Factors limiting the yield of some field crops and prospects for improvement

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Climate change and the challenge of yield performance and stability

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More and more randomly extreme weather events

Extreme weather events (> décile 8) since the mid 90's in France

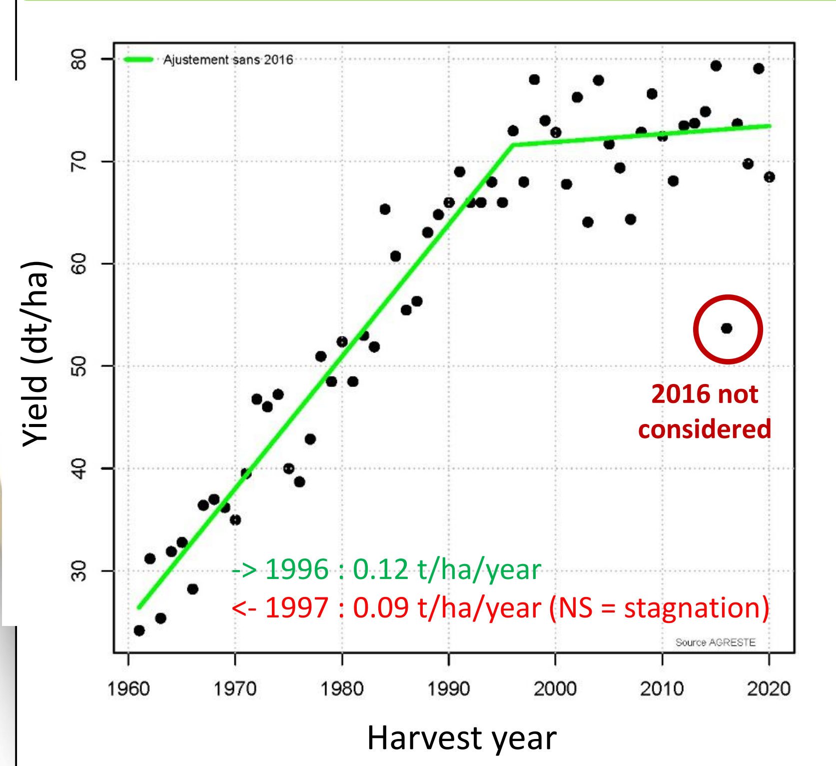
Per harvest year of cereals (regions concerned may varie according to the year)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Water logging in winter				x	x							x					x	x						x
Drought autumn-winter																						x		
Frost-thaw cycles							x																	
Late frost after a hot winter																x								
N stress at stem elongation	x					x	x			x	x				x			x	x		x			
Water logging end of growth cycle	x										x	x								x				
Heat stress during grain filling									x	x											x		x	x
Abiotic stress meiosis / flowering (rain, low temp, lack of rad.)											x	x								x				

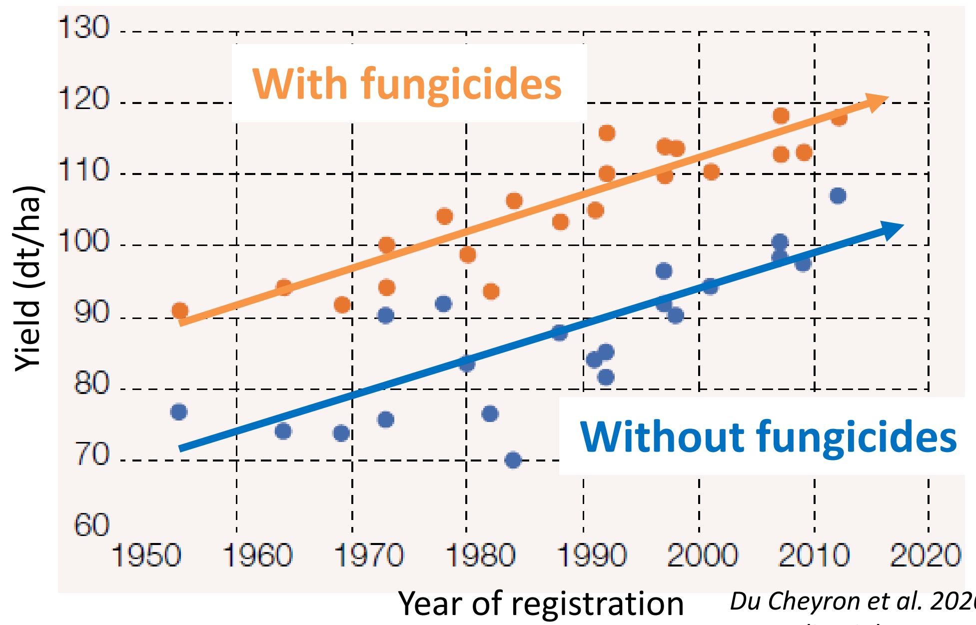
Impact on yield

✓ **Adverse climate events mask the genetic progress**

Mean yield for bread wheat in France



Genetic progress in bread wheat



Du Cheyron et al. 2020
5 Arvalis trials 2013-2014

Why ? -> Brisson et al. 2010

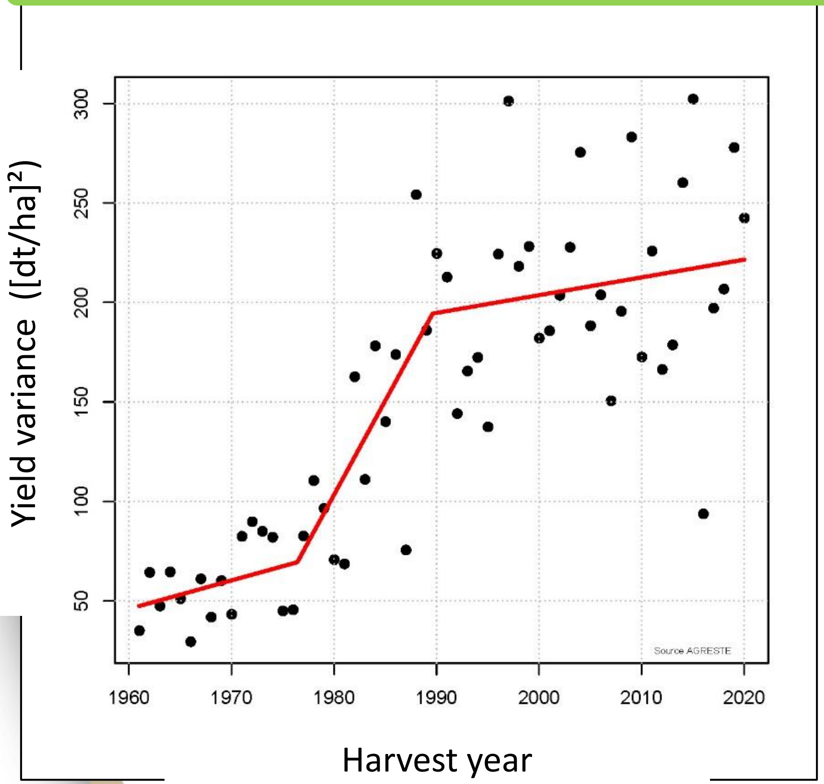
- +++ adverse climate events
- + rotation, pest/disease and N input effects
- + ? Soil fertility issues

Without constant genetic progress, yield would decrease…

Impact on yield

✓ **Variability : the challenge of stability!**

Inter-region variance of bread wheat yield in France



Commentary : P. Gate (Arvalis) from P. Bertuzzi (INRAE AGROCLIM)
Update 2020 : Arvalis

- **-> 1976 :** stable and low variance ➔ **stable climate, genetic progress implementation**
- **From 1977 to 1989 :** variance significantly increases ➔ **regions express their yield potential diversity**
- **<- 1990:** stable and high variance ➔ **geographical diversity regarding the climate**

➔ **Beside high yield, stability is also strategic for farmers and the downstream value chain**

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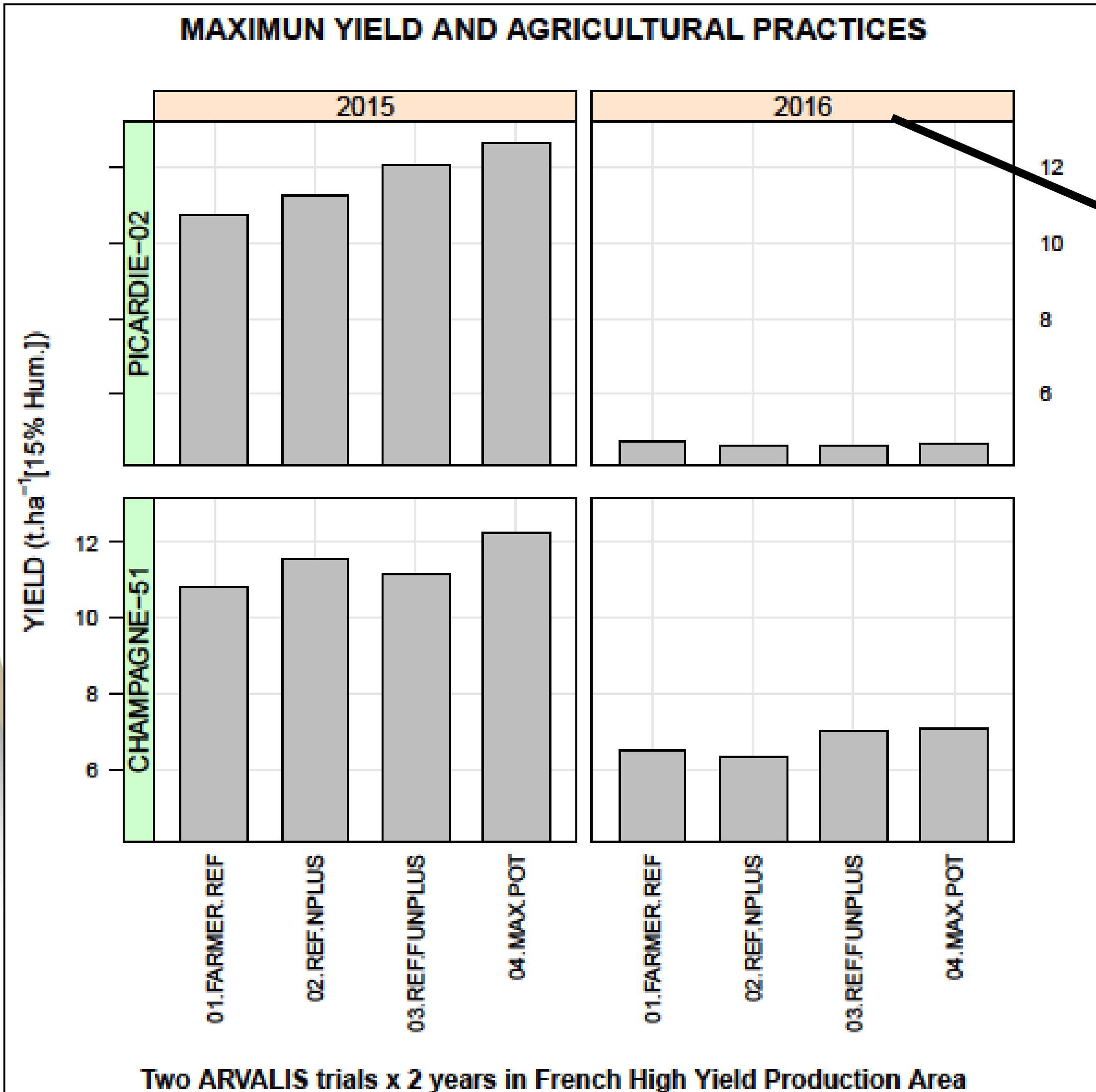
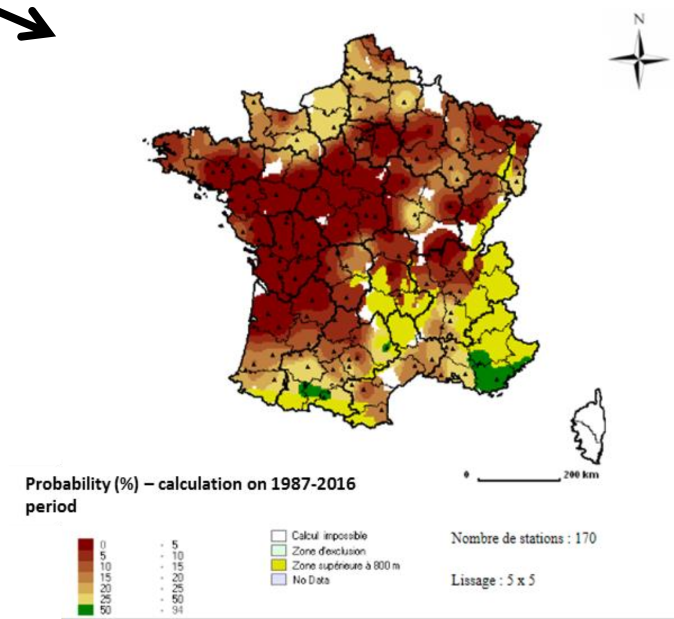
High yields, agricultural practices and climatic trap…



Probability to obtain a cumulative radiation under 2016 level during wheat grain filling



Source of data: Météo-France/ARVALIS/INRA/TI/SRPV
Calculation and mapping : ARVALIS

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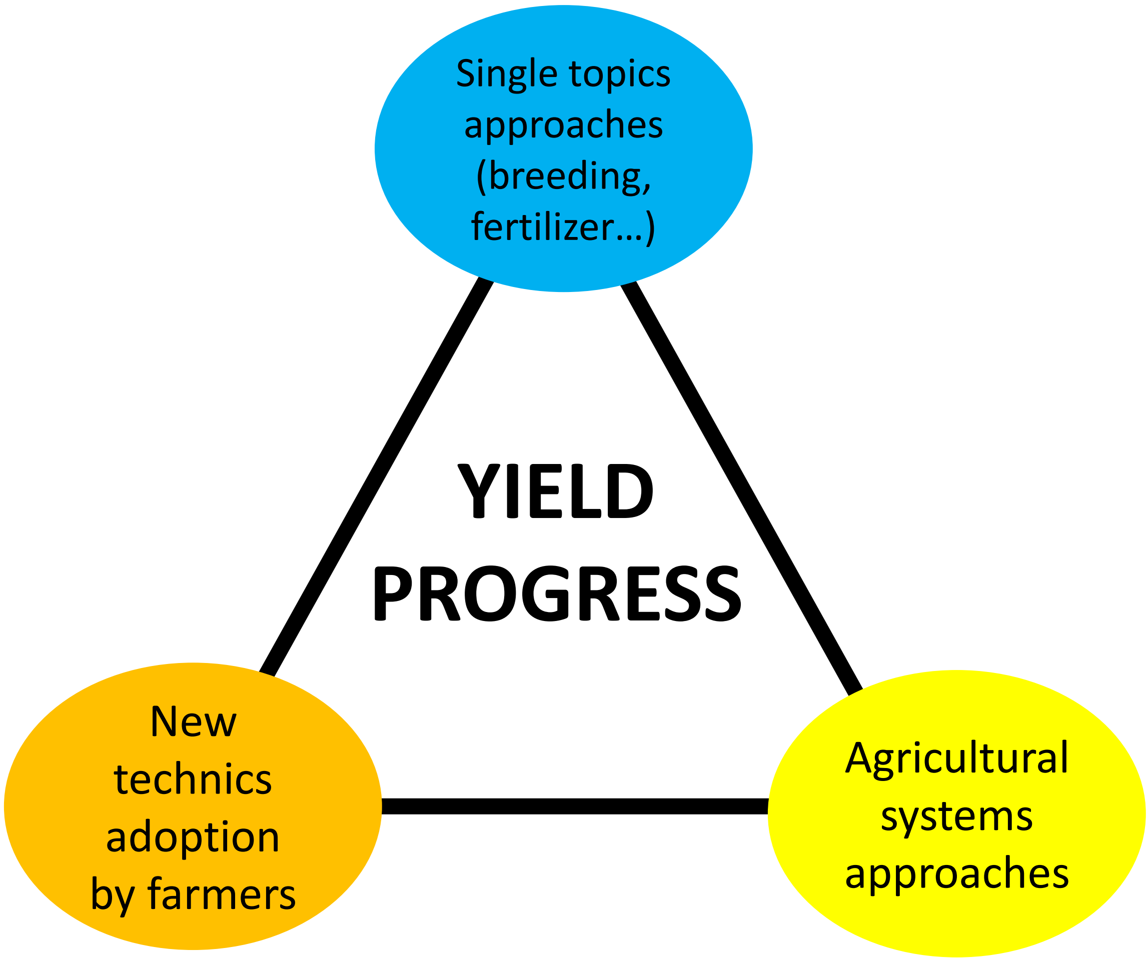
Wheat yield progress : build a multivariate response



Considering the agricultural practices and context to target the right traits to select

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Example of RUE in wheat

Yield building in brief

Radiation

X

Foliar interception

X

Conversion to biomass

X

Harvest Index

Radiation Use Efficiency

Trade-off and compromises regarding the escape strategies for biotic and abiotic stresses

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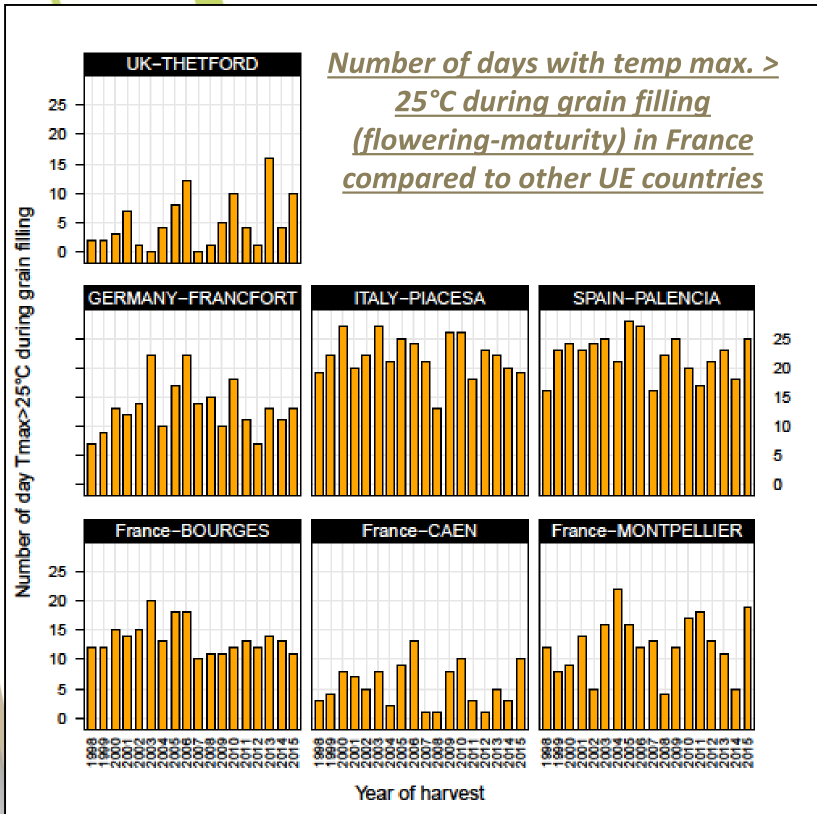
Multi-stress avoidance strategies



Modèle CHN
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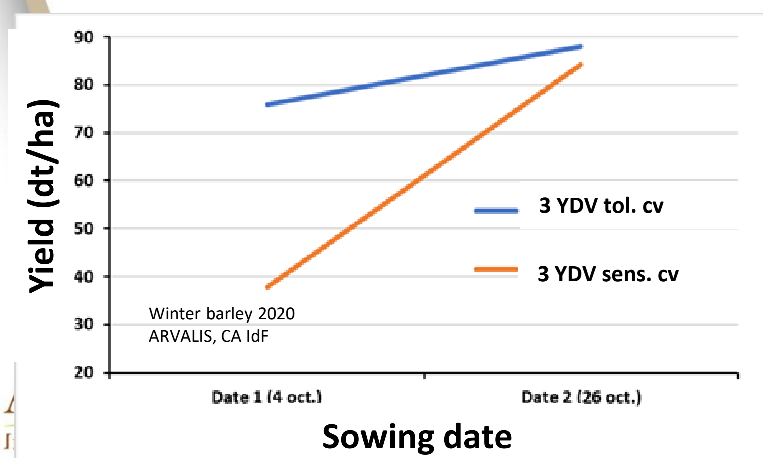
Growth stages simulation from CHN model
Genotype = PREMIO
Sowing date = oct. 28th
Meteo data = METEO-France and JRC Mars project for UE

Example on winter cereals

Abiotic escape strategy -> Tendencies to choose earlier cultivars



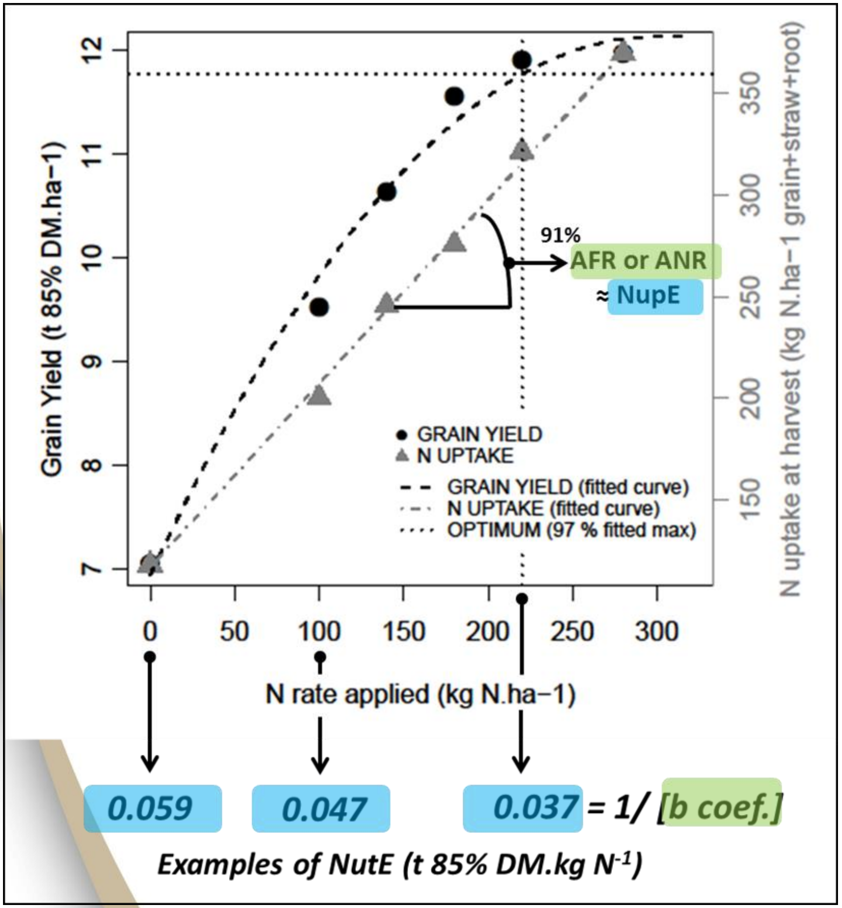
Biotic escape strategy -> Tendencies to delay the sowing date

Multi-escape strategies = Potential negative trade-off on the total length of the growth cycle

-> need to work on RUE

-> need to progress on tolerance/avoidance

Example of NUE



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

Moll *et al.*, 1982

$$NUE = NupE \times NutE$$

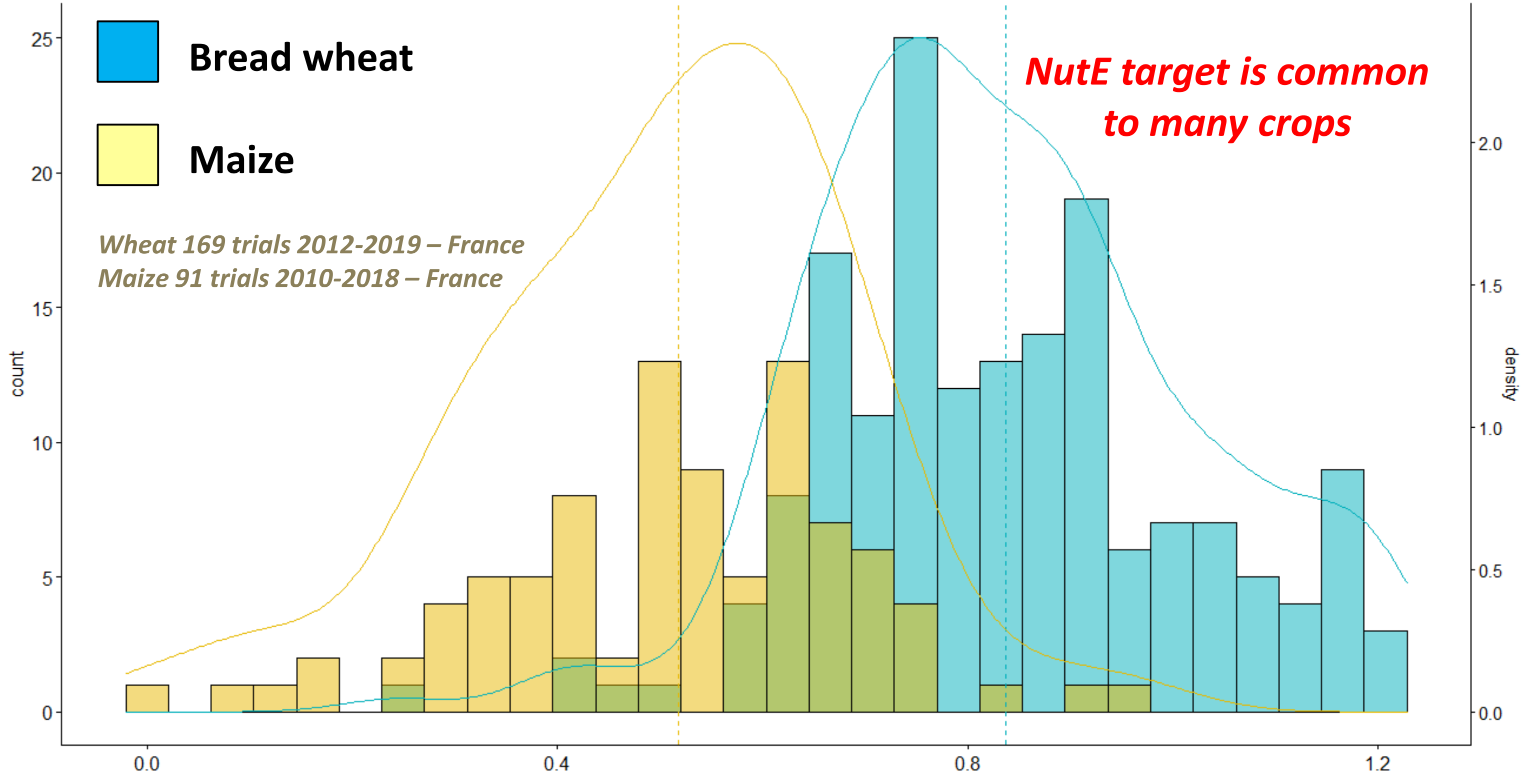
Moll et al., 1982; Hirel et al., 2007; Sylvester-Bradley and Kindred 2009

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

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

Precisely evaluating the agronomic situation to define the target

The priority of NupE target could vary from one crop to another



NutE target is common to many crops

ANR : Apparent nitrogen recovery = proxy of NupE

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ANR is firstly impacted by climate and agricultural practices

$$ANR = f(GR, CR, FT)$$

GR : Growth Rate at application time
CR : Cumulative Rain after application
FT : Fertilizer Type

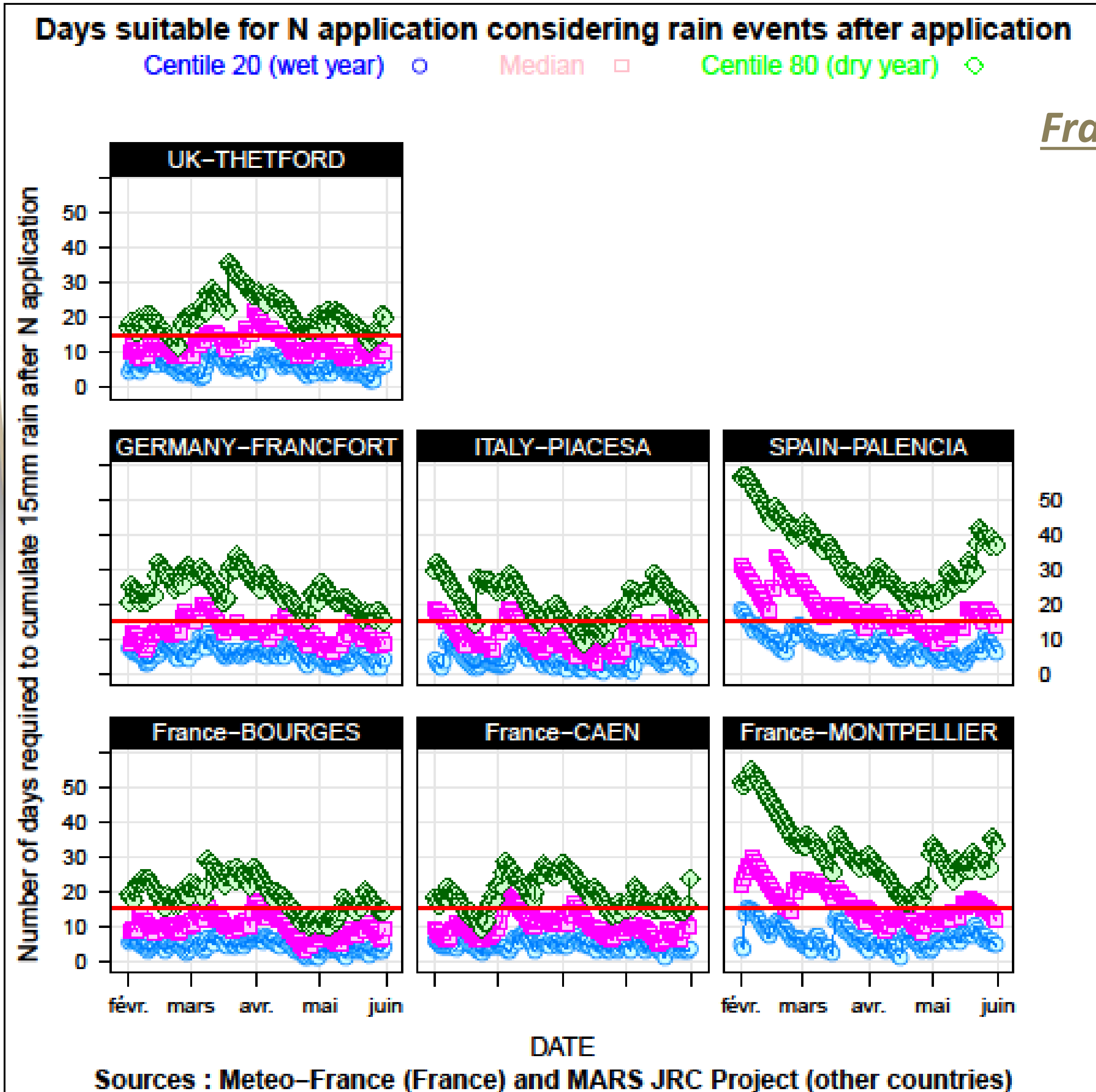
Collin 2012

Related to crop need and fertilizer application strategies

Related to fertilizer solubilization in soil water

Mainly related to susceptibility regarding ammonia volatilization

ANR and climate

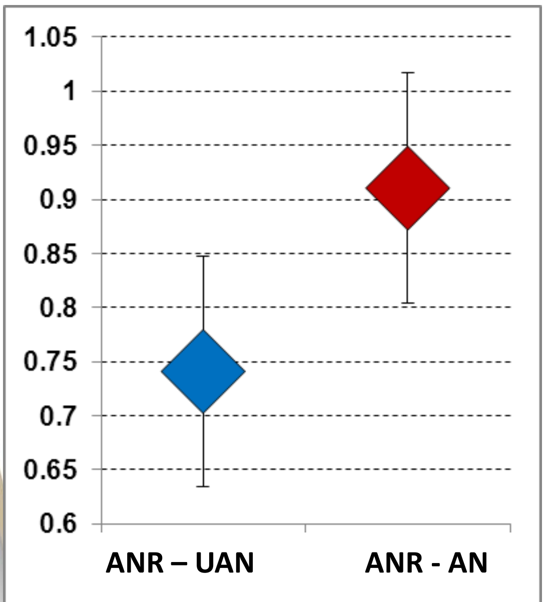


France compared to other UE countries

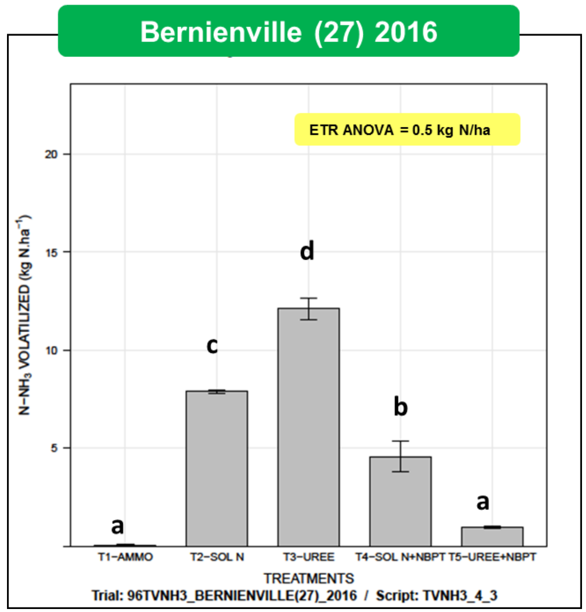
Remark:

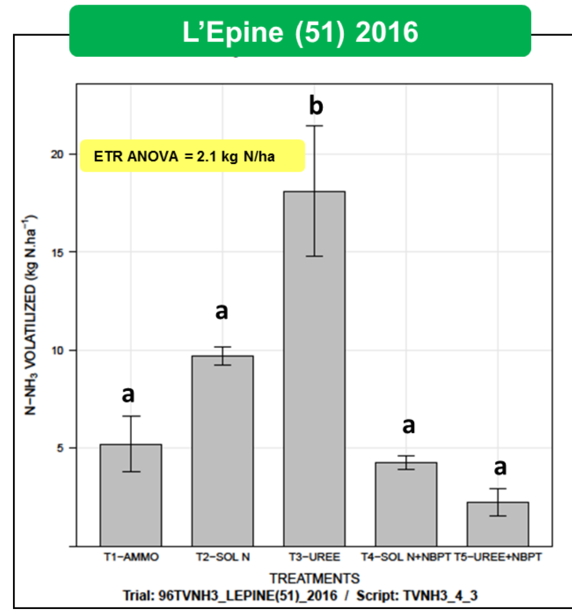
Irrigation can change the rules allowing good N uptake if made just after N application.

ANR and fertilizer type



15 ARVALIS trials 2004-2005
(N application at Z30





Flux analysis method : INRA-ECOSYS/ARVALIS

First results of ADEME EVAMIN project

SOL N + NBPT = UAN + Agrotain from Koch Fertilizer Products
UREE+NBPT = NEXEN from Koch Fertilizer Products
Letters = HG Tuckey tests

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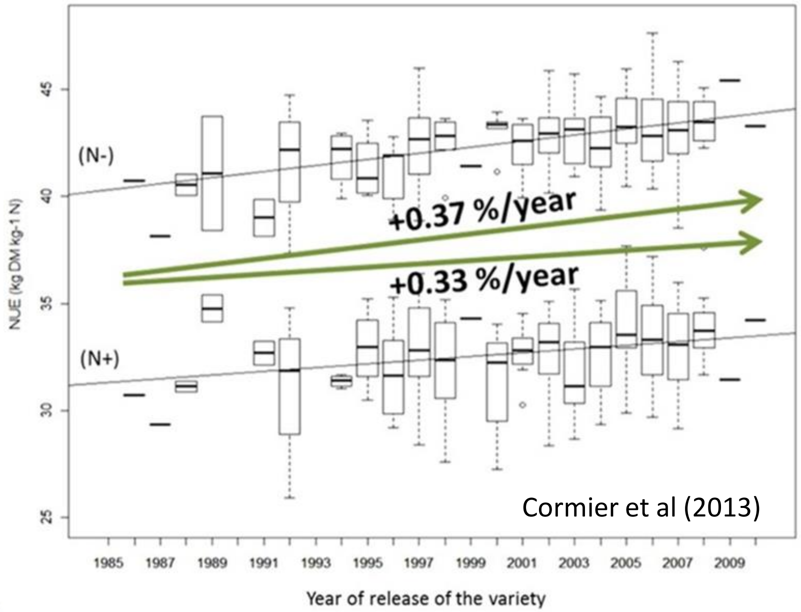
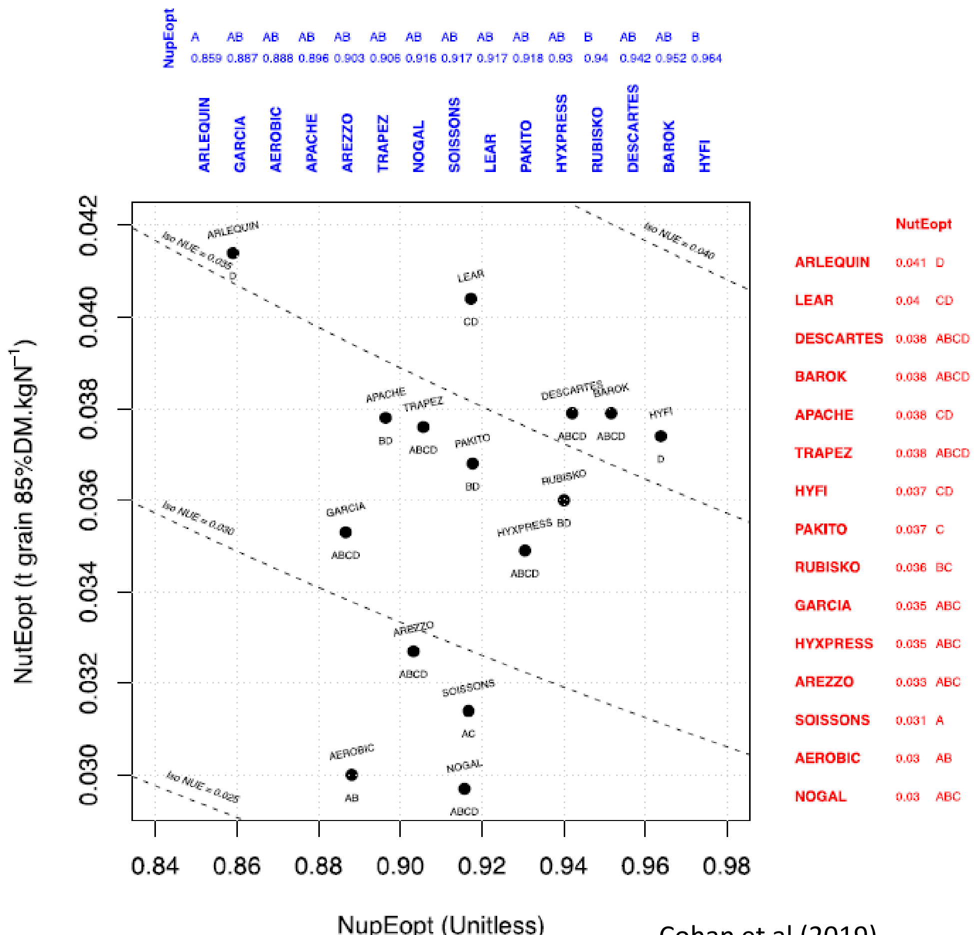
Genetic and NUE components

Example on winter wheat





Cohan et al (2019)

Heritability and variance components (N+)

Trait	h^2	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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Wrap-up

- Agro-climatic constraints are evolving according to climate changes
- Farms must face both trend evolutions of climatic parameters (Temperature, CO_2 …) and the rise of the randomly occurrence of extreme weather events -> stability is a major target (G x E x M interactions)
- Genetic is one of the major levers to face the yield challenges but the adaptation strategies must also consider the interaction with agricultural practices
- For each agricultural situation, the priorities and trade-offs between genetic and agricultural practices improvement (and their interaction) must be assessed to prioritize the R&D projects.

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Thank you for your attention