estimate effects

Multi-environment / Multi-trait

\[ P_{ij} = \mu + E_i + G_j + GE_{ij} \]
\[ P_{ij} = \mu + E_i + x_1\alpha + G_j^* + x_1\alpha + GE^*_{ij} \]

Genstat 12
(VSN international)
(Boer et al 2007; Mathews et al 2008)

Stepsize = 10cM
QTL detection for NUE

QTLxE effects

Arche
Récital

Eff >2
Large impact of development

Mons 2000HN+ ARE
Final model

Arche Récital
Correlations with NUE
Identification of NUE components QTL

N uptake
Efficiency

N utilization
Efficiency

QTL effects

cf01HN
cf01LN
m00HN
m00LN
m10HN
m10LN
ms00HN
ms00LN
ms01HN
ms01LN
nk00HN
nk00LN

Arche

Récital
Comparison between populations

N uptake

Efficiency

N utilization

Efficiency

Apache

Ornicar

QTL effects

jml04LN
icf04LN
hms04LN
gms04HN
fml03LN
ecf04HN
dml04HN
cms03LN
bml03HN
ams03HN

1B
2D
4B
5A

2A
3A
4B
5B
5D

19th ITMI, 3rd COST
Clermont-Ferrand
Environments cofactors

N uptake efficiency

QTL_5A

R² = 0.51

Arche

Récital

Low N

High N

NNI (%)
QTL detection for NNI

ARE c2D
A x O
S x B
C x H

20 40 60 80 100 120 140 160
NNI (%)

A R E
A x O
S x B
C x H

Inter
Add
Conclusions

- Using multi-environment trials on 4 mapping populations
  - Identify QTL for NUE and its components NUtE and NUpE
  - For some of the QTL (2A, 2D, 4B, 5A) the most probable candidates genes are development gene (Ppd, Vrn, Rht)
  - Most of the QTL showed a significant QxE interaction (17/21=80%)
  - For one QTL (ARE-NUpE-5A) a significant correlation found between the allelic effect and NNI
  - QTL detected for NNI (2D, 1A, 4A)
Perspectives

Complete/Extend QTL detection to other populations
- INRA/BBSRC NUEtraits project (J. Foulkes)
- Perform multi-trait/multi-environment detection (/multi-population)
- Project QTL on a consensus map

Better characterize the environment to explain QxE interaction
- Measured environment covariates (NNI)
- Probe genotypes
- Crop model to simulate environment stress indicators

Identify / validate candidate genes
- Map-based cloning for one QTL on 3B (U. Masood, J. Salse)
- Near-Isogenic lines currently constructed for ARE QTL
Acknowledgements

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