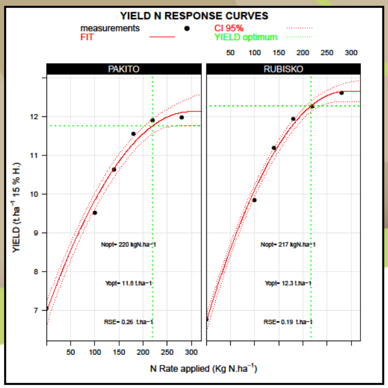
Effect of variety on nitrogen use efficiency of bread-wheat: from breeding programs to farm practice

Effect of variety on Nitrogen Use Efficiency (NUE) of bread-wheat: from breeding programs to farm practice

IFS Conference, Cambridge (UK), 07-08 December 2017



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(1) ARVALIS Institut du végétal (2) INRA SCIENCE & IMPACT (3) GEVES Expertise & Performance (4) biogemma

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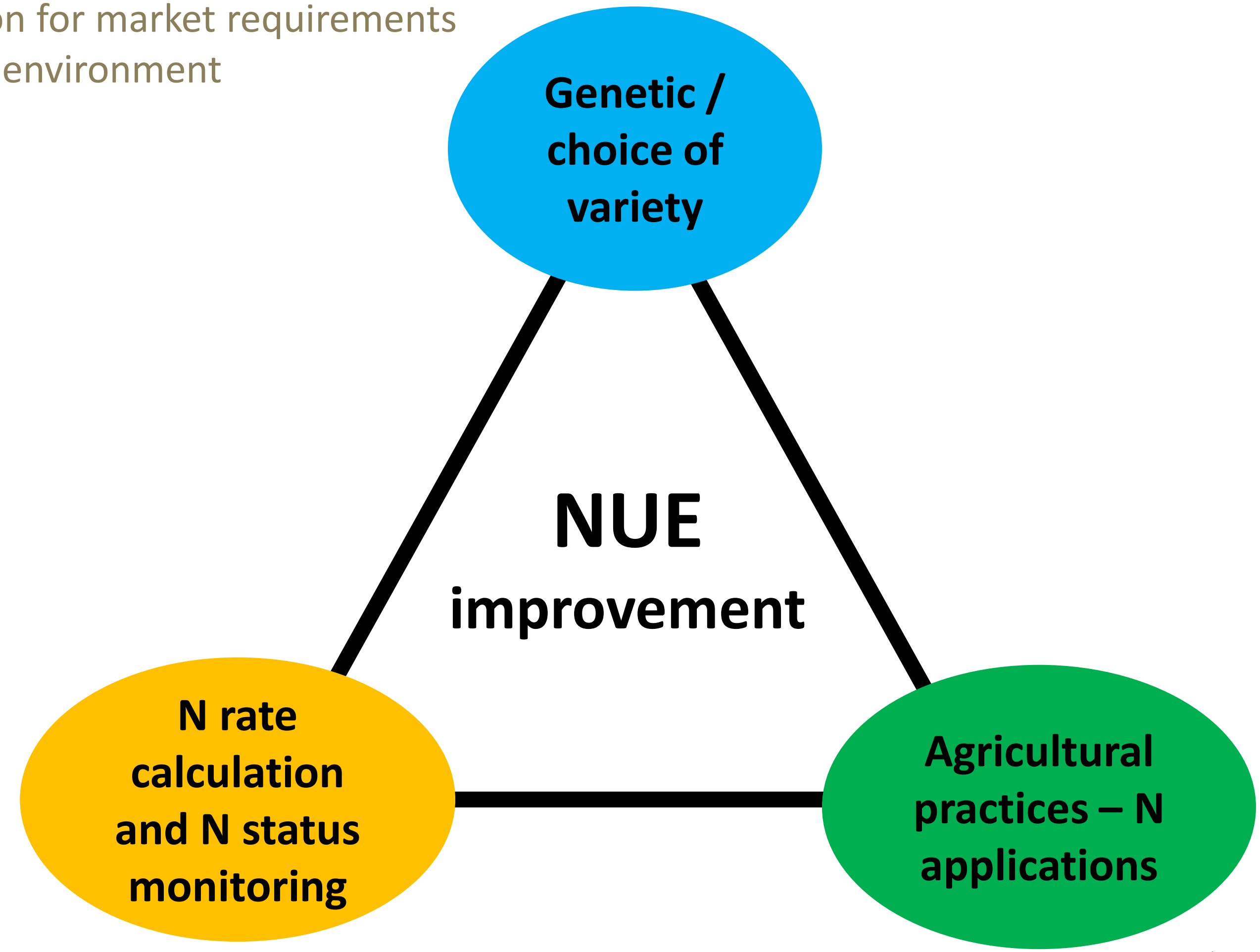
Introduction

Introduction

N.U.E = Nitrogen Use Efficiency

NUE optimisation for bread-wheat pursues 3 main objectives:

- High yield
- Grain protein concentration for market requirements
- Preventing N losses in the environment

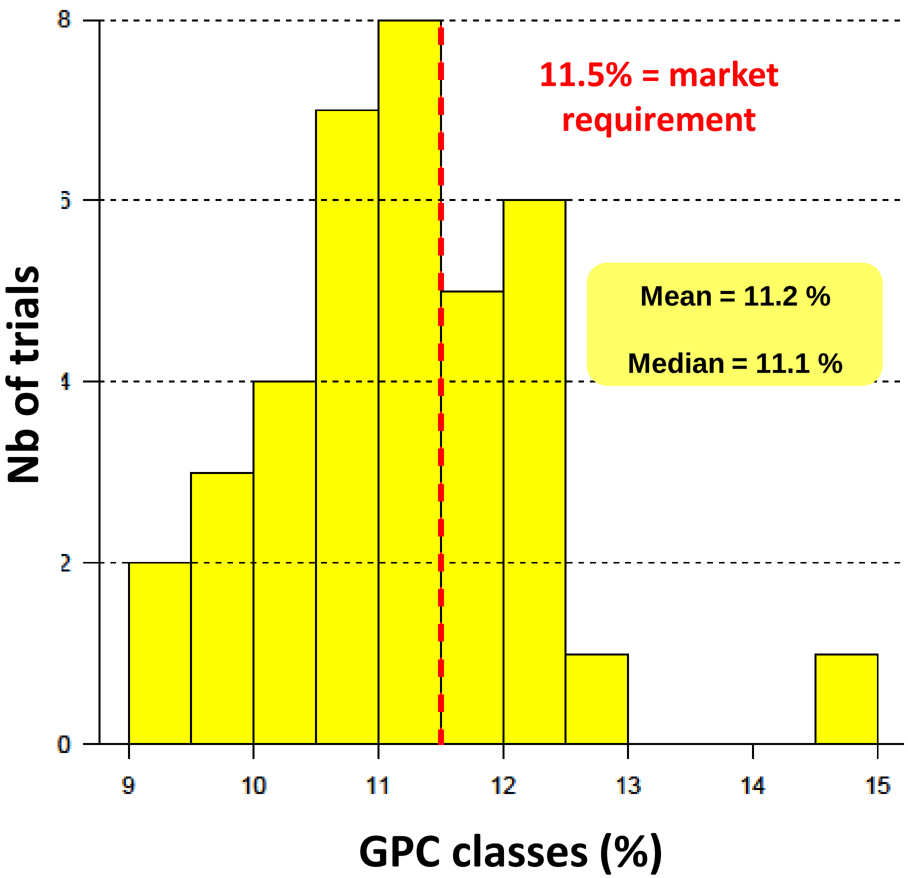


Introduction

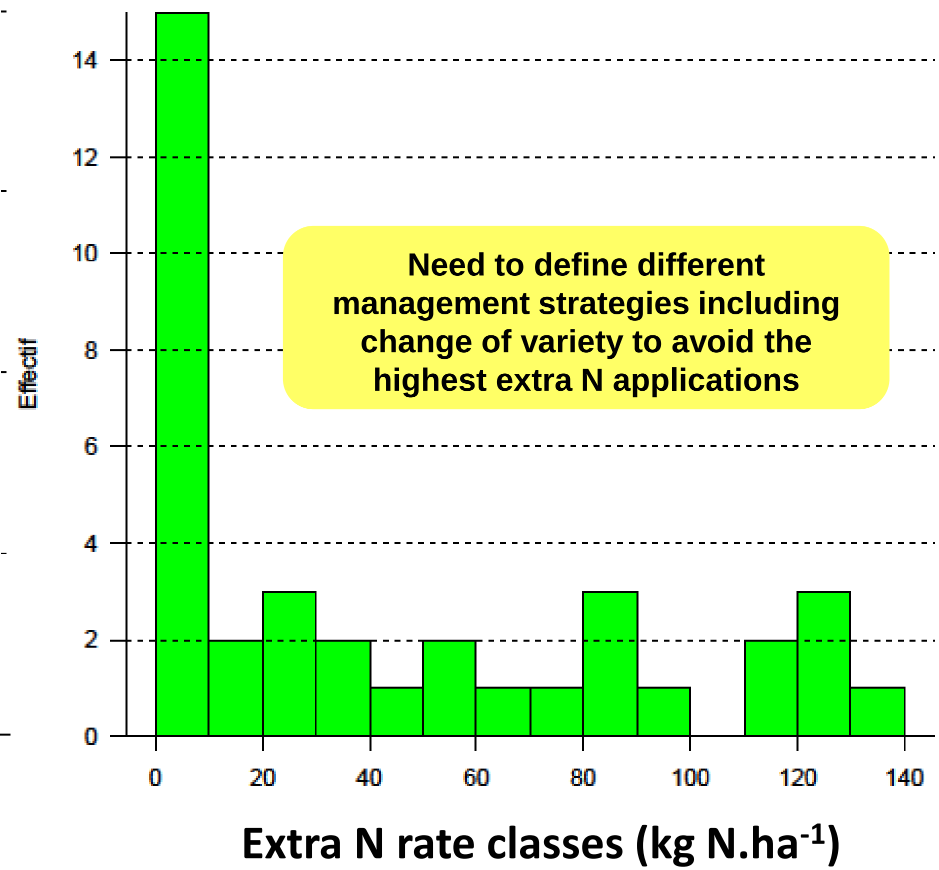
Example of year 2015 in France

Double target for bread wheat : yield and grain protein concentration

GPC at optimum yield



Extra N rate needed to reach GPC 11.5 %



37 N response curve trials in 2015

ARVALIS and partners (west and north regions)

Yield N response fitted with a quadratic-plateau model

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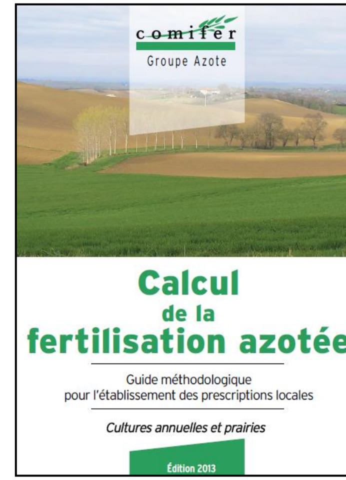
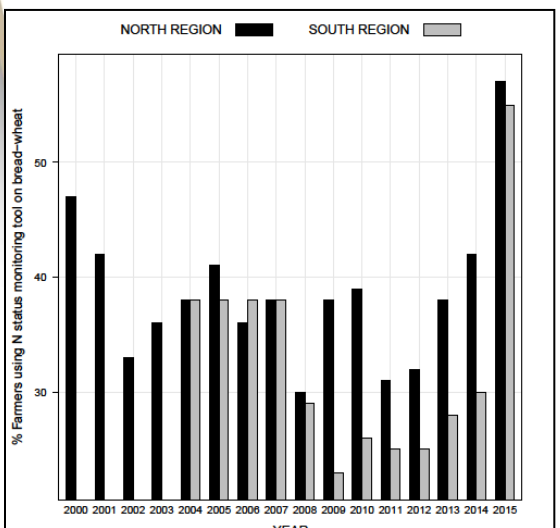
Introduction

N rate calculation and N status monitoring



N balance sheet methods widely used:

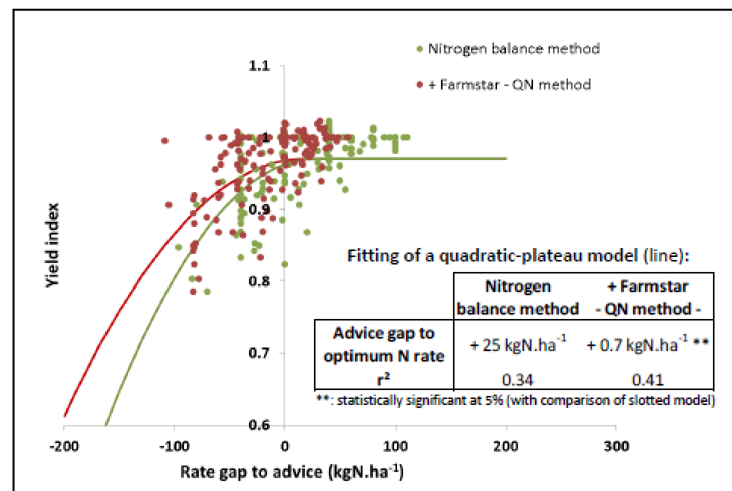
- Known and optimised since the 80's (Rémy and Hébert, 1977; Rémy and Viaux, 1983)
- Normalised in an "official document" (Comifer 2013)
- Farmers required to use it because of UE Nitrates Directive



Sources: N fertilisation practices annual survey – (c) ARVALIS 2015

N status monitoring and management tools:

- Known since the 90's
- Technologies continuously improved (stem sap, transmittance, reflectance)
- Widely used by farmers



Soenen et al. 2017 – Farmstar tool (ARVALIS-AIRBUS-TERRES INOVIA)

Introduction

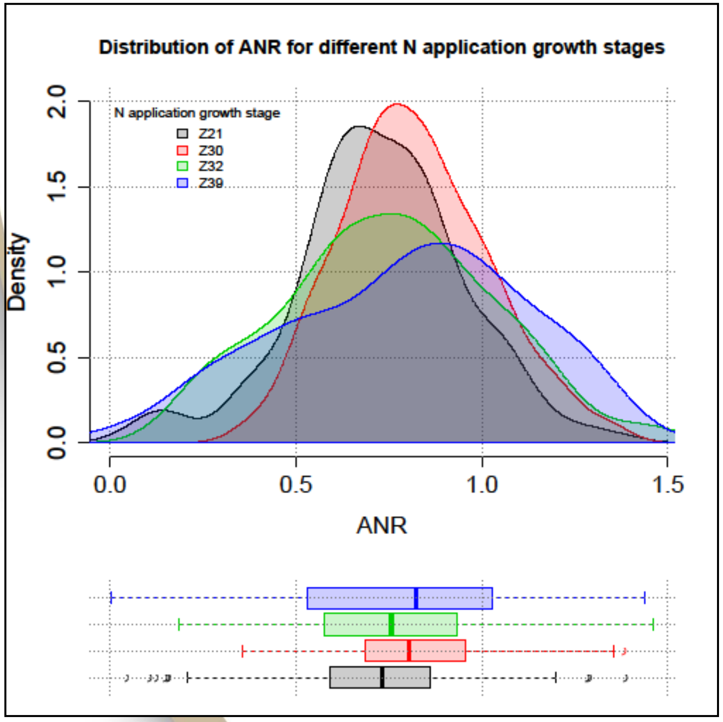
Agricultural practices – N applications

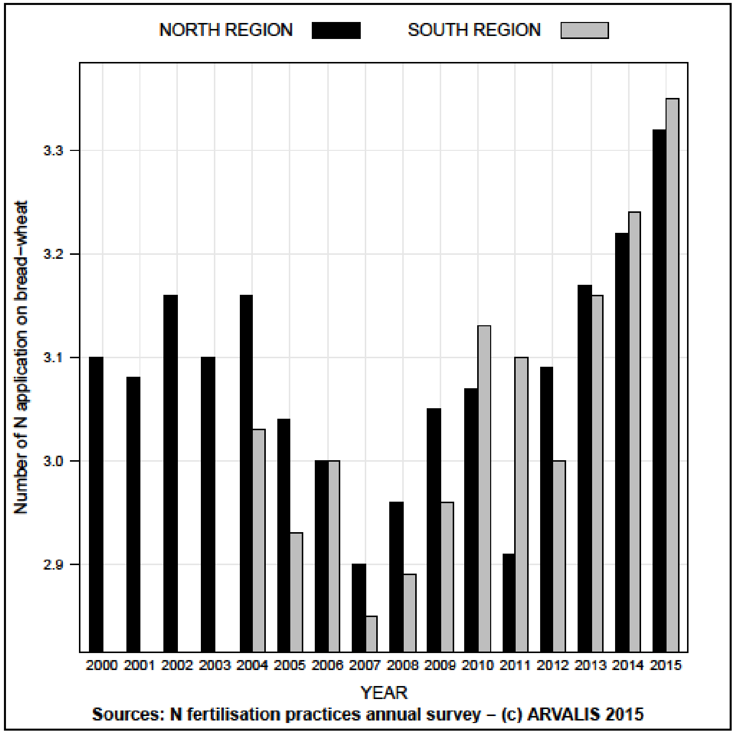
Split applications:

- Known to improve Apparent N recovery (Limaux et al. 1999, Collin 2012)
- Widely used by farmers

Choice of fertilizer type (ARVALIS 2016-2016):

- Crucial to optimise grain yield and GPC (AN = UREA +NBPT > UREA > UAN)
- Crucial to prevent NH_3 emissions (AN =< UREA+NBPT < UAN < UREA)





ANR = Apparent (fertilizer) N Recovery

38 Bread Wheat trials 2004-2006 / Different soil types / Fertilizer type : AN and UAN / Collin 2012

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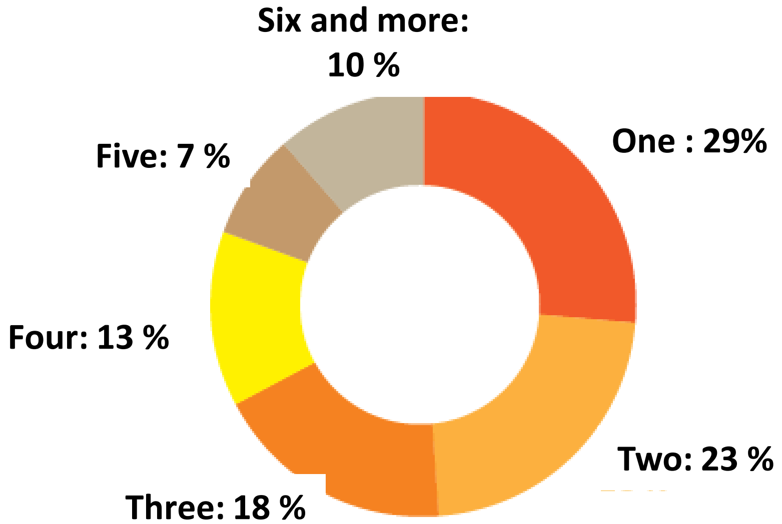
Introduction

Genetic / choice of variety

Could be a powerful opportunity to improve NUE if:

- Breeding programs include this objective and produce relevant varieties
- The genetic progress is large enough
- NUE related traits are well characterised and understood
- Practical information on NUE characteristics are available to farmers*

***Farms classification according to the number of cultivated bread-wheat varieties**



Source: F.A.M. survey 2016

Aim of the presentation

Describing the recent progress being made in France to characterise the NUE of different genotypes, along the continuum from breeding programs to practical information provided to farmers, including changes in the variety registration process.

Presentation agenda

1. Introduction
2. Definition of NUE: unifying the geneticist and agronomist points of view
3. NUE genetic progress assessment
4. Three complementary trial networks for a global research program
5. Impact of variety on NUE components
6. New NUE assessments in the registration process
7. Practical information concerning NUE provided to farmers
8. Perspectives and conclusion
9. Acknowledgements

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Definition of NUE: unifying the geneticist and agronomist points of view

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Definition of NUE

The basics : example for grain yield

$$NUE = \frac{Grain\ Yield}{Available\ N\ (soil + fertiliser)}$$

Moll *et al.*, 1982

Estimated:

- Considering equal for all genotypes ➔ not calculated (Ortiz-Monasterio et al., 1997)
- Assessed with soil N measurements (Le Gouis et al. 2000)
- Assessed with N uptake by control genotypes (Cormier et al. 2013)

Known

$$NUE = NupE \times NutE$$

Moll et al., 1982; Hirel et al., 2007; Sylvester-Bradley and Kindred 2009

$$N\ uptake\ Efficiency = \frac{N\ uptake}{Available\ N\ (soil + fertiliser)}$$

$$N\ utilization\ Efficiency = \frac{Grain\ Yield}{N\ uptake}$$

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Definition of NUE

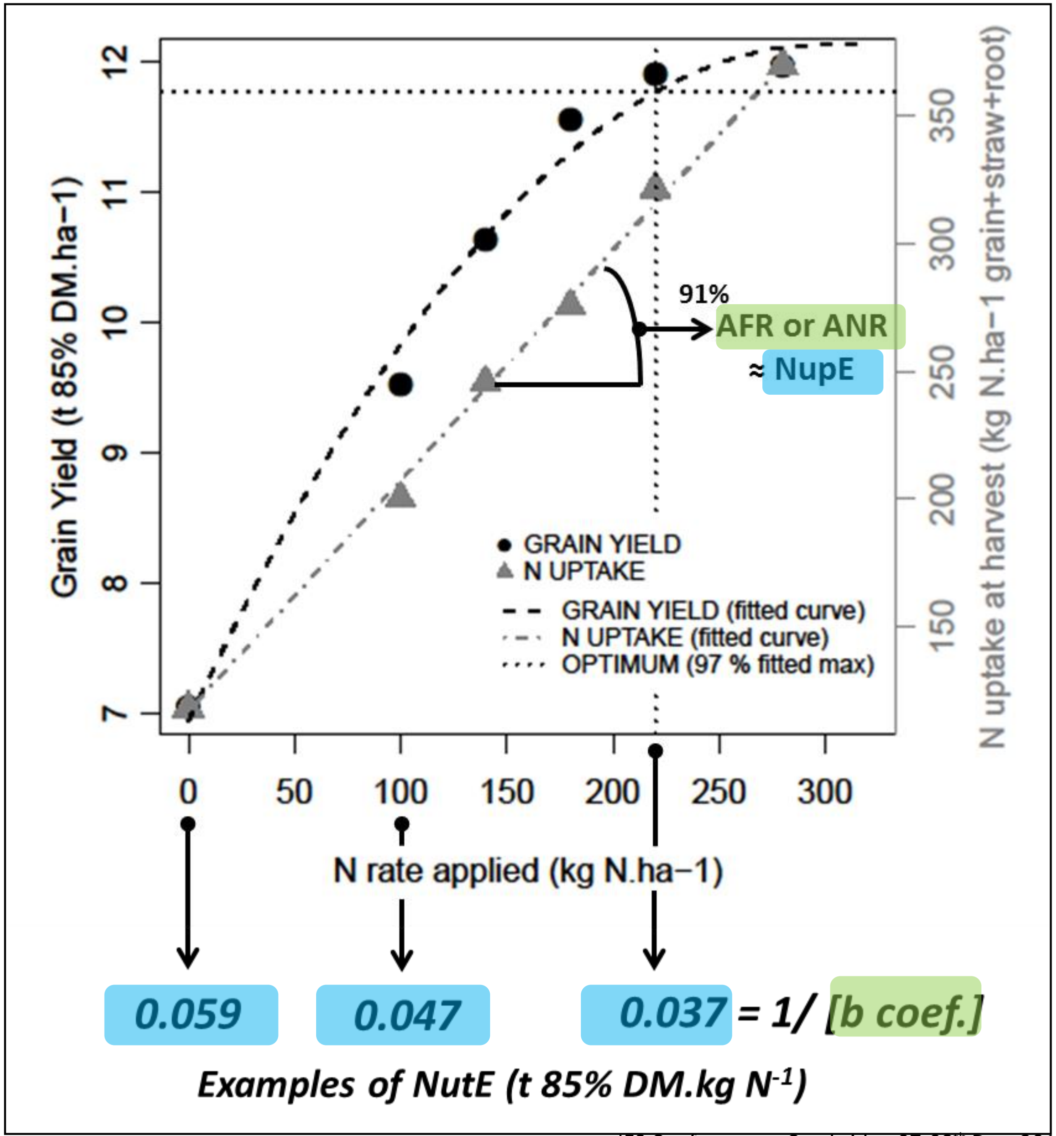
Geneticist and agronomists points of view

Geneticist point of view:

- Using NupE and NutE
- Indicators calculated on trials with numerous genotypes (> 200) and 1 to 3 N rates

Agronomist point of view:

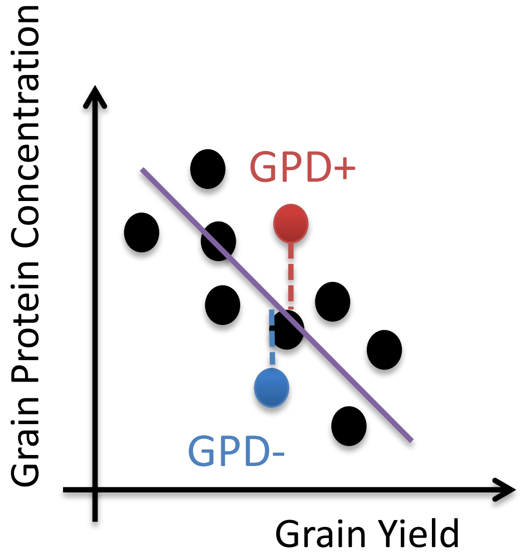
- Using NupE and NutE with different acronyms
- Systematic standardisation referring to the optimum N rate
- Indicators calculated on trials with 1 to 15 genotypes and complete N response curve

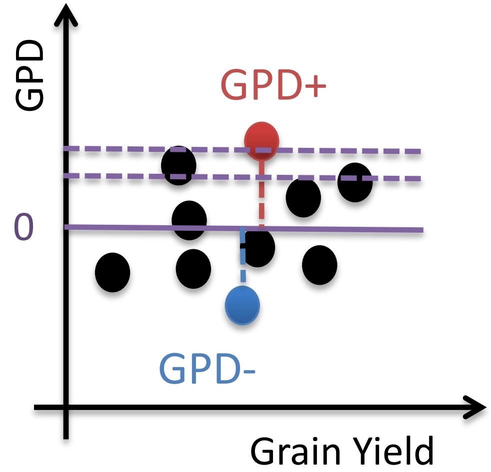


AFR-ANR references : Foulkes et al. 1998; Limaux et al. 1999
“b coefficient” reference: Le Souder and Bernicot 1993

Definition of NUE

Other useful N indicators



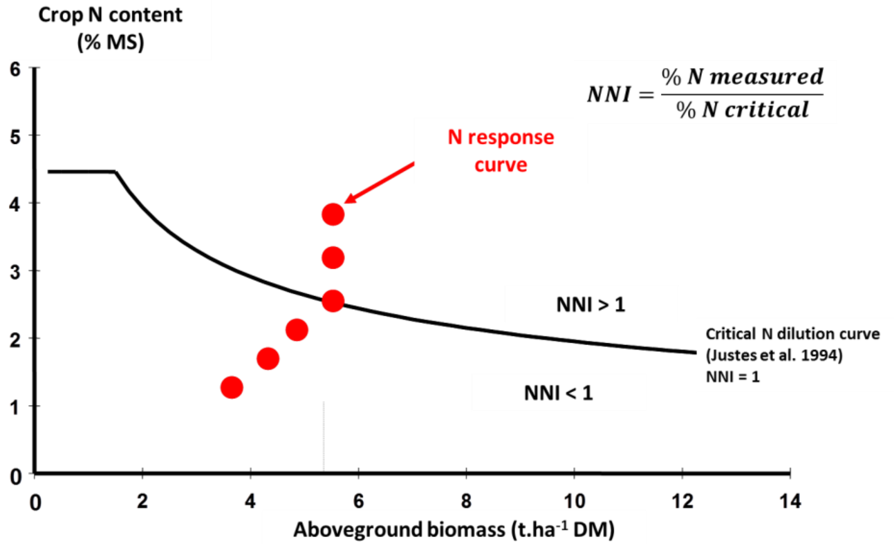


GPD: Grain Protein Deviation

- Based on the negative relationship between Grain Yield and Protein Concentration (Monaghan et al., 2001)
- Standardized calculation based on Oury and Godin 2007
- Used by geneticist **and** agronomist
- Used in registration process

NNI: Nitrogen Nutrition Index

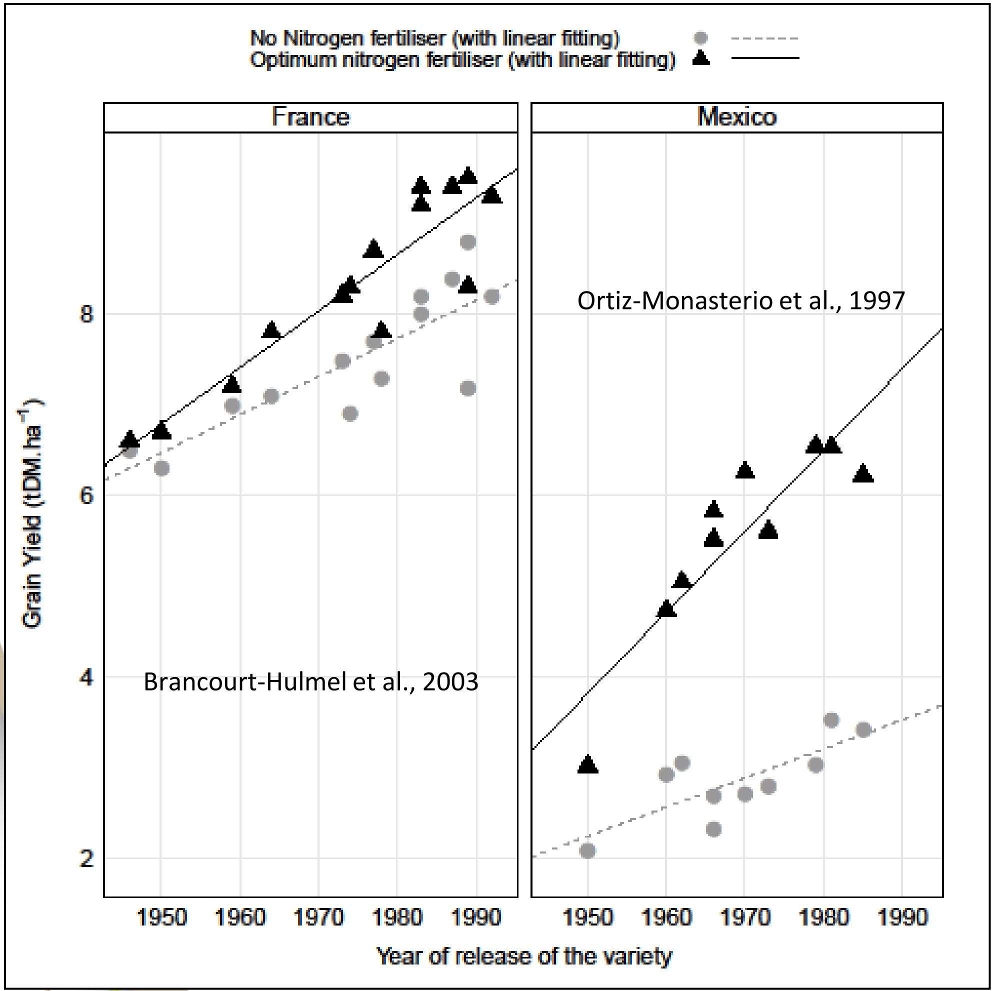
- Based on the critical N dilution curve (Justes et al. 1994)
- N status indicators before grain filling
- Widely used by agronomists (particularly NNI at flowering)

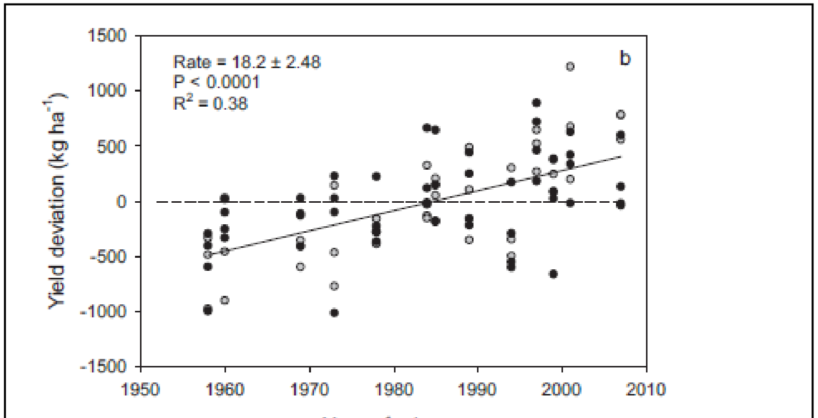


NUE genetic progress assessment

Genetic progress assessment

Same N supplying for all varieties ➔ yield progress = NUE progress





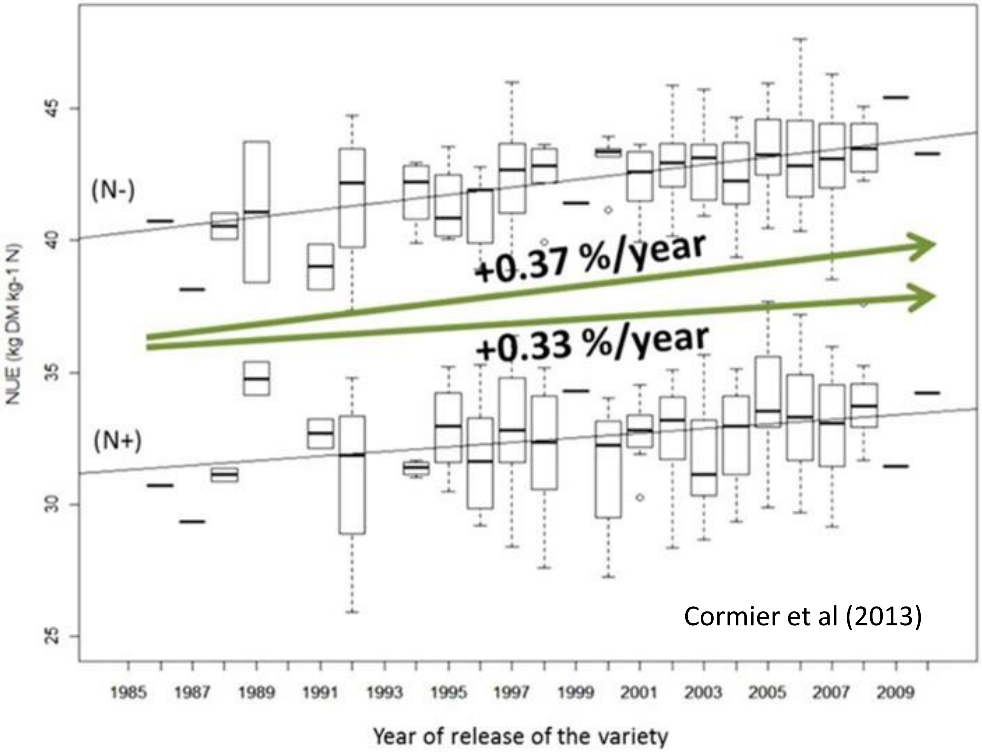
Sadras and Lawson 2013

NUE genetic progress:

- Continuous progress since the 50's
- Indirect NUE selection via yield selection
- Significant under optimum N application
- Some studies showed significant progress under low N application
- Seems to be supported both by NutE and NupE.

- What about recent French varieties with a more rigorous NUE calculation ?

Recent genetic progress in France



- Panel of 225 lines(160 from France)
  - Registered between 1985 and2010
  - Tested on a trial network:
    - 8 experiments = 2 N (N- and N+) * 4 sites (localisation x year)
    - 2865 micro-plots, 10 traits measured
  - Controls : Apache, Orvantis, Soissons, Caphorn

Genetic progress	Condition	Yield dt/ha/year	Protein %/year
225 French/european cultivars since 1985	High N	+0,33	-0.0200
	Low N	+0,37	-0.0100

Heritability and variance components (N+)

Trait	h²	G	G × E	G × N
Uptake	0.00	10% ns.	77% ***	13% ns.
Utilisation	0.79	63% ***	30% ***	7% ***
NUE	0.80	69% ***	26% ***	5% *

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Which N levels in breeding programs ?

<u>In western Europe</u>

- NUE progress is an indirect selection from breeding programs targeting yield but it works !
- Modern cultivars are more efficient than old cultivars, even under low N level.
- NUE progress at low N level is also an indirect selection because no breeding programs included low N level in the past 30 years (in western Europe).

But alternating high and low N levels along the breeding generation could be a good option to obtain the best NUE progress (Van Ginkel et al., 2001)

NUE genetic progress is significant <u>but not large enough</u> to face agricultural challenges
➔ Along the other agronomic ways to maximize NUE, it is time to boost the genetic progress, starting with new NUE characterisation tools from breeding programs to farm practice

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Three complementary trial networks for a global research program

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Three complementary trial networks

	6 to 10 tested varieties	20 to 35 tested varieties	30 to 50 tested varieties
6 N rates (N response curve including 0N control)	**Network 1:** • 12 trials over 3 years (2014-2015-2016) carried out by ARVALIS • Old genetic reference in all trials : cv SOISSONS (registered in 1987 in France) • Yield, GPC, N uptake, soil N		
3 N rates		**Network 2:** • 37 trials over 4 years (2013-2016) carried out by GEVES, INRA, breeders and ARVALIS • Registration and post-registration trials • Yield, GPC, N uptake on control cv.	
1 N rate			**Network 3:** • 1 105 trials over 12 years carried out by ARVALIS and partners • Post-registration trials • Yield, GPC

Detailed studies on variety X NUE components
Need to renew old results (Le Souder and Bernicot, 1993)

Validation

NUE indicators for registration

Validation

NUE indicators calculation for farmers

Validation

Trials partially funded by the FSOV N-BT project

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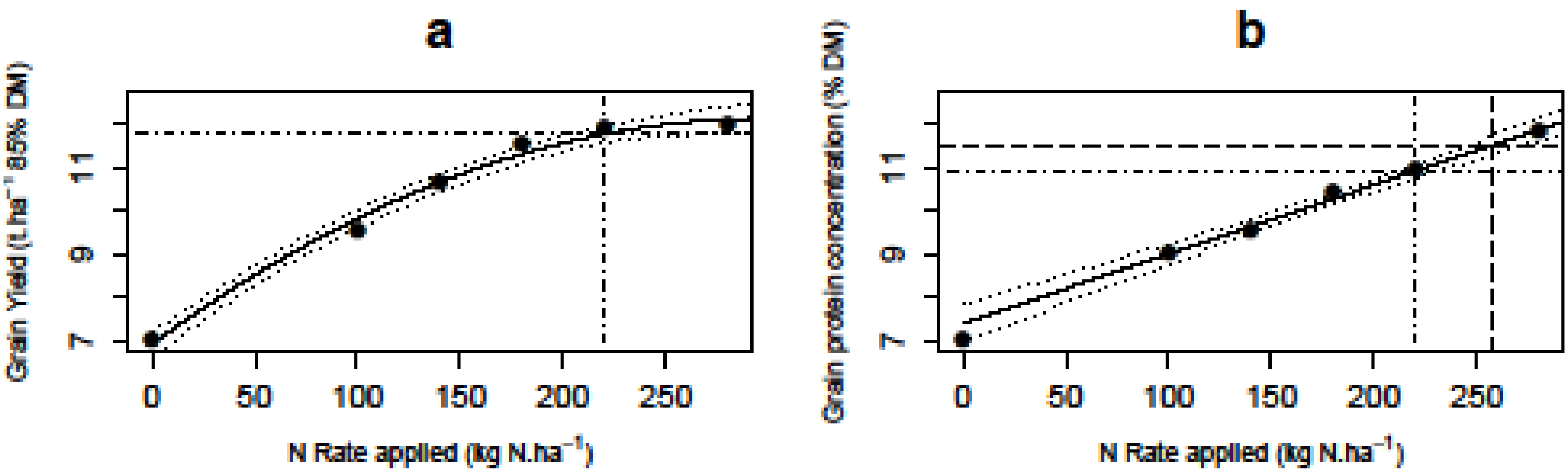
Impact of variety on NUE components

Network 1: data processing



<u>Grain Yield (GY) N response modelling</u>

- Quadratic-plateau model
- Determination of optimum grain yield (97% max) and corresponding optimum N rate

<u>Grain Protein Concentration (GPC) N response modelling</u>

- Linear model (without 0 N control)
- Determination of optimum GPC corresponding to optimum GY
- Determination of optimum N rate combining optimum GY and GPC=11.5 %

Data from Arvalis, location Binas 15 trial (variety = Pakito)

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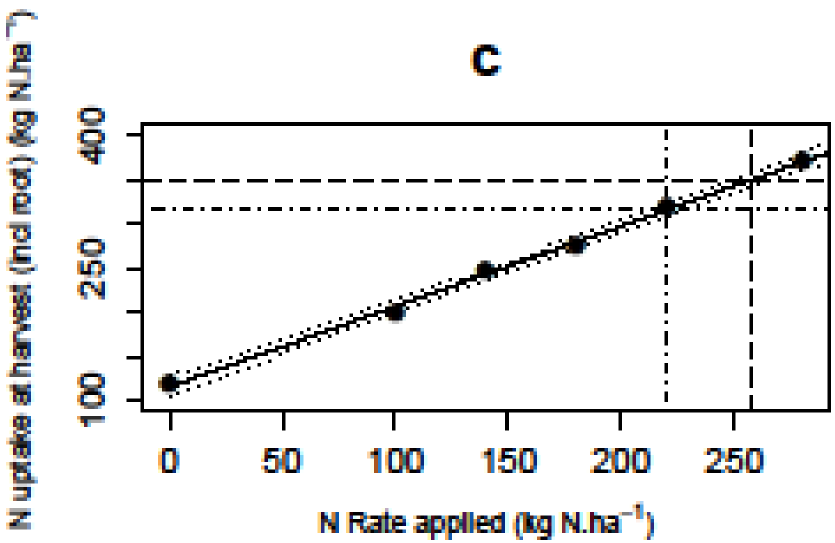
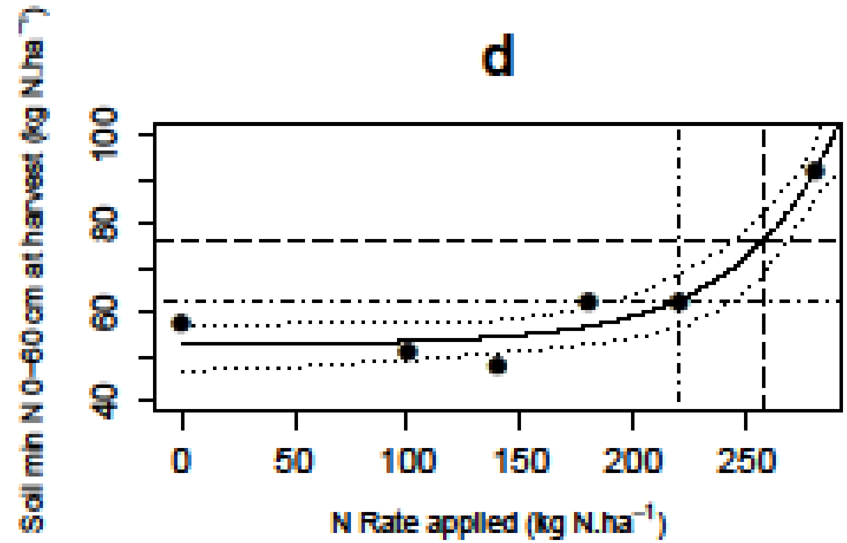
● Measurements
—— Fitted model
······ 95% confidence intervals
-·-· Optimum for yield
- - - Optimum yield and GPC=11.5%

Network 1: data processing





Total N uptake (TNU) N response modelling

- Linear model
- Determination of optimum grain yield (97% max) and corresponding optimum N rate
- Slope = **AFR**
- At GY optimum : TNU/GY = **b coefficient**
- At GY optimum + GPC 11.5% : TNU/GY = **bq coefficient**

Soil Mineral N (SMN) N response modelling

- Exponential model
- Determination of potential Nitrate leaching risk linked to an extra-N application to reach 11.5 % GPC

● Measurements
—— Fitted model
······ 95% confidence intervals
-·-·- Optimum for yield
– – – Optimum yield and GPC=11.5%

Data from Arvalis, location Binas 15 trial (variety = Pakito)

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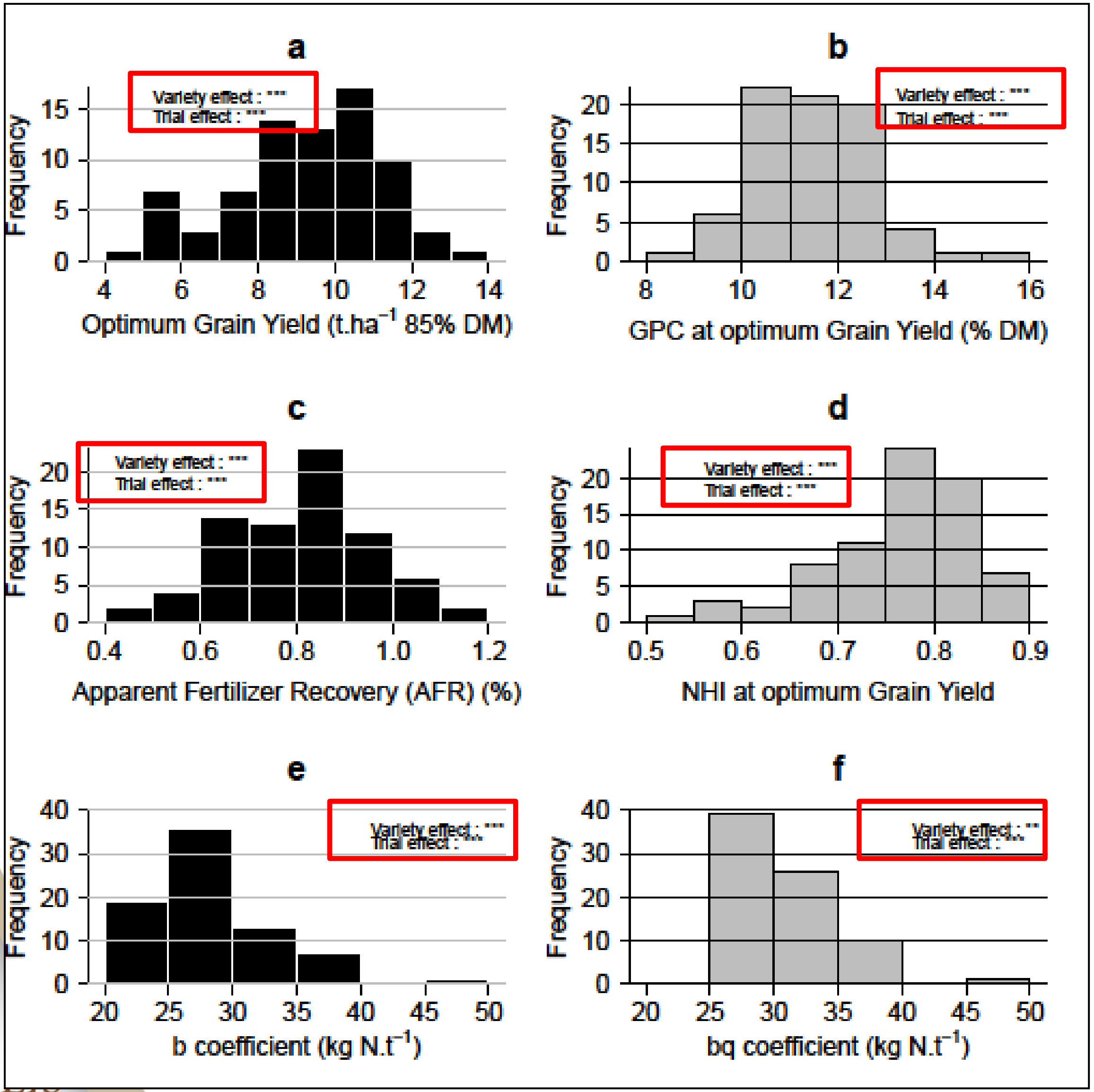
Impact of variety on NUE components



Significant variety effect on all major NUE components

Consistent with UK studies
(Foulkes et al. 1998; Sylvester Bradley et al. 2009)

Consistent with old French results
(Le Souder and Bernicot 1993)

Data from Arvalis, 12 trials (network 1). Variance analysis with a mixed model (fixed effect = variety; random effect = trial)

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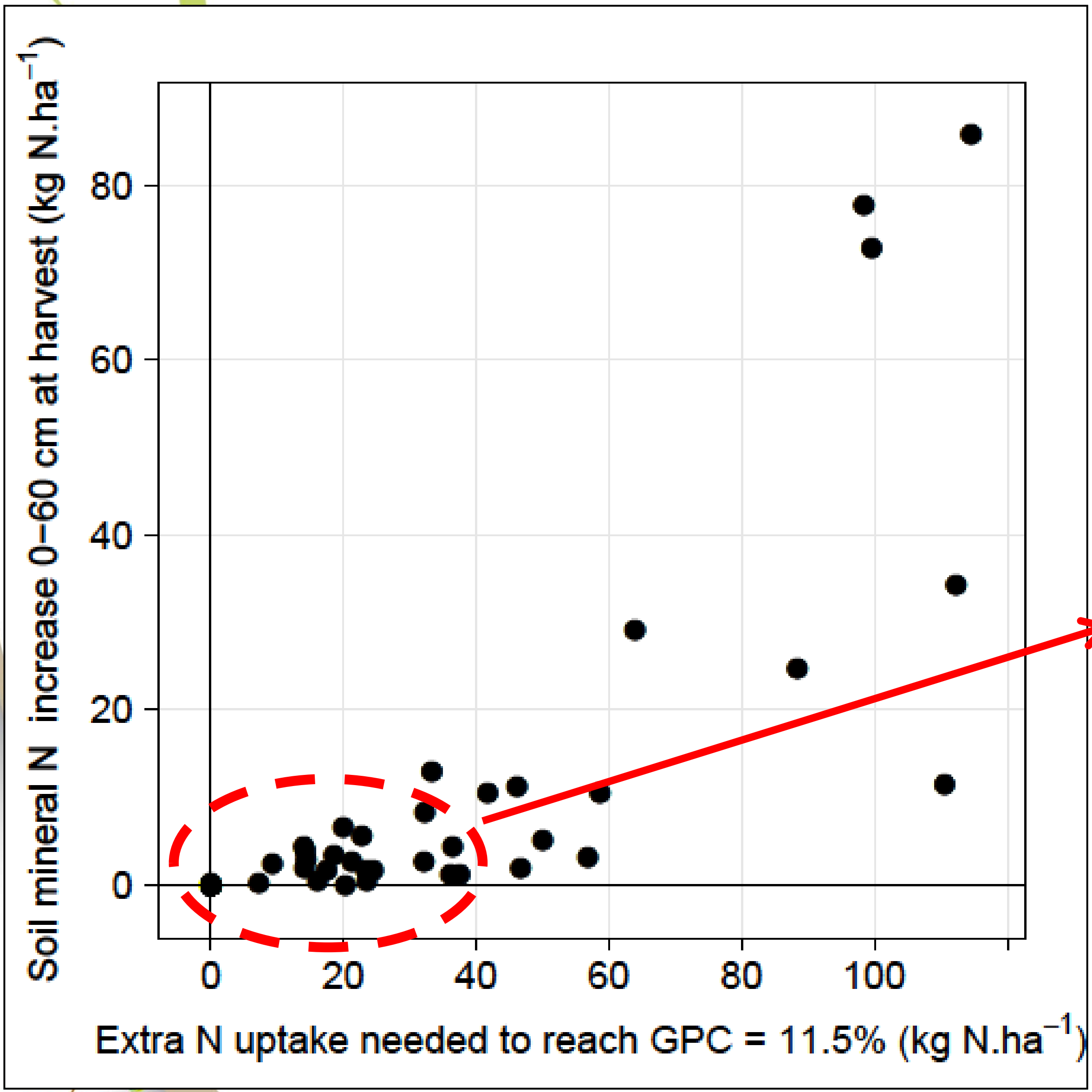
Extra N uptake and leaching risk



Soil Mineral N (SMN) increase is moderate if extra N uptake needed to reach GPC = 11.5 % does not exceed 30 to 40 kg $N.ha^{-1}$

Data from Arvalis, trial network 1

New NUE assessments in the registration process

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Indicators for tolerance to N deficiency

- Based on network 2 trials
- Calculated on yield and grain protein concentration
- **First type :** ratio (High N-Low N) / (High N) and residue of the robust linear regression Low N = f(High N)
- **Second type :** [High N-Low N] difference assessed with variance analysis including fixed effects (variety and fertilizer rate) and random effects
- **Third type :** interaction between variety and N uptake at flowering (mean of control varieties characterizing the intensity of the N deficiency applied) in a multi-environment model
- N deficiency intensity assessment has been studied with first type indicators, using a GGE-Biplot method.

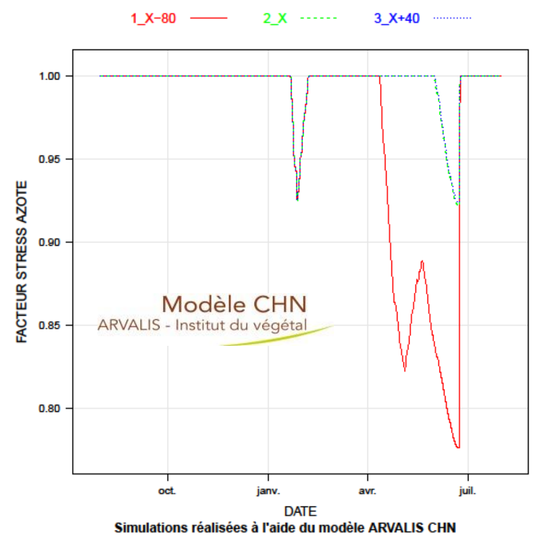
All indicators are highly correlated ➔ choice of first type indicators (the simplest to calculate)

Need to characterize the intensity of N deficiency

Variety *(More than 200 varieties tested)*	**First type indicator classification (all trials)**	**Classification inside clusters of trials according to N deficiency intensity assessment**			
		Low	Early and low	Early and strong	Strong all through growth period
Robigus	1	8	33	5	3
Oakley	2	47	88	3	5
Sy Mattis	3	13	49	2	2
Arlequin	4	9	15	21	8
Moskito	5	50	63	40	28
Altria	6	1	1	66	4
Swinggy	7	22	68	1	1
Garcia	8	2	2	120	15
Bergamo	9	32	60	8	6
Lear	10	6	13	20	7
Ambition	11	11	14	32	12
Claire	12	18	25	63	25
Orcas	13	31	57	12	10
Graindor	14	26	40	51	23
Fairplay	15	14	29	16	9
Sirtaki	16	41	28	167	92
Expert	17	83	118	6	11
Karillon	18	17	37	26	13
Hisseo	19	7	9	59	16
Laser	20	24	26	91	39

Data from Breedwheat project trials (first type indicators for yield)

- Need to characterize each trial in terms of N deficiency intensity
- Use of CHN crop model (Le Bris et al. 2016)



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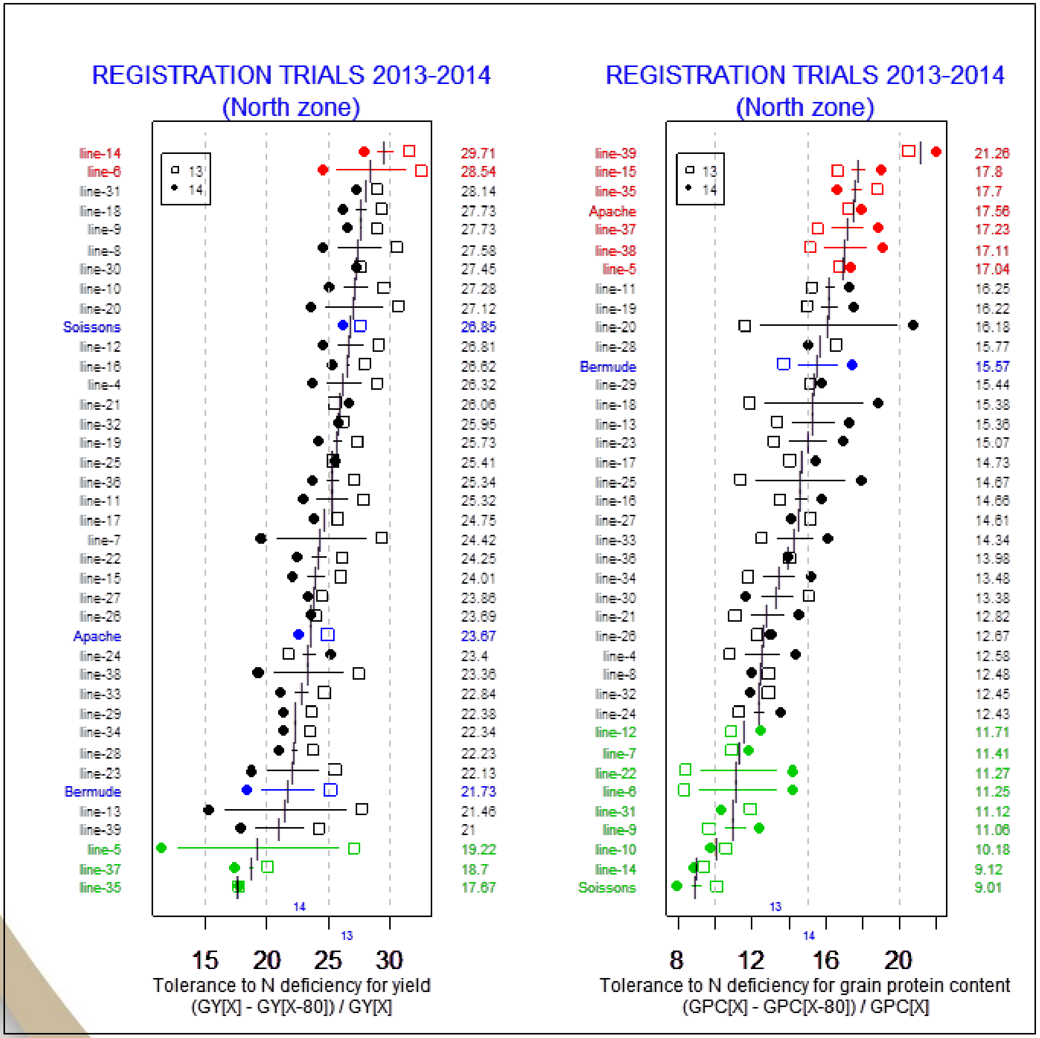
Tolerance to N deficiency indicator

$$N\ deficiency\ yield\ tolerance\ index = \frac{GY[X] - GY[X-80]}{GY[X]}$$

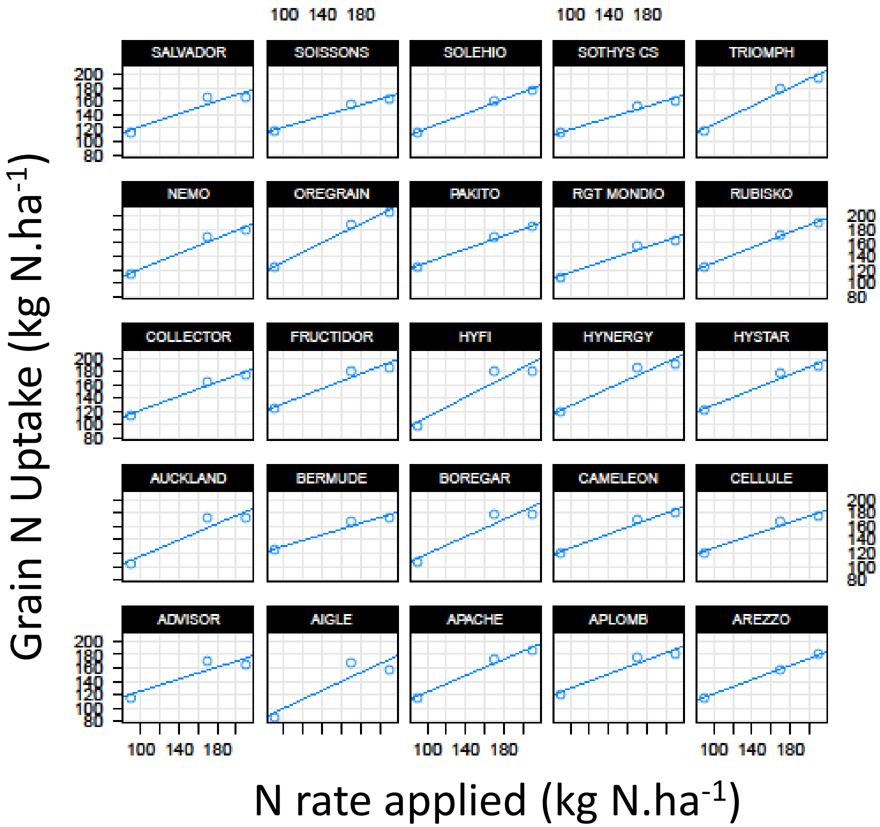
where: GY[X] = Grain yield with X nitrogen rate (t 85% DM. ha^{-1})
GY[X-80] = Grain yield with X-80 kg ha^{-1} N rate (t 85% DM.ha^{-1})

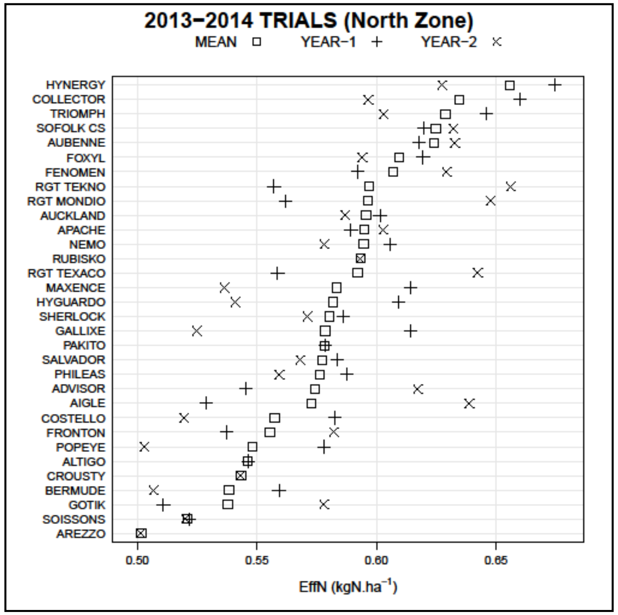


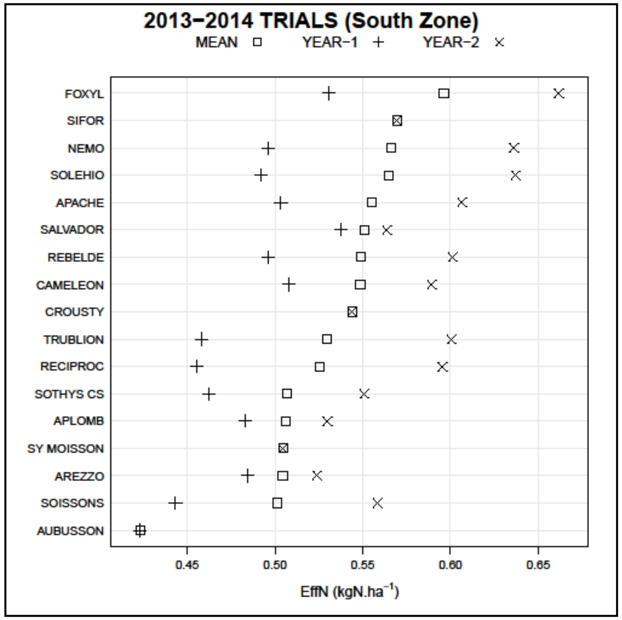
- Rather stable across years
- Not redundant with GPD
- Disseminated for "informative purpose" since 2016 registration

Data from CTPS trial networks

N efficiency indicator







- Linear regression Grain N uptake=f(N rate)
- Slope = EffN = proxy of AFR/ANR
- Work in progress to determine the stability across years and the correlation with GPD

Data from CTPS and FSOV N-BT project trial networks

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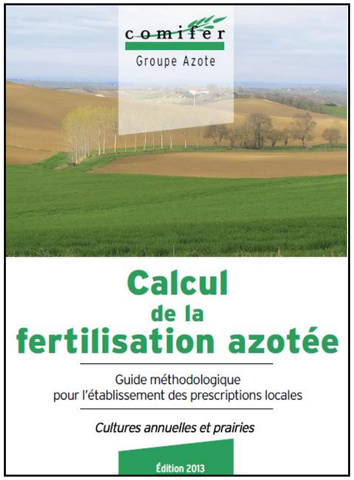
Practical information concerning NUE provided to farmers

What a farmer does need ?



N balance sheet methods widely used:

- Known and optimised since the 80's (Rémy and Hébert, 1977; Rémy and Viaux, 1983)
- Normalised in an "official document" (Comifer 2013)
- Farmers required to use it because of UE Nitrates Directive

- **N requirement = GY objective X b coefficient**

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REPARTITION DES VARIETES SELON LEUR BESOIN EN AZOTE (Coefficient b)

2012

GROUPE	VARIETES
b = 2,8	Accroc, (Adhoc), Ambition, Amundsen, Andalou, Aramis, Arlequin, Bermude, Expert, Glasgow, Hekto, (Hybery), Hymack, Hyscore, Hystar, Hysun, Istabraq, JB Diego, Lear, Oakley, (Pakito), Parador, Perfector, Pierrot, Prevert, Royssac, Scipion, Scor, Selekt, Sobbel, (Sokal), Sponsor, (Sweet), Trapez, Trémie, Viscount
b = 3,0	Adequat, Aldric, Aligator, Alixan, Altigo, Altria, Amador, Andino, Apache, Aprilio, Arezzo, Aristote, (Arkeos), (As de cœur), Attitude, Aurele, Autan, Bagou, Barok, Bastide, Boisseau, Boregar, Boston, (Brentano), Campero, Catalan, Celestin, (Centenaire), Charger, Chevron, Compil, Cordiale, Dialog, Dinosor, Epidoc, Ephoros, Equilibre, Euclide, (Flaubert), Fluor, (Folklor), (Forblanc), Galopain, (Garantus), Garcia, Goncourt, Haussmann, Hybred, Hyxo, Illico, (Innov), Isengrain, (Kalystar), Karillon, Marcelin, Maxwell, (Minotor), Nirvana, Nucleo, Orcas, Orvantis, Oxebo, Paledor, Pepidor, Perceval, Phare, Plainedor, Pr22r20, Pr22r28, Pr22R58, Premio, Razzano, Richepain, Rochfort, Rodrigo, Rosario, Rustic, Sankara, Seyrac, Sirtaki, Sogood, Solehio, Sollario, Swinggy, Toisondor, Uski
b = 3,2	Accor, Adagio, (Aerobic), Allez y, (Altamira), Ambello, (Amerigo), Athlon, Attlass, Aubusson, Avantage, Azimut, Azzerti, Camp-Rémy, Caphorn, CCB Ingenio, Cézanne, Chevalier, Croisade, Exelcior, Exotic, Farandole, Frelon, Galactic, Graindor, Instinct, Interet, Iridium, Isidor, Kalango, Koreli, Limes, Lukullus, Manager, Mendel, Mercato, Miroir, Musik, Nogal, Nuage, Oratorio, Paindor, Racine, Recital, (Ressor), Saint Ex, Samurai, Soissons, (Sophytra), Sorrial, Sy Alteo, Valodor, (Zinal)
b = 3,5	Antonius, Arfort, Courtot, Bagatelle 007, Bologna, Bussard, CH Nara, Esperia, (Fiorina), Florence Aurore, Furio, Galibier, Hyno-rista, Levis, Logia, Lona, (Ludwig), Monopole, Pireneo, Qualital, Quality, Quebon, Renan, Runal, Saturnus, Sebasto, Segor, Somme, Stefanus, Tamaro, Togano, Trofeo, (Turelli), Valbona

- Les variétés de blés améliorants non référencées ici sont positionnées par défaut en classe b = 3,5

Attention, cette année dans certaines régions (ex Centre-IdF-Ouest), une adaptation plus précise du coeff b pour ces types de blés a été réalisée. Pour ces situations, utiliser le tableau régional.

- Le classement est provisoire pour les variétés entre parenthèses
- Les autres variétés non référencées ici et non améliorantes sont positionnées par défaut en b = 3,0

Cette répartition pourra être soumise à des modifications avec l'acquisition de nouvelles références

(05 décembre 2011)

b coefficient references:

- Based on old results and methodology (Le Souder and Bernicot 1993)

- Methodology needs to be reviewed

- Specific target of 11.5% GPC needs to be introduced

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Network 3 : Data processing

$$GNU = GY \times 8.5 \times \frac{GPC}{5.7}$$

where: *GNU = Grain N Uptake at harvest (kg N .ha^{-1}).*
GY = Grain Yield (t 85% DM .ha^{-1}).
GPC = Grain Protein Concentration (% DM).

Step 1: GNU calculation for all varieties in all network trial

Network 1 analysis:
- Equation
- Minor impact of variety effect on NHI

$$TNU = a \times GNU + c$$

where: *TNU = Total N Uptake at harvest (kg N .ha^{-1}).*
GNU = Grain N Uptake at harvest (kg N .ha^{-1}).
a and c = Coefficient of the linear regression fitted on data from Network 1.

Step 2: conversion of GNU to TNU

Network 1 and 2 analysis:
- Sensitivity analysis of b, bc and bq coefficient classification vs N rate
- OK if in the vicinity of optimum +/- 40 kg N.ha^{-1}

GY > 7 t 85% DM .ha^{-1}
10 % < GPC < 14%
0.7< NNI at flowering < 1.2

Modèle CHN
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Step 3: N status diagnosis of each trial and choice of relevant trials

$$b\ coefficient = \frac{TNU}{GY}$$

where: *b coefficient = N uptake per yield unit (kg N .t^{-1} 85% DM).*
TNU = Total N Uptake at harvest (kg N .ha^{-1}) from Equation [step 2].
GY = Grain Yield (t 85% DM .ha^{-1}).

Step 4: b coefficient calculation

$$bc\ coefficient = (11.5 - GPC\ ajusted) \times \frac{8.5}{5.7} \times a$$

where: *bc coefficient = complementary N uptake for a GPC=11.5% (kg N .t^{-1} 85% DM).*
GPC adjusted = Grain Protein Concentration (adjusted mean) at national scale (% DM).
a = coefficient from Equation [step 2].

Step 5: bc coefficient calculation

$$bq\ coefficient = b\ coefficient + bc\ coefficient$$

Step 6: bq coefficient calculation

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b, bc and bq ranking sensitivity to N rate

Sensitivity analysis made on network 1

Method : Spearman correlation

b coefficient variety ranking remains the same regardless of the N rate

Ex.	b T0	b X-80	b X-40	b dose X	b opt rate	b X+40	b X+80
Variety ranking	Apache →	Apache →	Apache →	Apache →	Apache →	Apache →	Apache
	Pakito →	Pakito →	Pakito →	Pakito →	Pakito →	Pakito →	Pakito
	Rubisko →	Rubisko →	Rubisko →	Rubisko →	Rubisko →	Rubisko →	Rubisko
	Soissons →	Soissons →	Soissons →	Soissons →	Soissons →	Soissons →	Soissons

Same conclusion for bc coefficient

Same conclusion for bq coefficient, but only in the vicinity of X rate !

Study carried out during the FSOV N-BT project

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b, bc and bq ranking sensitivity to N rate

Sensitivity analysis made on network 2

- Spearman correlation coefficient :
  - p-value < 5% : variety ranking is considered identical for the two compared N rates
  - p-value > 5% : variety ranking is considered different for the two compared N rates

Coef b

b.X-80		0	0
b.X	0		0
b.X+40	0	0	
	b.X-80	**b.X**	**b.X+40**

Coef bc

bc.X-80		0	0
bc.X	0		0
bc.X+40	0	0	
	bc.X-80	**bc.X**	**bc.X+40**

Coef bc

bq.X-80		0	0.21
bq.X	0		0
bq.X+40	0.21	0	
	bq.X-80	**bq.X**	**bq.X+40**

- ➢ **b and bc coefficient: same ranking regardless of the N rates**
- ➢ **bq coefficient: same ranking only for X N rate vs the neighbouring rate**

Study carried out during the FSOV N-BT project

2017 update

References dissemination

Yield unit : t.ha-1 (85% DM)

b coefficient (kg N.t-1)	VARIETIES	bq coefficient 11.5% GPC (kg N.t-1)	Recommendation of N split applications when using bq 11.5%: bc coefficient 11.5% GPC (kg N.t-1)	Recommendation of N split applications when using bq 11.5%: Recommended N rate at flag leaf growth stage (Zadoks 37-45)
28	Addict, Adhoc, Advisor, Aigle, Ambition, Arlequin, Armada, Basmati, Bermude, Boisseau, **Chevignon**, Costello, Diderot, Garcia, **Gedser**, Granamax, Hybello, Hybery, Hybiza, Hyclick, Hyguardo, Hyking, **Hypodrom**, **Hypolite**, Hystar, Kundera, Lear, Lithium, Lyrik, **Meeting,** Modern, **Mogador**, **Montecristo CS**, **Mortimer**, **Mutic**, Popeye, RGT Mondio, RGT Texaco, Salvador, **Sanremo**, **Sepia**, Sokal, Trapez, Viscount, Zephyr	30	2	60 kg N.ha-1 (40*+20)
	Glasgow, Istabraq, **Reflexion**, Sobred, Torp	32	4	70 kg N.ha-1 (40*+30)
30	Accor, Alhambra, Allez Y, Apache, Apanage, Aprilio, Arezzo, Aubusson, Bagou, Bonifacio, Boregar, Brentano, Buenno, Calabro, Calcio, Calisol, Calumet, Cellule, Cezanne, Chevalier, Comilfo, Compil, Descartes, Diamento, Ephoros, Euclide, **Filon**, Fluor, Forblanc, Foxyl, Galactic, Galopain, **Gimmick**, Goncourt, Gotik, Hyfi, Illico, Interet, Kalystar, Koreli, **KWS Dakotana**, Lavoisier, LG Abraham, LG Absalon, LG Altamont, **Lipari**, Musik, Numeric, Oregrain, Paledor, **Pastoral**, Pibrac, RGT Ampiezzo, **RGT Cyclo**, RGT Kilimanjaro, **RGT Producto**, RGT Tekno, RGT Velasko, RGT Venezio, Rochfort, Rubisko, Rustic, Scenario, Silverio, Sirtaki, Sobbel, Solehio, Sollario, Solognac, Solveig, **Sophie CS**, Sothys CS, Sponsor, Starway, **Stromboli**, Syllon, Vyckor	30	0	40* kg N.ha-1
	Accroc, **Adriatic**, Alixan, Andalou, Arkeos, Ascott, **Attraktion**, Auckland, Barok, Belepi, Bergamo, Chevron, Collector, **Complice**, **Creek**, **Donjon**, **Etana**, Expert, **Faustus**, Fructidor, Gallixe, Grapeli, **Hydrock**, Ionesco, **Kylian**, Laurier, **Maori**, Matheo, Milor, Nemo, Oxebo, Pakito, Pr22r58, **RGT Cesario**, RGT Libravo, RGT Sacramento, Ronsard, Sherlock, **Stereo**, **SY Mattis**, SY Moisson, System, Terroir, Tobak, Triomph, Valdo, Waximum	32	2	60 kg N.ha-1 (40*+20)
32	Altamira, Athlon, Attlass, Bienfait, Camp Rémy, **Cecybon**, Centurion, Exelcior, Exotic, Falado, Graindor, Hendrix, Lazaro, **LG Armstrong**, **LG Ascona**, Lukullus, Manager, Nogal, **Orloge**, **RGT Forzano**, Scipion, Soissons, Sorrial, Tulip	32	0	40* kg N.ha-1

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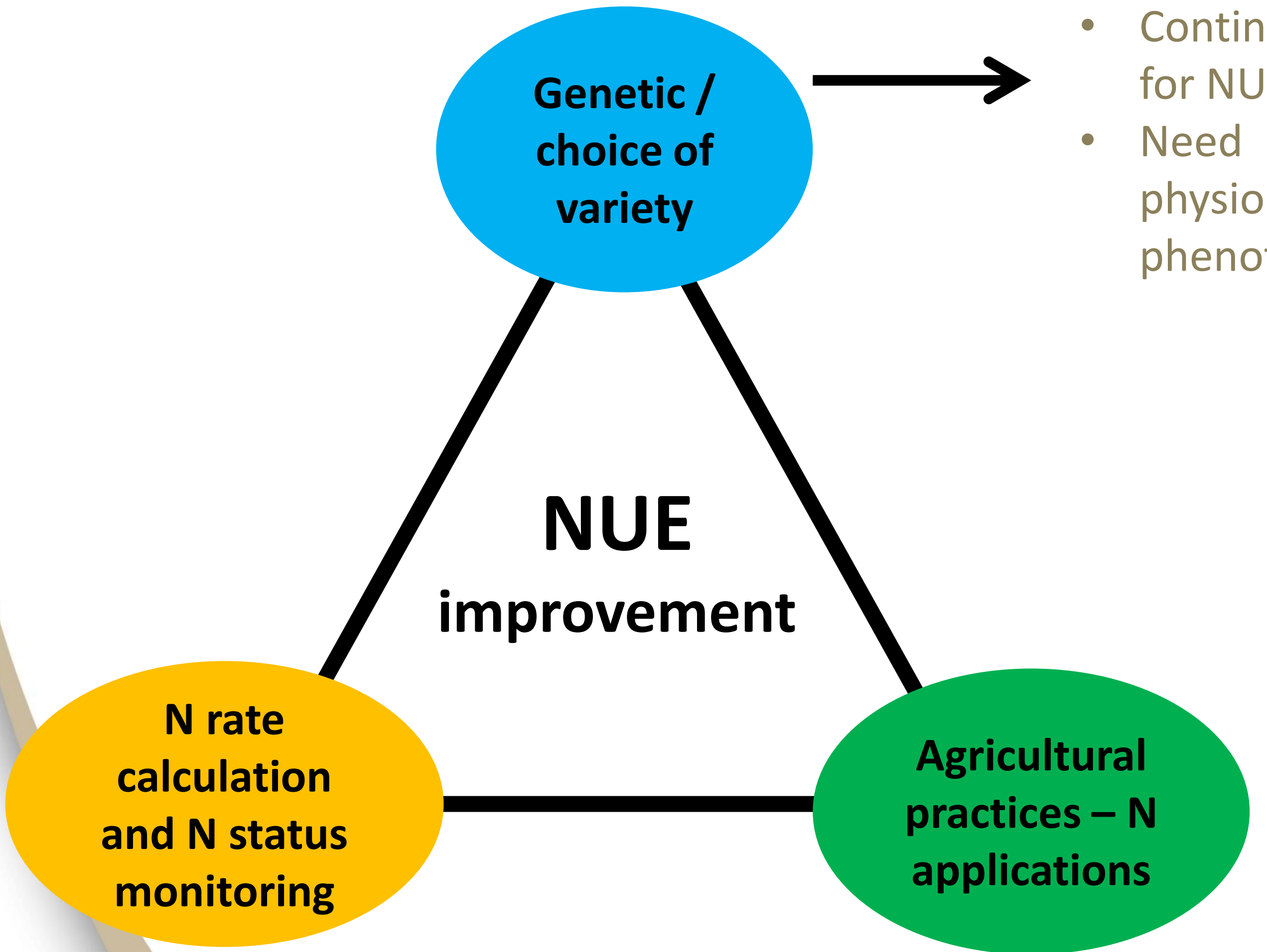
Bold = new 2018 varieties
Red = modified varieties compared to 2017

*: minimum rate of 40 kg N.ha-1 could be reduced in the case of a low yield potential.

November 22th 2017

Perspectives and conclusion

Conclusion



- Large amount of results
- Continuum breeding to farmers OK for NUE characterization
- Need to go further mixing crop-physiology, genetics and new phenotyping tools

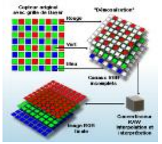
High Throughput Phenotyping Tools

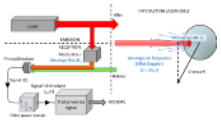
RGB Camera

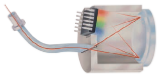
LIDAR

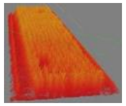
Multispectral Camera

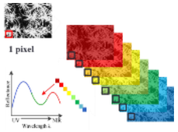
Spectro-radiometer

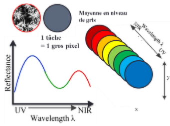




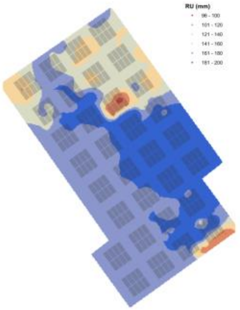








Soil water storage capacity mapping (soil sensors and climatic units)



The infrastructure

- **Located on heart of French farmland,** adapted to all major crops (cereals, maize, potato, sugar beet, oilseeds), irrigating area **8 mobiles rainout shelters :** 655 m² each (25 x 25 m), 16 irrigation carts
- **Autopilot interface displacement of greenhouses with climate software and registration data**
- **Up to 350 micro experimental plots covered / Rotation of 4 growing areas / Sub-meter scale map of soil water holding capacity**

High Throughput Phenotyping Tools

Pheno3C
Phénotypage au Champ sous Contraintes Climatiques

PHACC
Phénotypage au Champ des Céréales

GDEC
Génétique Diversité Ecophysiologie des Céréales

The infrastructure

- 24 experimental plots enabling crop rotation (possibility of irrigation)

- 4 x 1 200m² mobile rain-out shelters :

4 x 96 (384) protected micro-plots, 1.15 x 1.9 m (2.2 m²) each
4 x 96 (384) control micro-plots, 1.15 x 1.9 m (2.2 m²) each

- 2 CO_2 FACE Grids (2018):

2 x 96 (192) elevated CO2 micro-plots (protected or not, + control areas)

- Phénomobile V2 (in development, 2019)
- Sensors
  - RGB camera
  - Multispectral camera
  - LIDAR

Climatic units and soil sensors

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High Throughput Phenotyping Tools

Other example of mobile facilities

ALPHI

PHENOMOBILE

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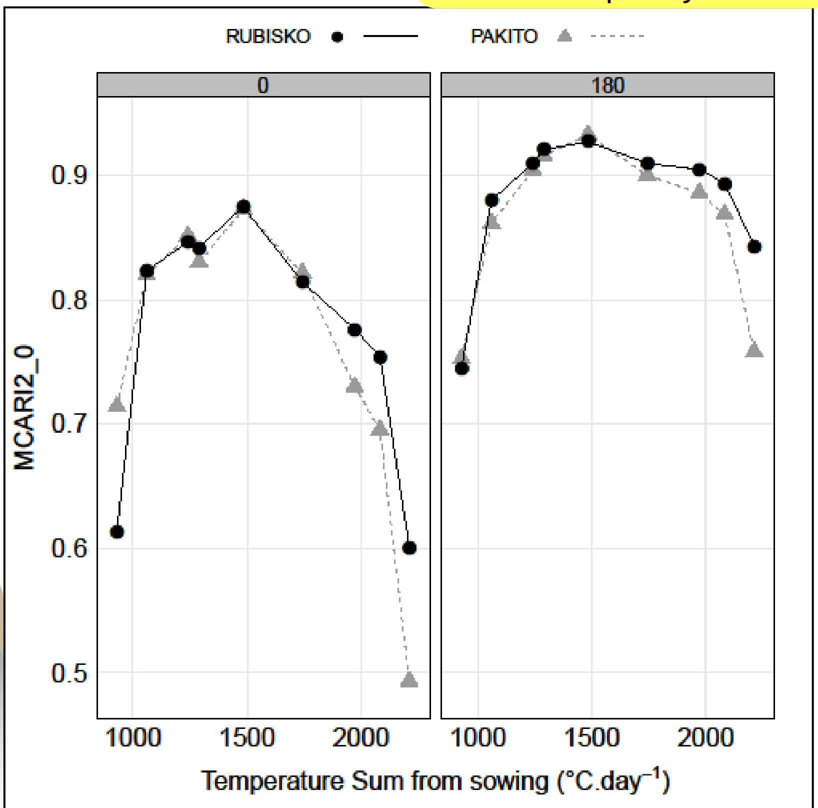
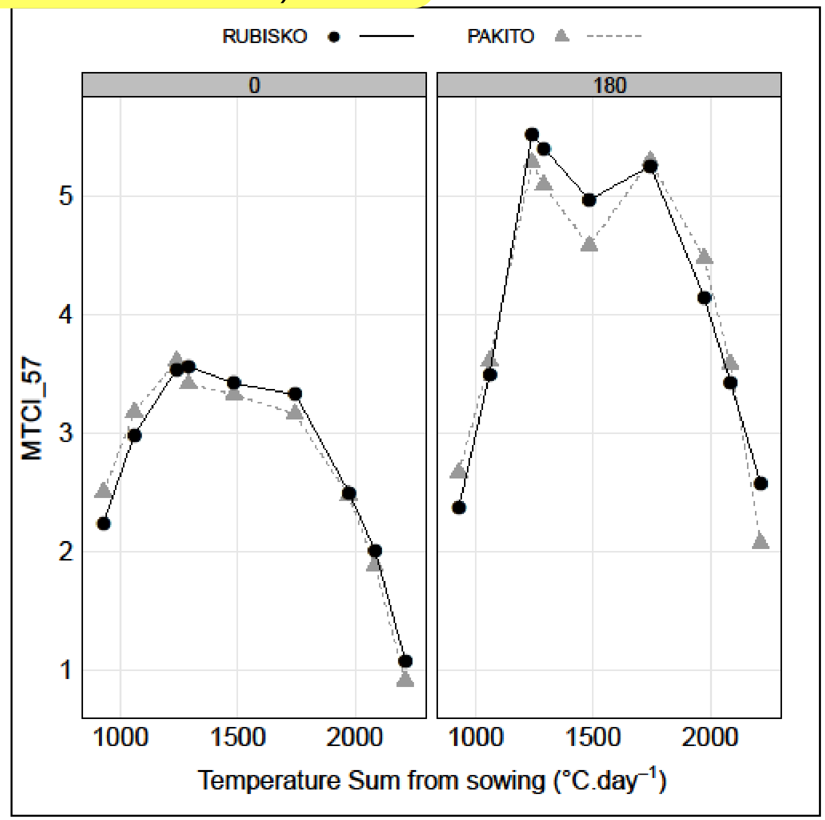
NUE components proxy with High Throughput Phenotyping Tools

Able to phenotype:

- Numerous micro-plots without destructive measurements
- More frequently than usual (dynamic characterisation)





Data from Arvalis, location Binas 15 trial.
ALPHI Phenotyping tool

MCARI 2: Modified Chlorophyll Absorption Ratio Index 2

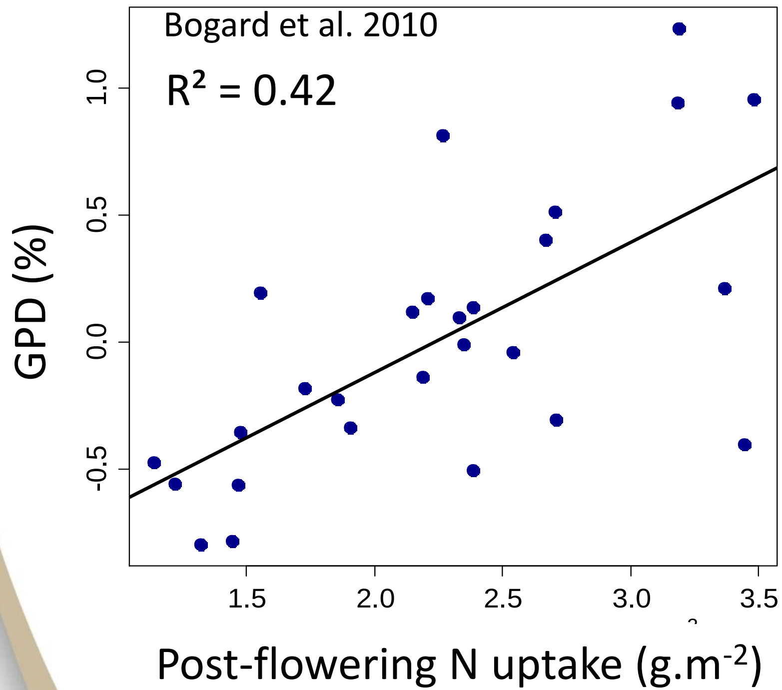
(Haboudane et al., 2004)

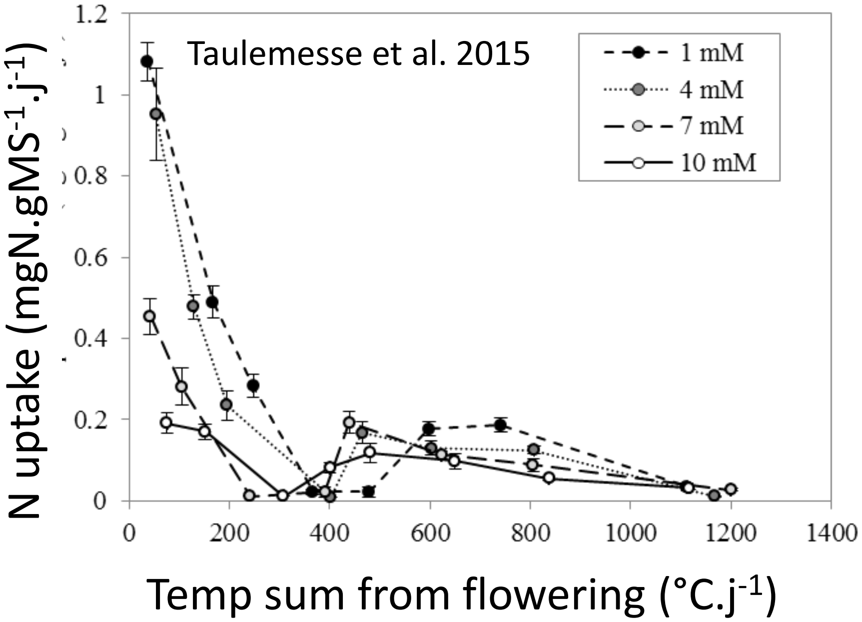
MTCI : MERIS Terrestrial Chlorophyll Index

(Dash and Curran, 2004)

New eco-physiological and genetic discoveries

Post-flowering physiology





The understanding of the physiology of N uptake after flowering is crucial to target breeding programs and farm practice to better GPC with high yields

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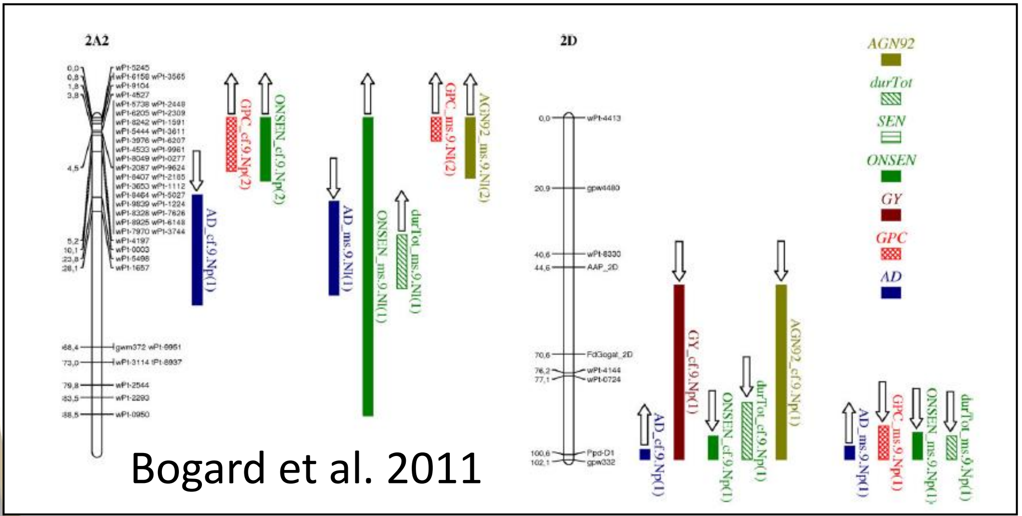
New eco-physiological and genetic discoveries

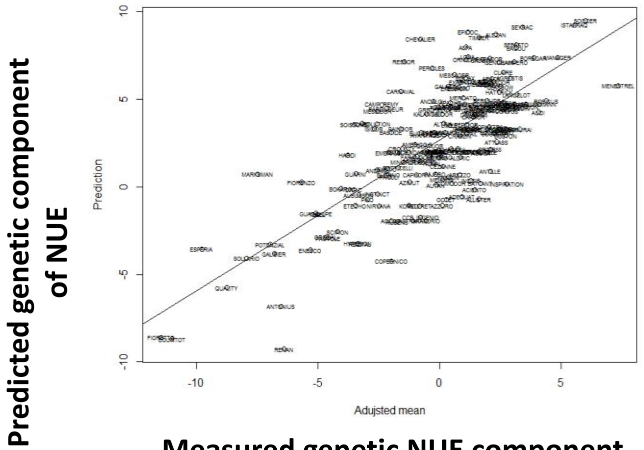
Genetic mapping linked to NUE



Bogard et al. 2011

Genomic prediction of NUE

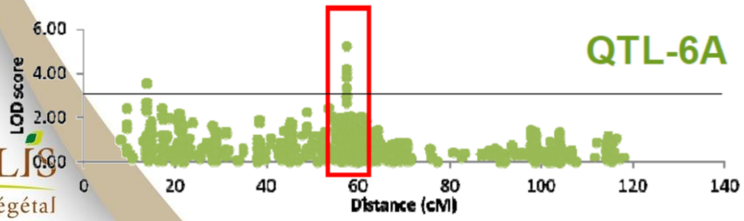
PhD thesis F. Cormier 2015



QTL detection

PhD thesis F. Cormier 2015

NUE = ENV + Quality + Precocity + SNP + **SNP x N** + K



- Promising results from genetic studies to boost breeding programs targeting NUE and to genetically characterise existing varieties
- GWAS studies boosted when associated with HT phenotyping tools

Acknowledgements

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Thank you for your attention