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

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Context

Nitrogen (N) fertilizer in the wheat production system

> impact on grain yield (GY)

and grain protein content (GPC)

> economic issues

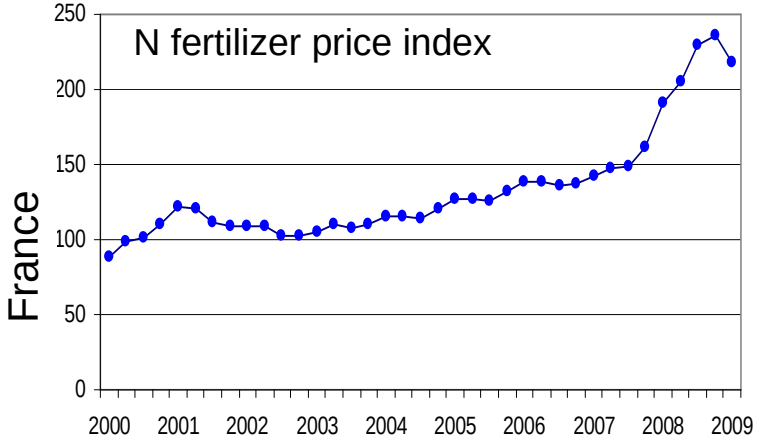
> about 30% of operational cost

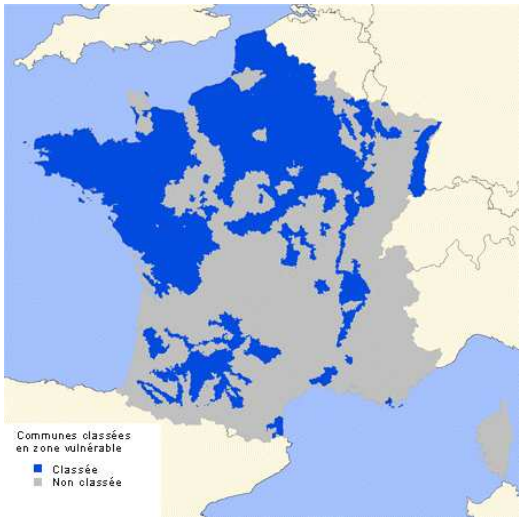
> about 66% of energetic cost

> environmental issues

> water pollution

> greenhouse effect



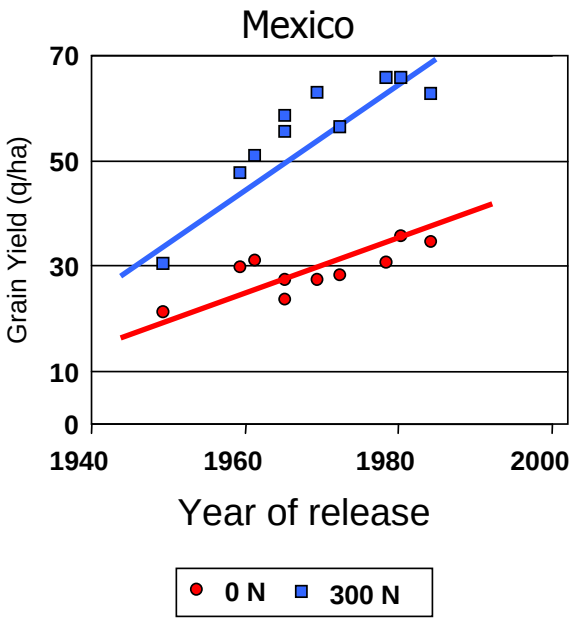


⇒ Agronomical solutions

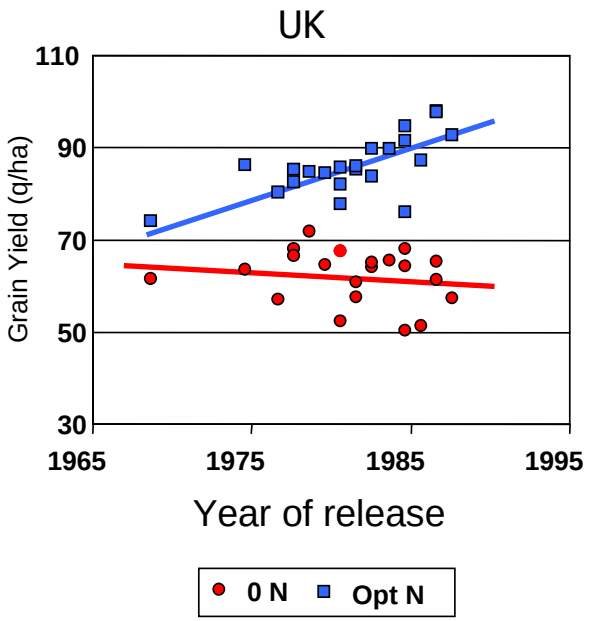
⇒ Need to breed for wheat varieties that

> have a high N use efficiency (NUE)

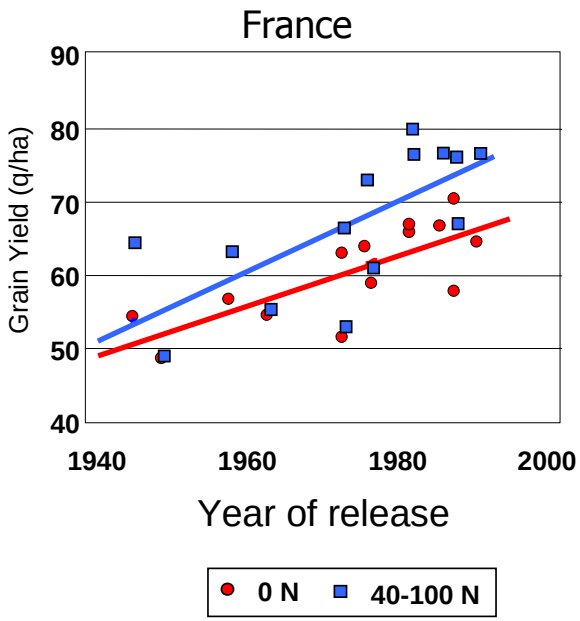
Lower genetic progress at low N



Ortiz-Monasterio et al, 1997



Foulkes et al, 1998



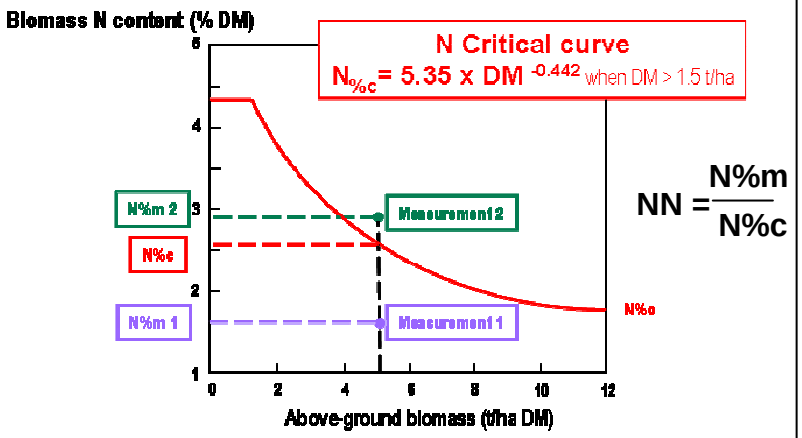
Brancourt et al, 2003

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



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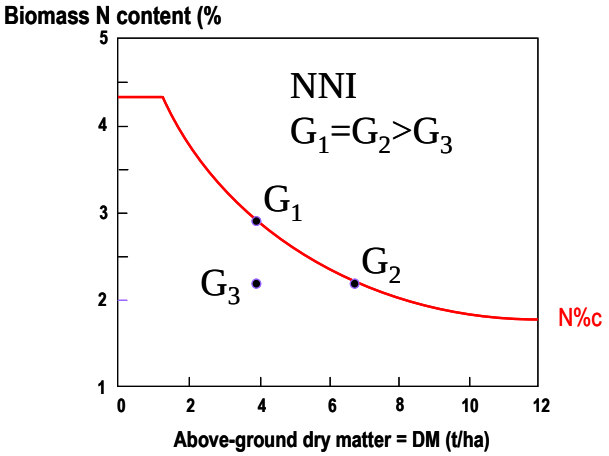
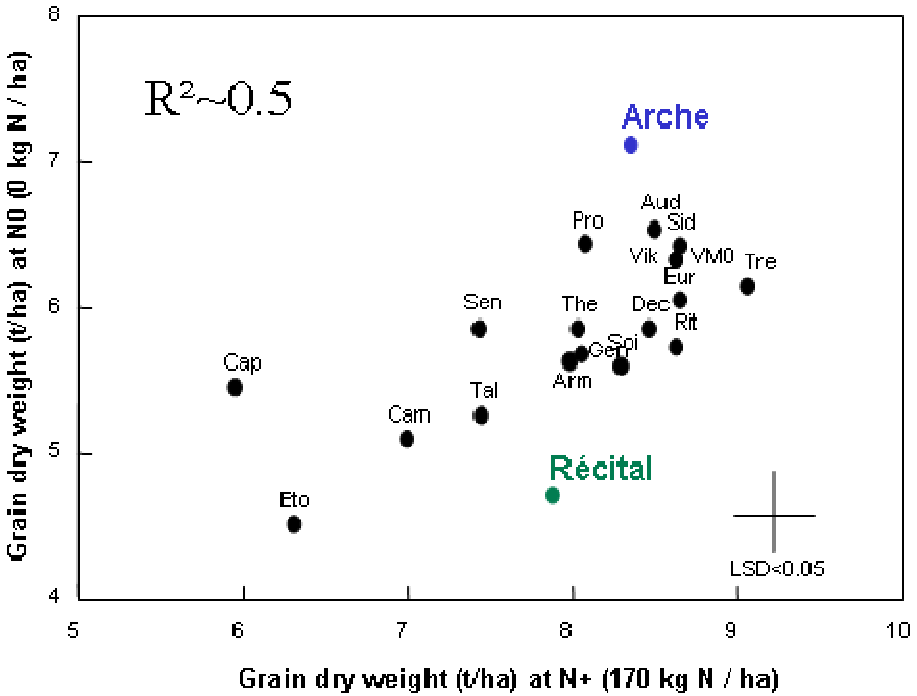
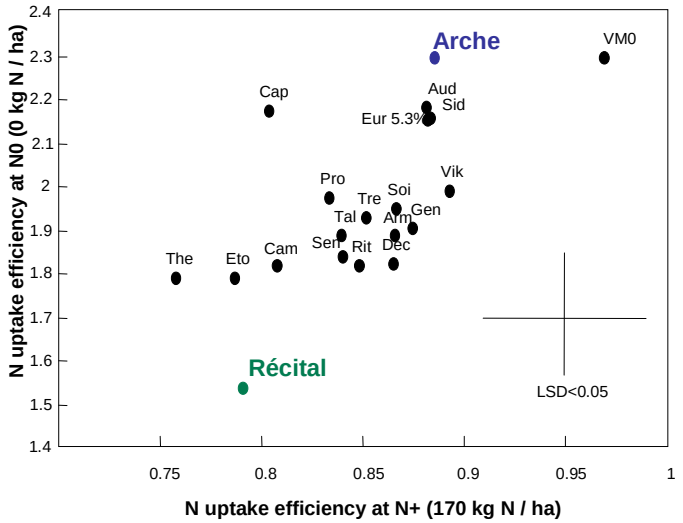
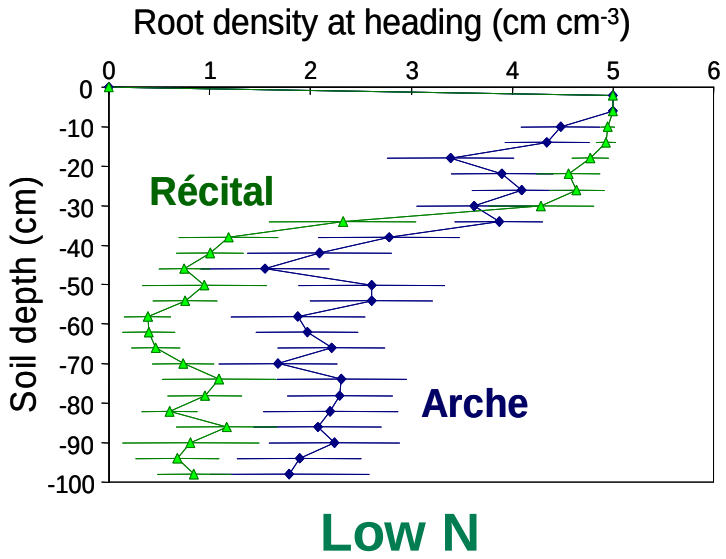


Genetic variability for response to N stress







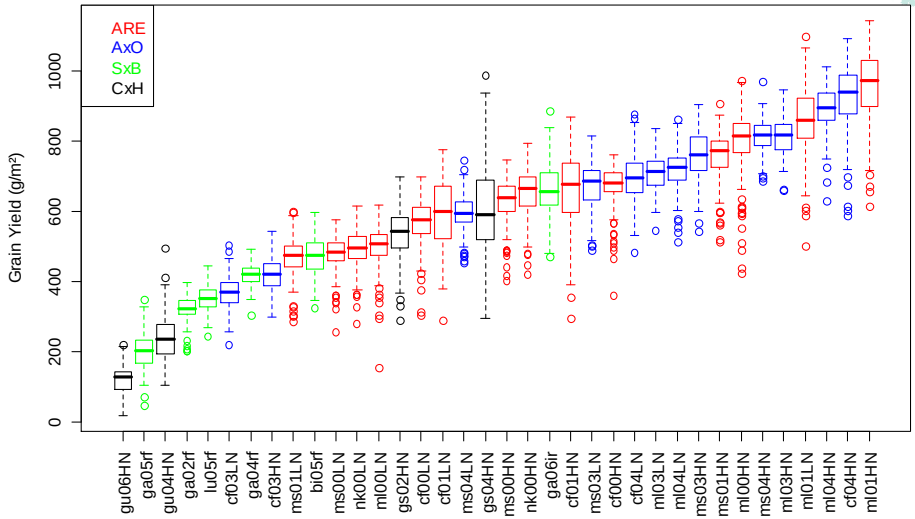
(Le Gouis et al 2000, Devienne-Barret et al unpublished)

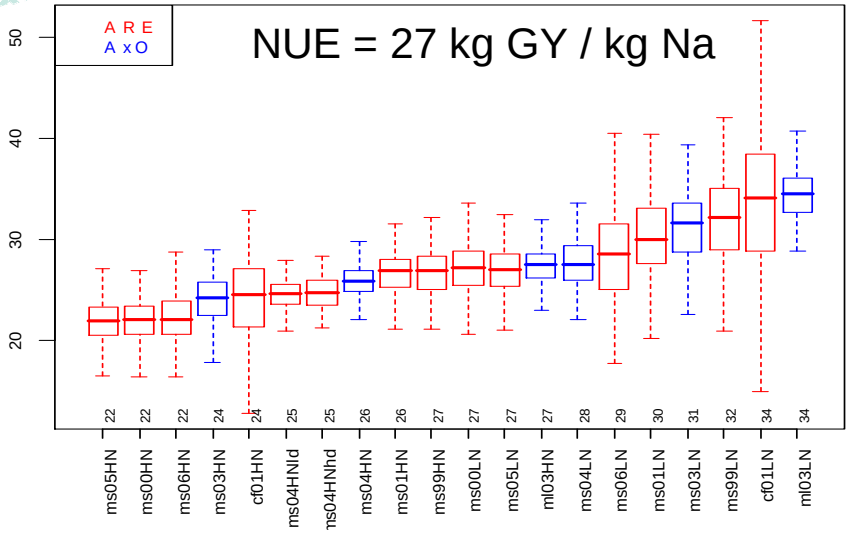
Low N

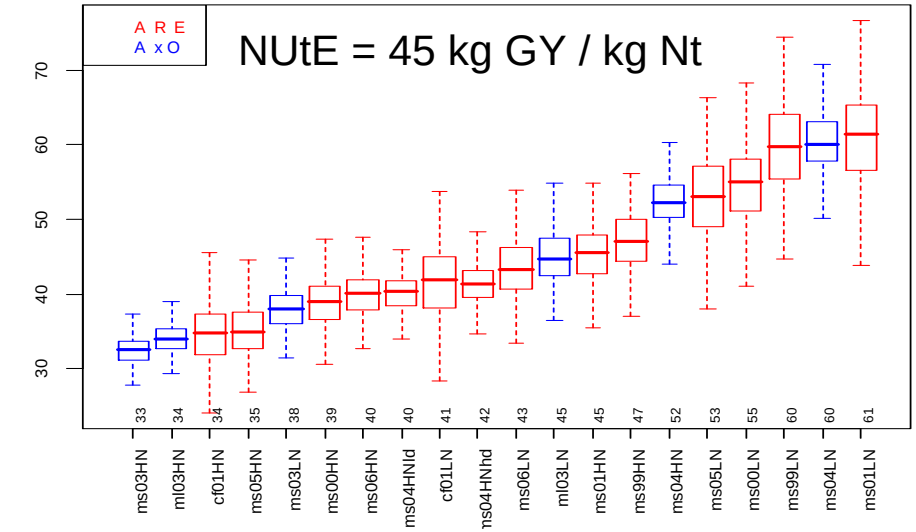
Populations and Trials

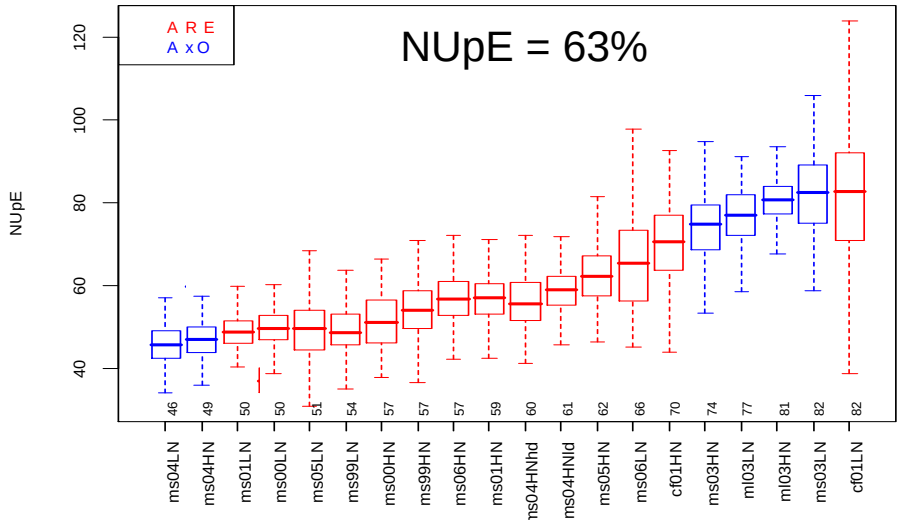
	Arche x Récital (F)	Apache x Ornicar (F)	Seri x Babax (Au)	Cranbrook x Halberd (Au)
Size	198	158	186	139
Map	208	188	425	405
Env	14	12	6	4
Traits	Biomass / N% Flo-Mat	Biomass / N% Flo-Mat	Biomass / N% Flo	Biomass / N% Flo+180°Cd
	NUE, NUtE, NUpE, NNI		NNI	

Range of variation

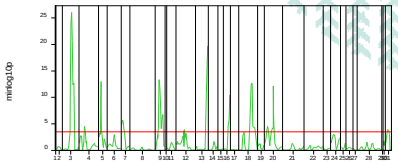


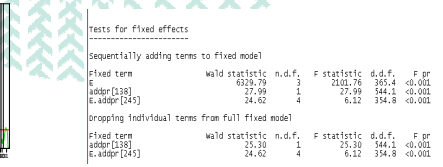


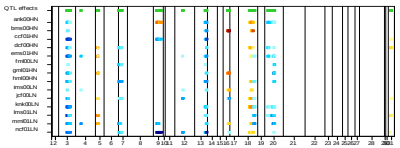


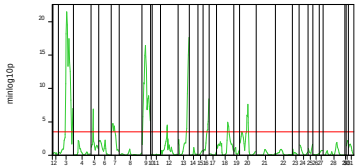


QTL detection - mixed linear QxE model









5
CIM
CofWin=
50cM

6
Backward
selection

7
Estimate
effects

4
SIM
QTLwin=
30cM

Multi-environment / Multi-trait

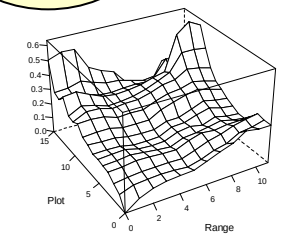
Pij = μ + Ei + Gj + GEij
Pij = μ + Ei + *x*iα+G*j + *x*iαj+GE*ij

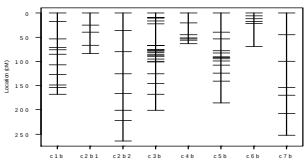
1
Estimate
means
(BLUEs)

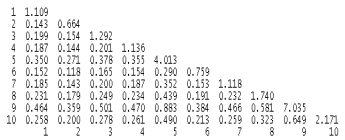
2
Choose
Var/Cov
Model

3
Estimate
genetic
predictors

Stepsize
=10cM



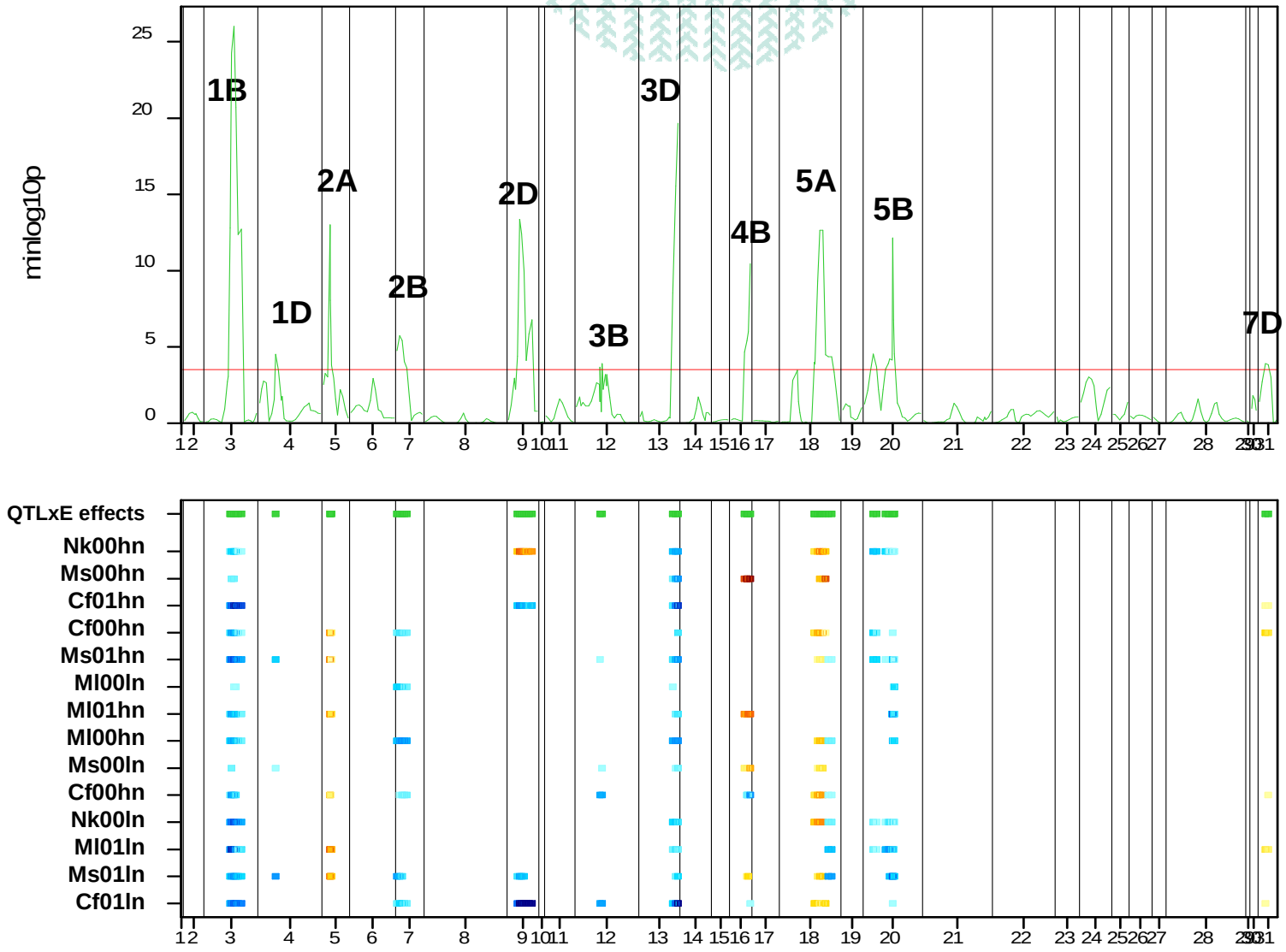




Genstat 12
(VSN international)

(Boer et al 2007;
Mathews et al 2008)

QTL detection for NUE

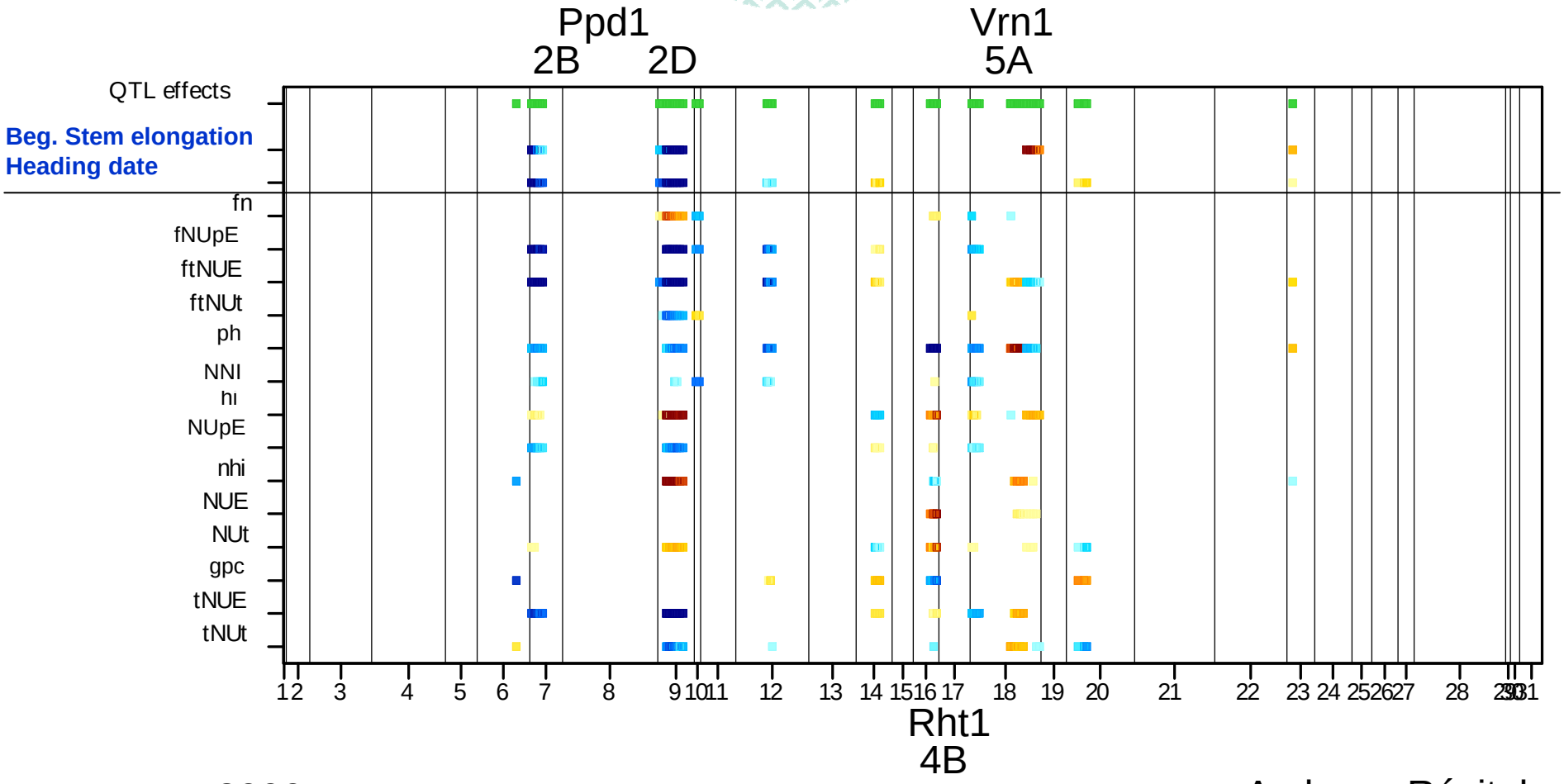


Arche

Récital

$\frac{Eff}{SE} > 2$

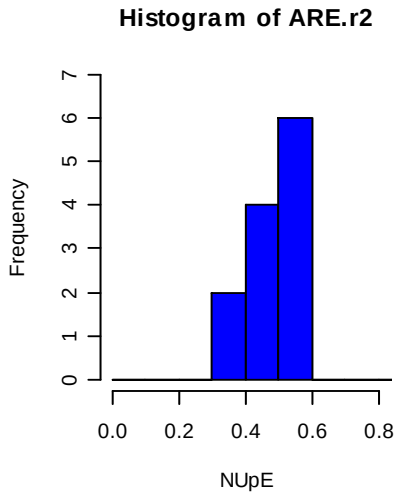
Large impact of development

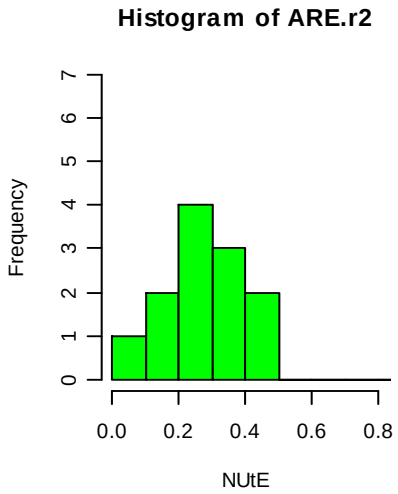


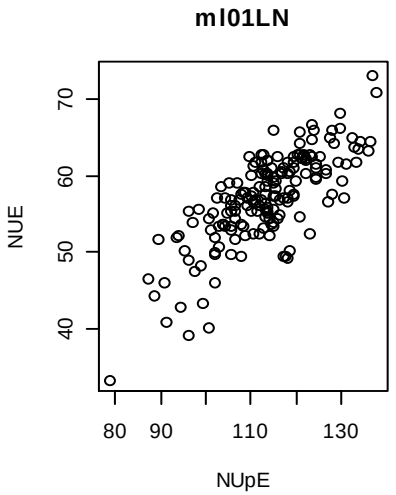
Mons 2000HN+ ARE
Final model

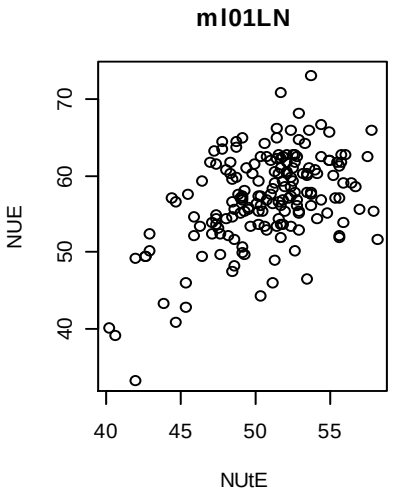
Arche Récital

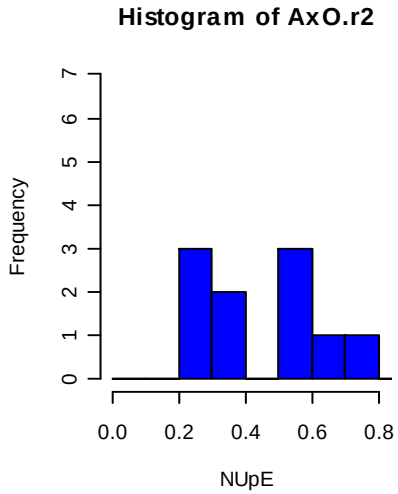
Correlations with NUE

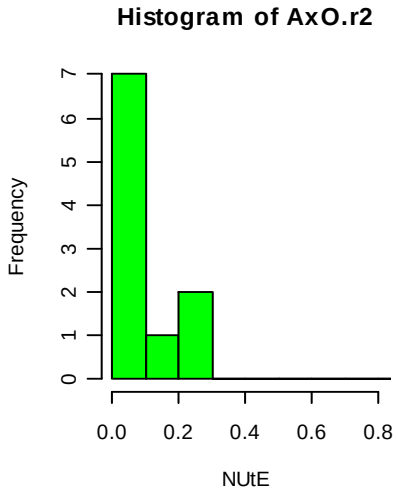


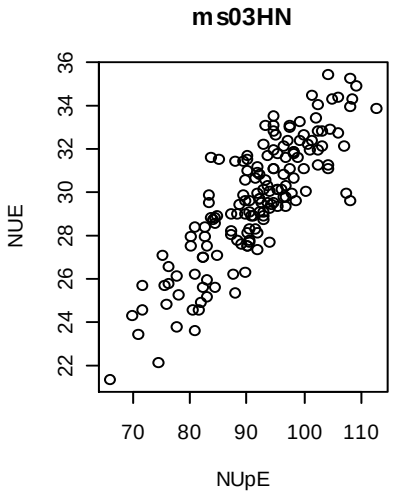


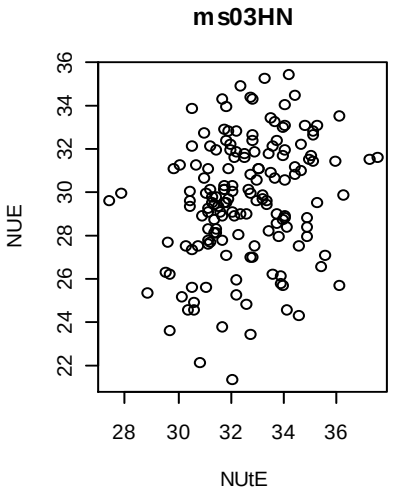






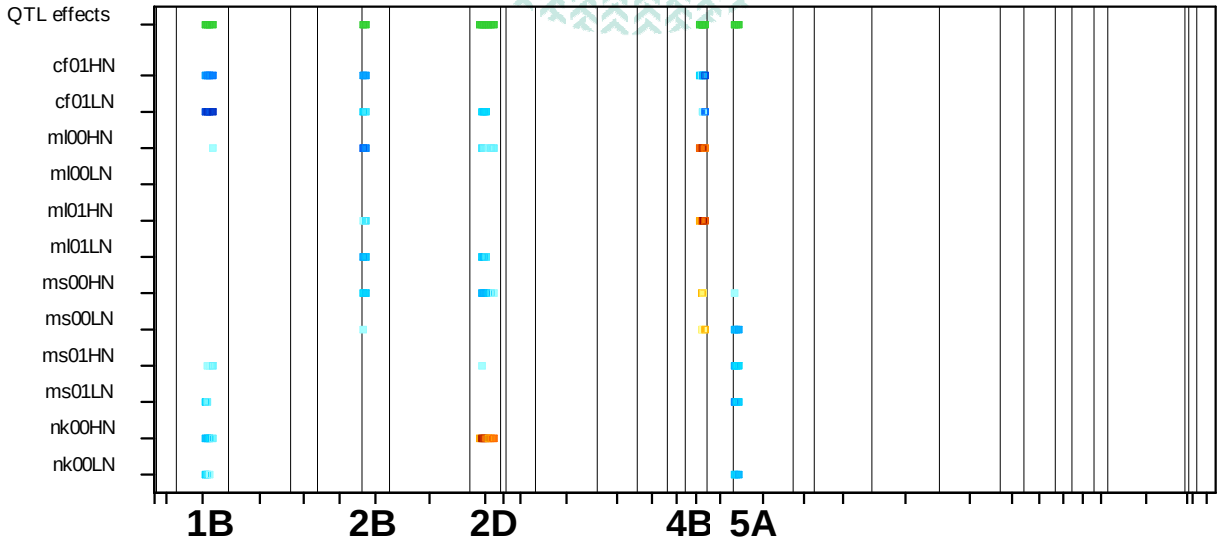




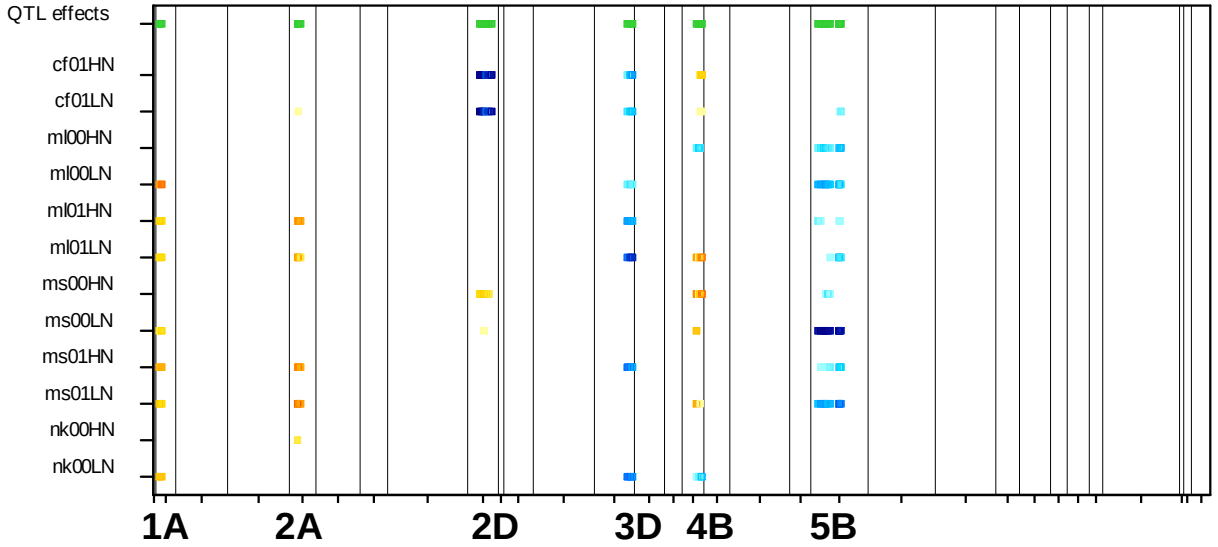


Identification of NUE components QTL

N uptake Efficiency



N utilization Efficiency

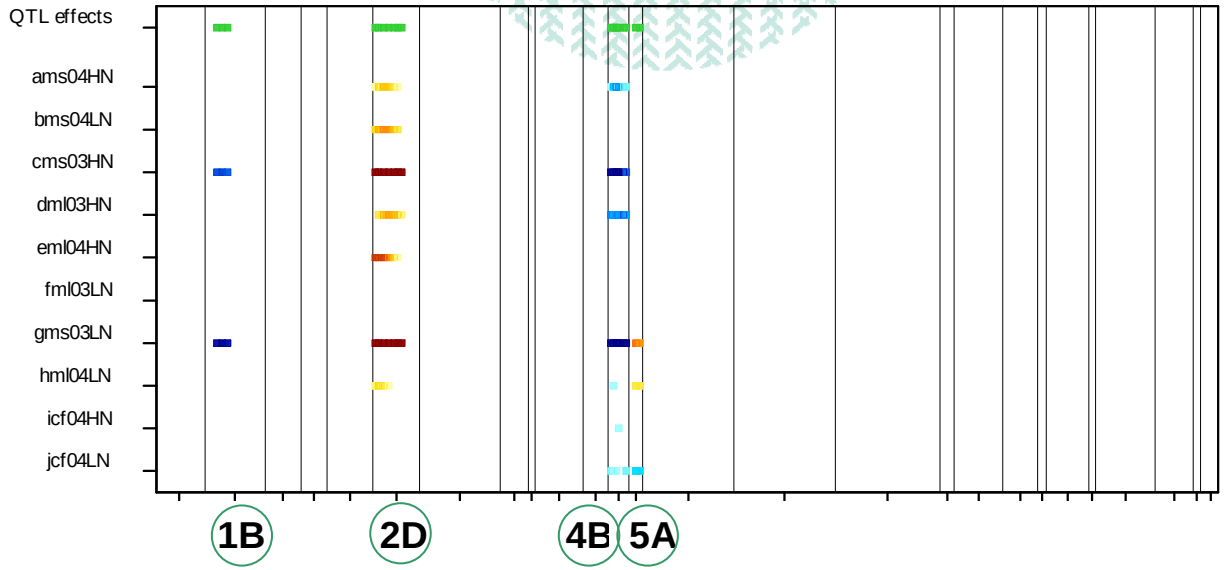


Arche

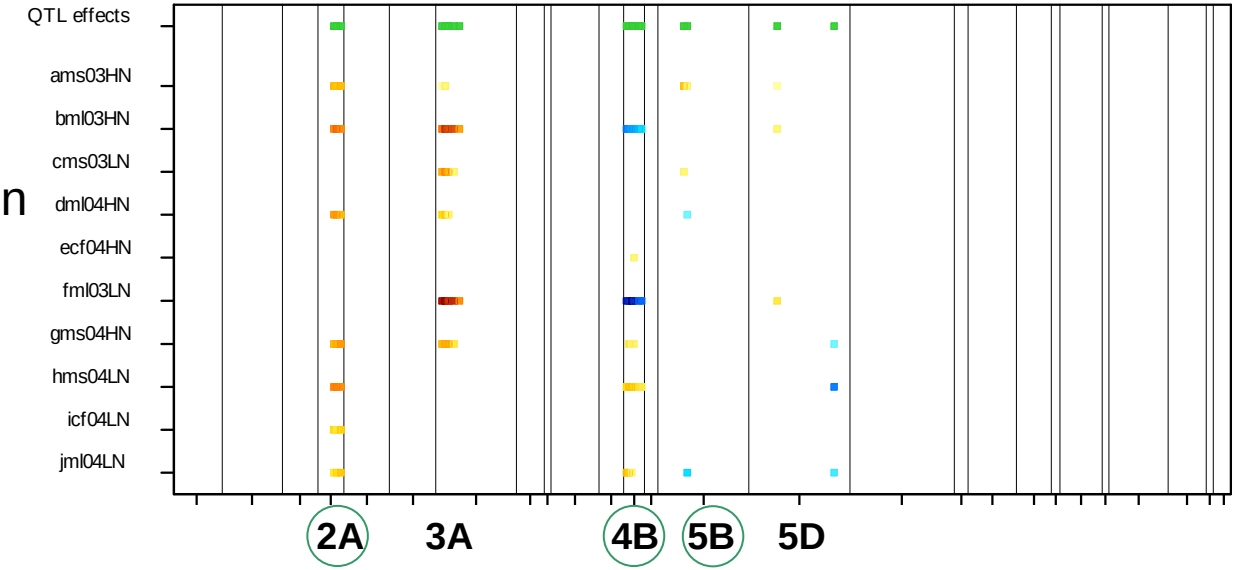
Récital

Comparison between populations

N uptake Efficiency



N utilization Efficiency

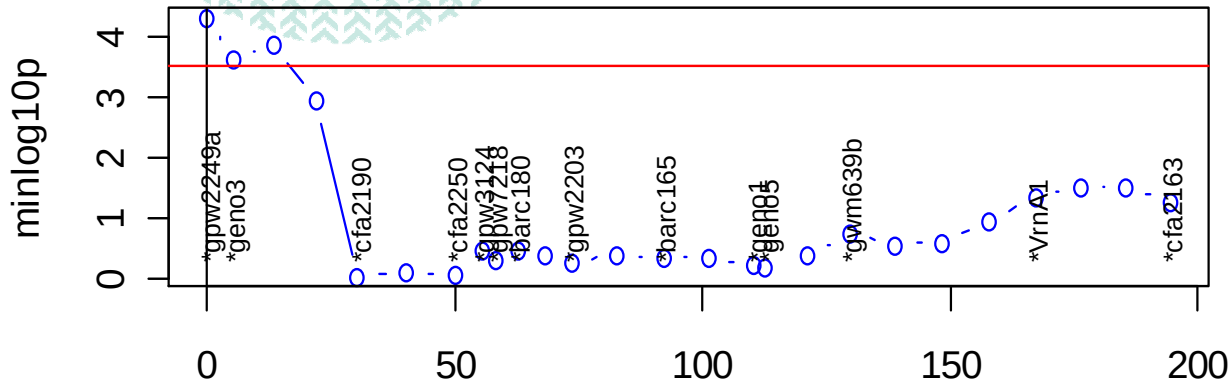


Apache

Ornicar

Environments cofactors

N uptake efficiency
QTL_5A



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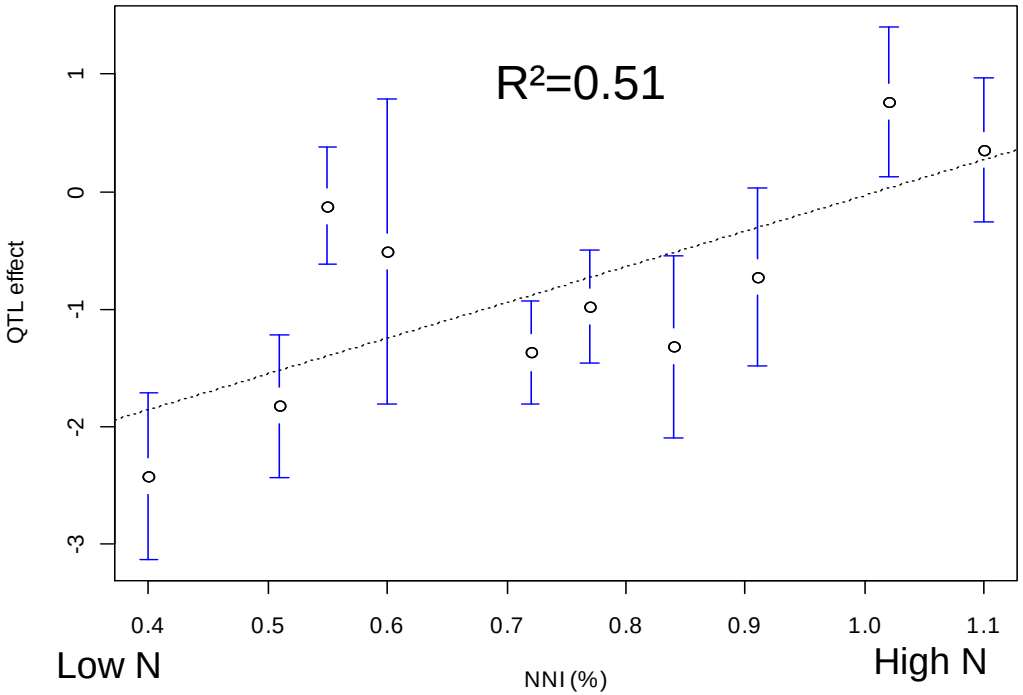

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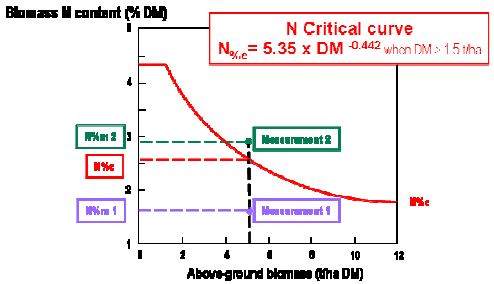
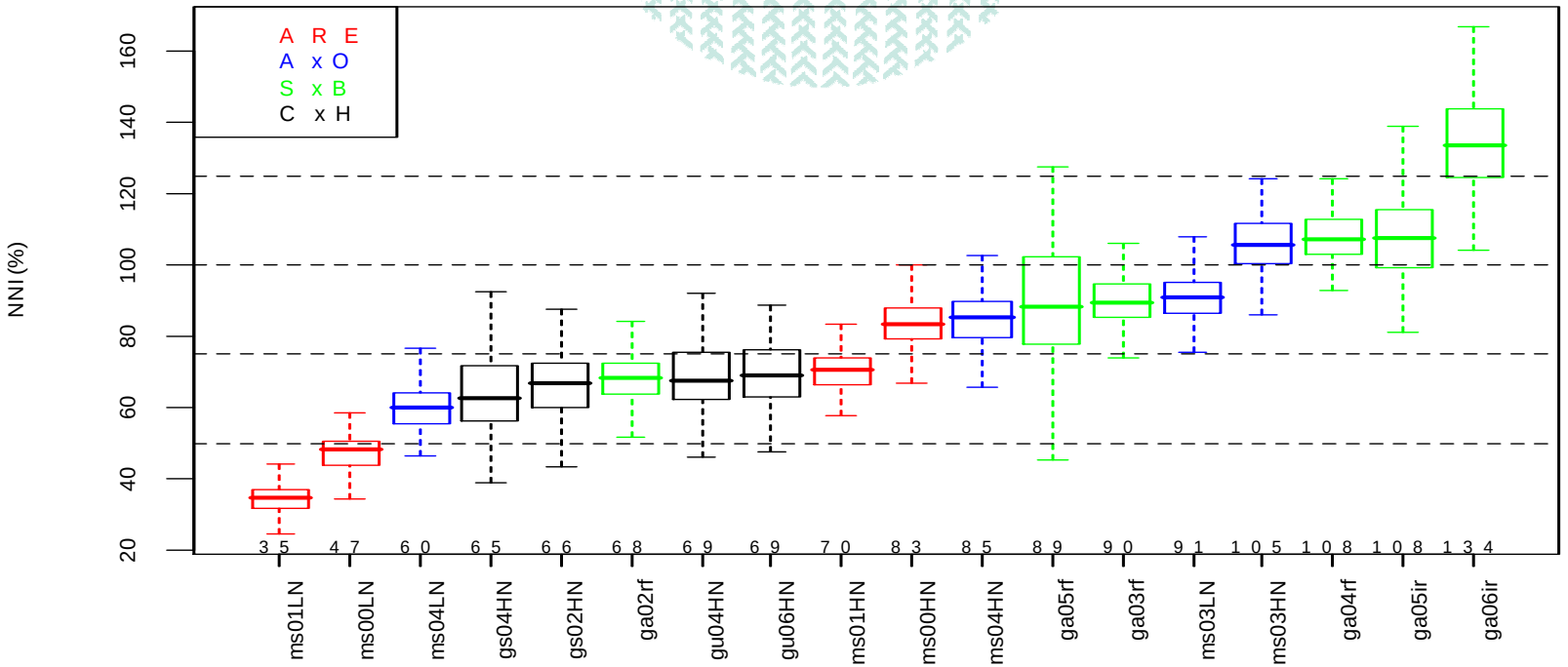


QTL detection for NNI



ARE c2D	-	-							-	A							Inter
AxO c2D			O								O			-	O		Inter
SxB c1A						-						-	B			S	B	-	Inter
SxB c4A						B						B	B			B	B	B	Add
CxH																			

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

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