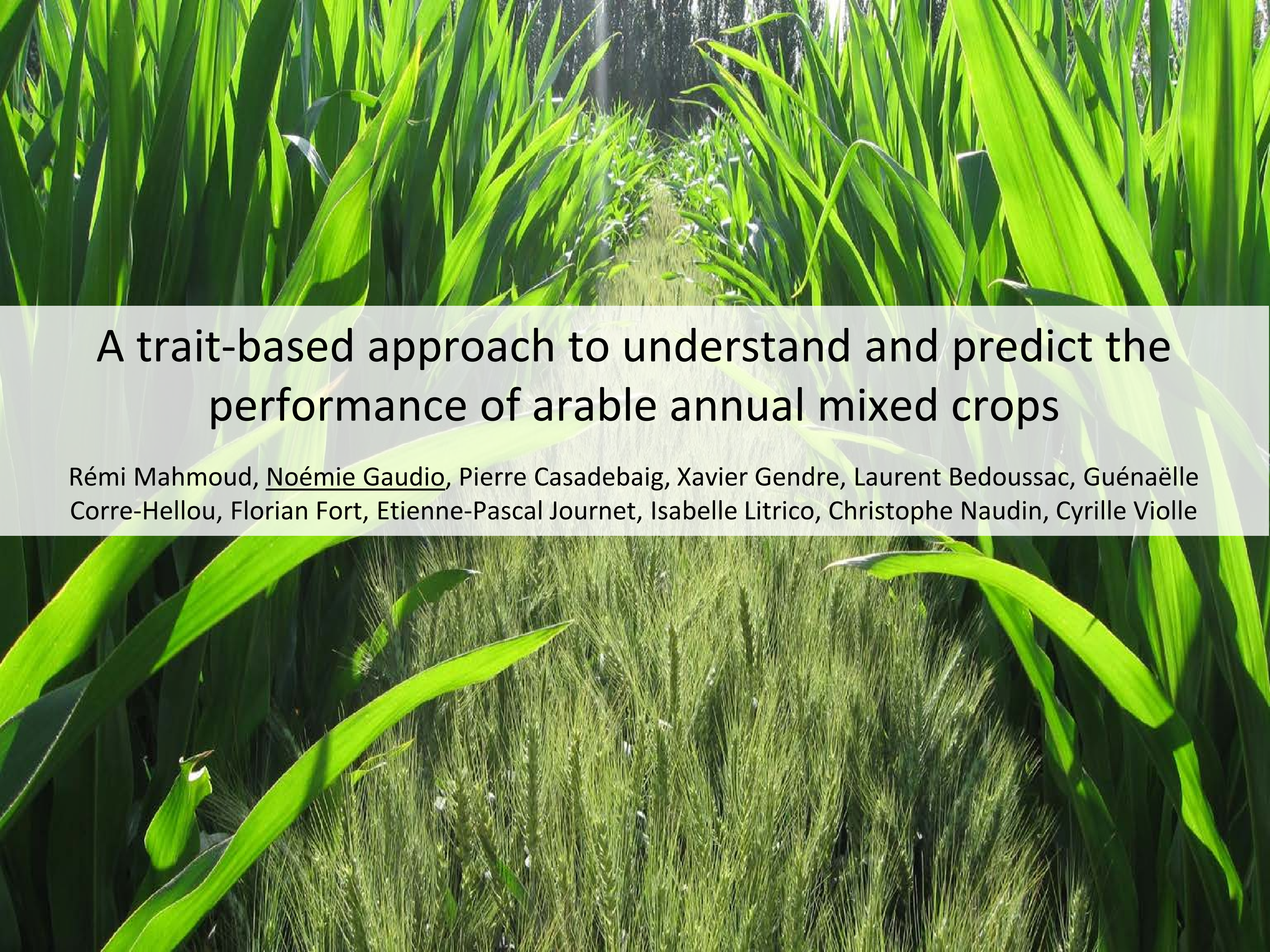

A trait-based approach to understand and predict the performance of arable annual mixed crops

Rémi Mahmoud, Noémie Gaudio, Pierre Casadebaig, Xavier Gendre, Laurent Bedoussac, Guénaëlle Corre-Hellou, Florian Fort, Etienne-Pascal Journet, Isabelle Litrico, Christophe Naudin, Cyrille Violle

Agronomic context: towards a more sustainable agriculture

Intensive agriculture

Environment optimized
through external inputs

Agroecological transition
System diversification
(field, rotation, landscape)

Sustainable agriculture

Less or no inputs → limiting conditions
Use of plant diversification

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Intercrops

Maximize complementarities and positive interactions

Divergence between species Complementarity or competition


Brooker et al. (2015)

Metrics = distance for target functional traits between the two species

Divergence between species Complementarity or competition


Brooker et al. (2015)

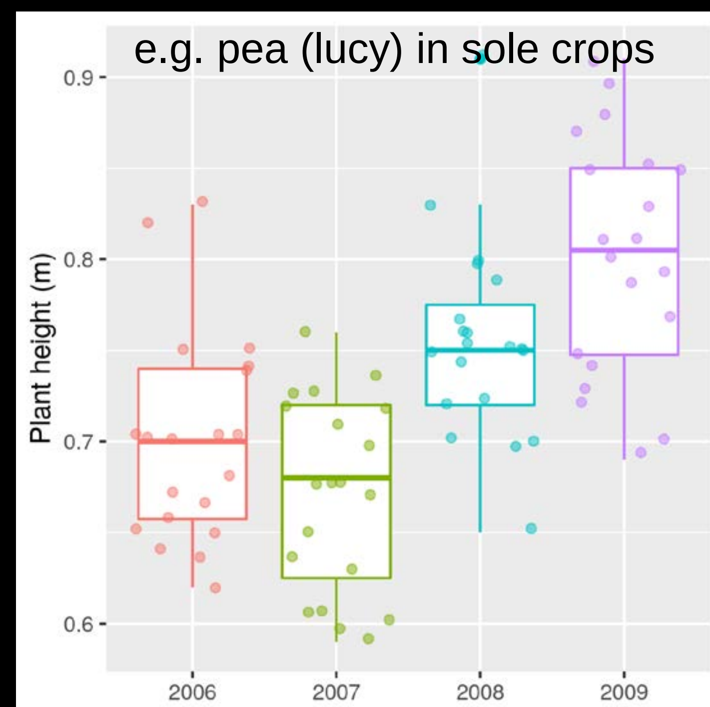
Metrics = distance for target functional traits between the two species

Phenotypic plasticity

1 genotype ↔ *n* phenotypes

= Adaptation to the environment

Metrics = variance of a target trait between environments



Reviewed by Nicotra et al (2010)
Trends Plant Sci 15:684-692

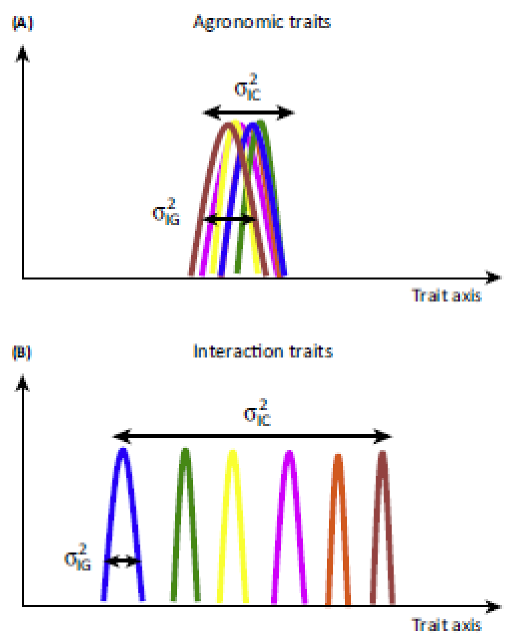
What about the transposability of these concepts to agroecosystems?

- Low diversity compared to natural communities
- Artificial selection for sole crops rather than natural selection

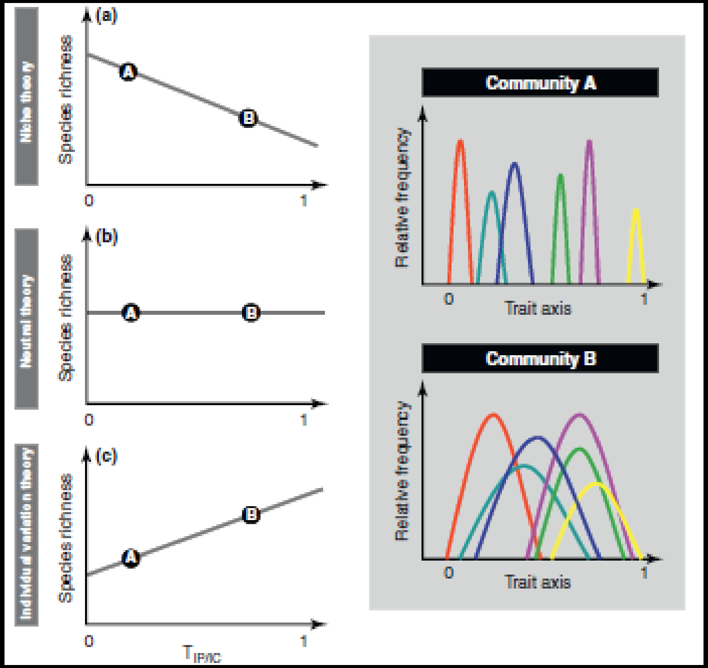
Conceptual framework: Recipes of ecology to make efficient mixtures

What about the transposability of these concepts to agroecosystems?
- Low diversity compared to natural communities
- Artificial selection for sole crops rather than natural selection

Can we gather relevant data to add experimental points on theoretical curves?



Litrico I, Violle C (2015)
Trends Plant Sci. 20:604–613



Violle C et al (2012)
Trends in Ecology & Evolution 27:244–252

Objective

- Agronomic interest of intercrops experimentally demonstrated
- High variability of results according to environmental conditions

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Interest of predictive approaches to generalize (and profusion of data)

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Interest of predictive approaches to generalize (and profusion of data)

Objective: develop statistical models to predict intercrops performance based on environmental conditions (soil, climate, practices), species intrinsic differences (trait values) and species plasticity (trait variance).

Approach: existing data (being acquired) → statistical models

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Data-driven models (empirical)

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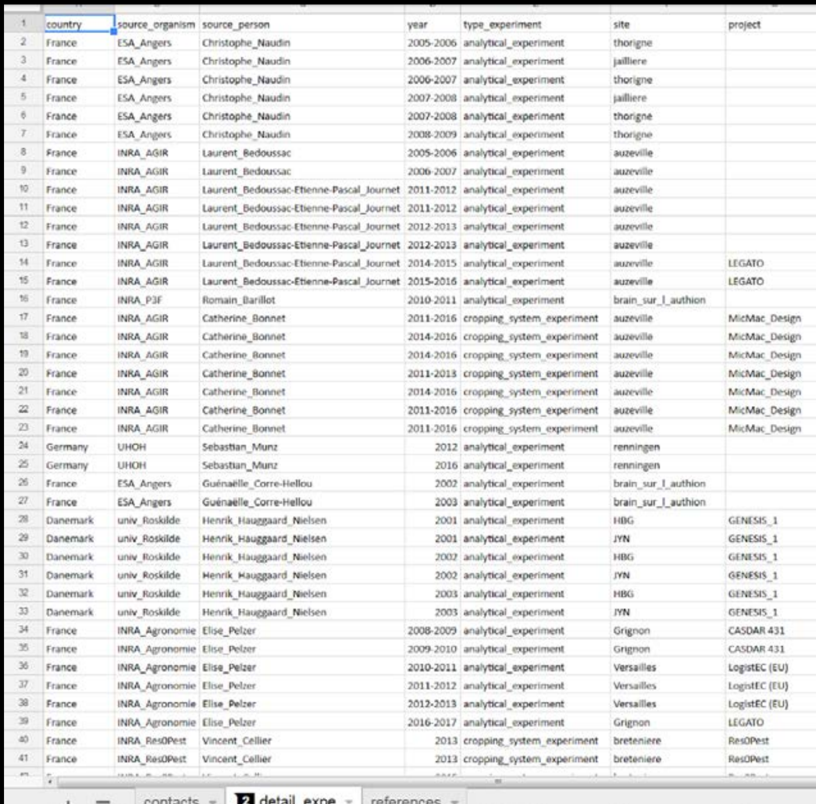

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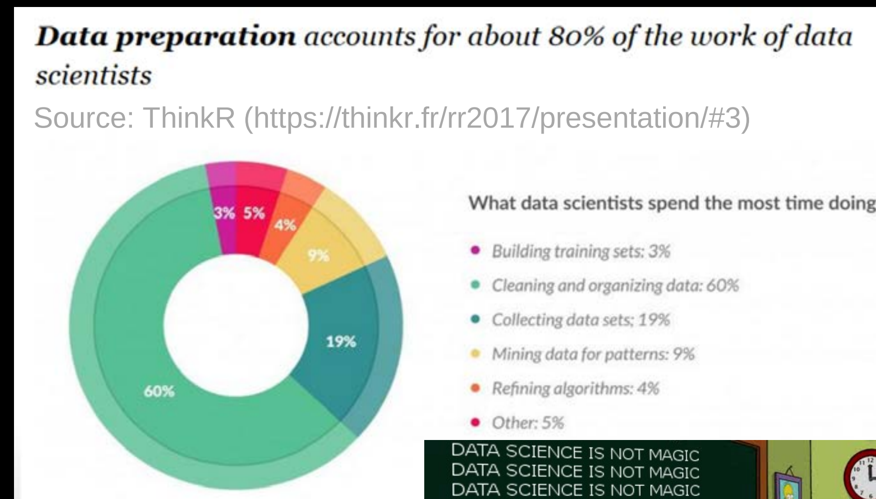

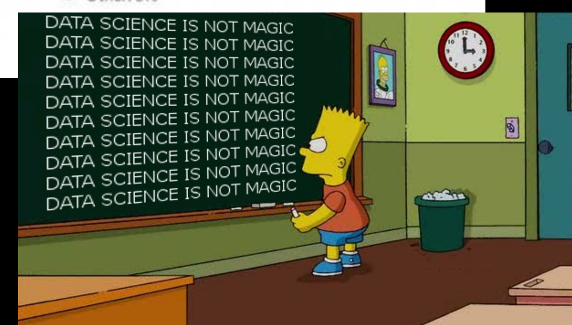

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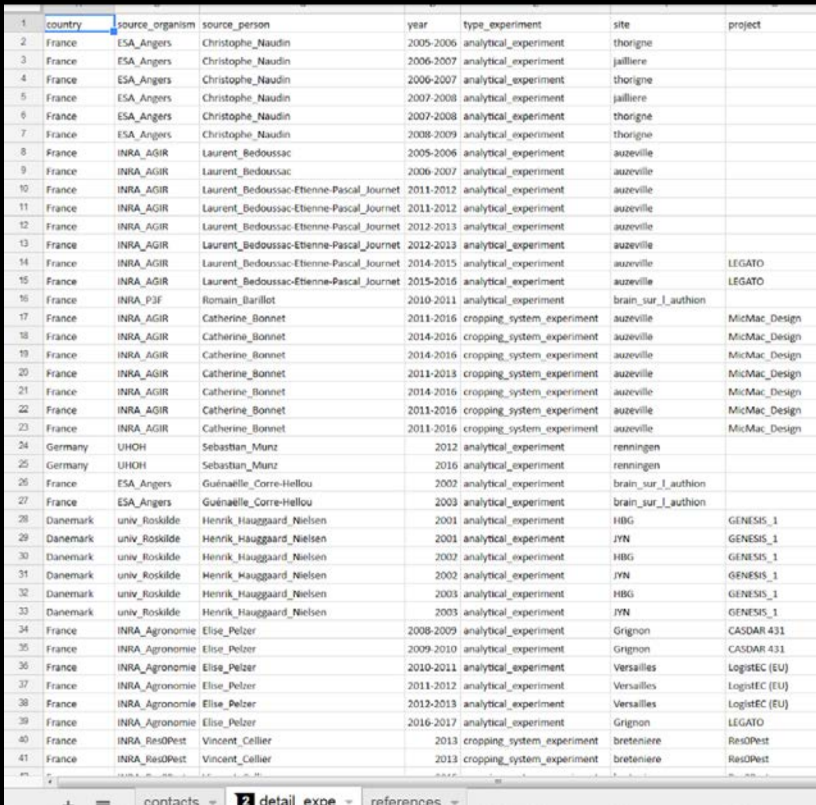

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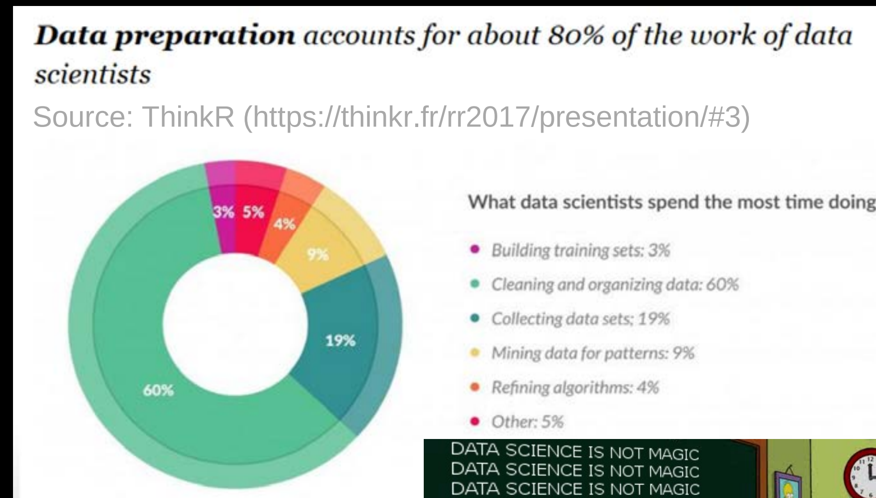

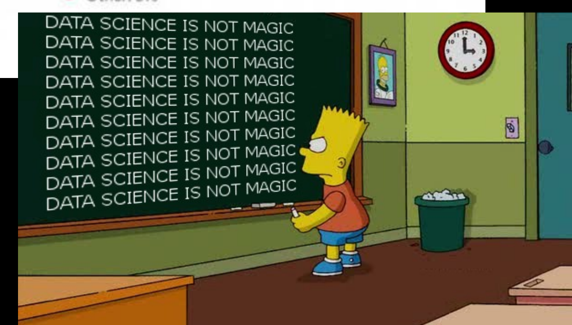

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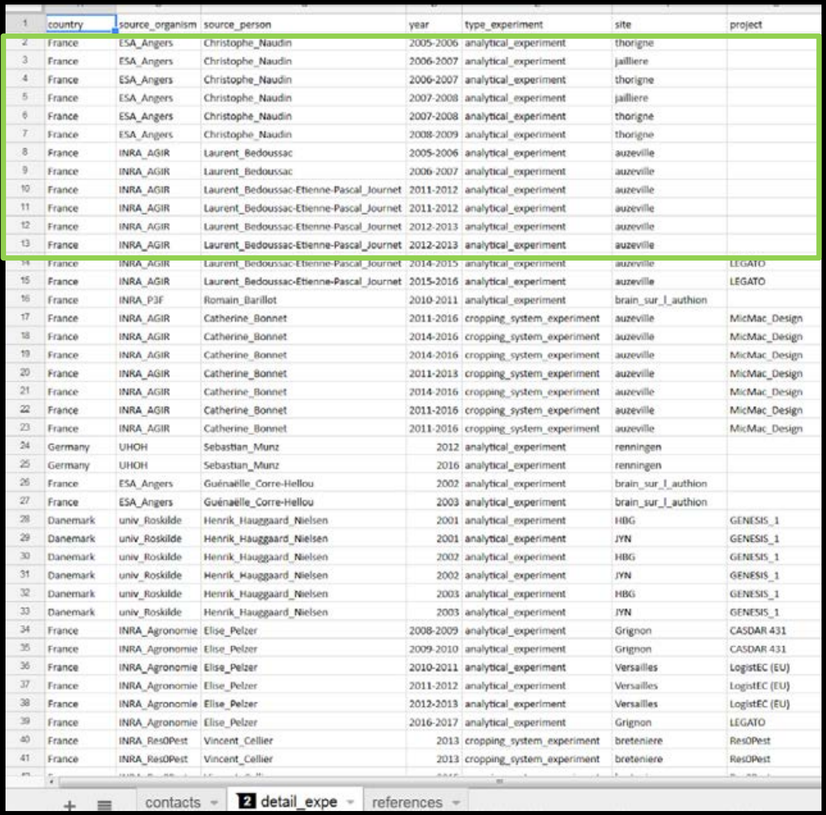
Data-driven models (empirical)

"intelligent": driven by ecological concepts

= mobilize agronomic and ecological knowledge to define integrative variables that are considered important for the performance of the modeled system

Approach: existing data (being acquired) → statistical models



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35	France	INRA_Agronomie	Elise_Pelzer	2009-2010	analytical_experiment	Grignon	CASDAR 431
36	France	INRA_Agronomie	Elise_Pelzer	2010-2011	analytical_experiment	Versailles	LogistEC (EU)
37	France	INRA_Agronomie	Elise_Pelzer	2011-2012	analytical_experiment	Versailles	LogistEC (EU)
38	France	INRA_Agronomie	Elise_Pelzer	2012-2013	analytical_experiment	Versailles	LogistEC (EU)
39	France	INRA_Agronomie	Elise_Pelzer	2016-2017	analytical_experiment	Grignon	LEGATO
40	France	INRA_ResOPest	Vincent_Cellier	2013	cropping_system_experiment	breteniere	ResOPest
41	France	INRA_ResOPest	Vincent_Cellier	2013	cropping_system_experiment	breteniere	ResOPest

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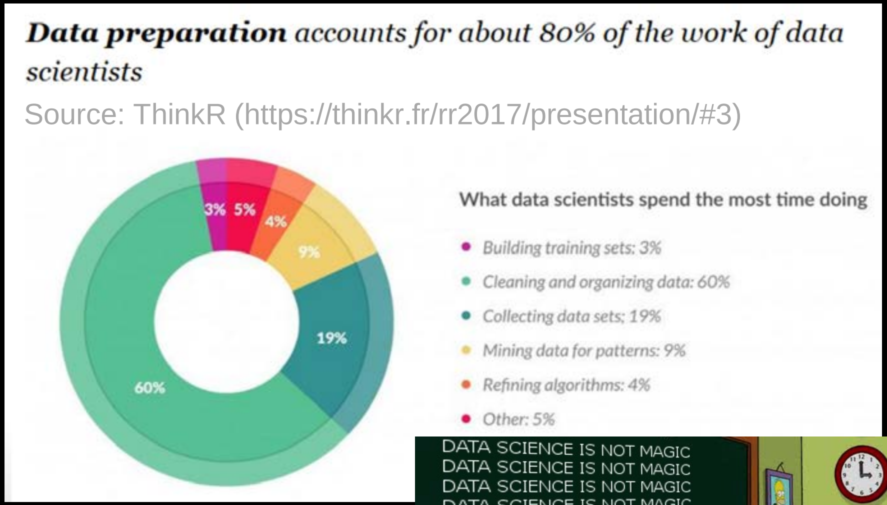
- France, Germany, UK, Denmark, Netherlands, Italy
- 42 field experimentations, in 15 sites and 16 years
- 153 intercrops combinations and ~ 10.000 plots
- Measured traits: biomass, height, LAI, N…dynamically



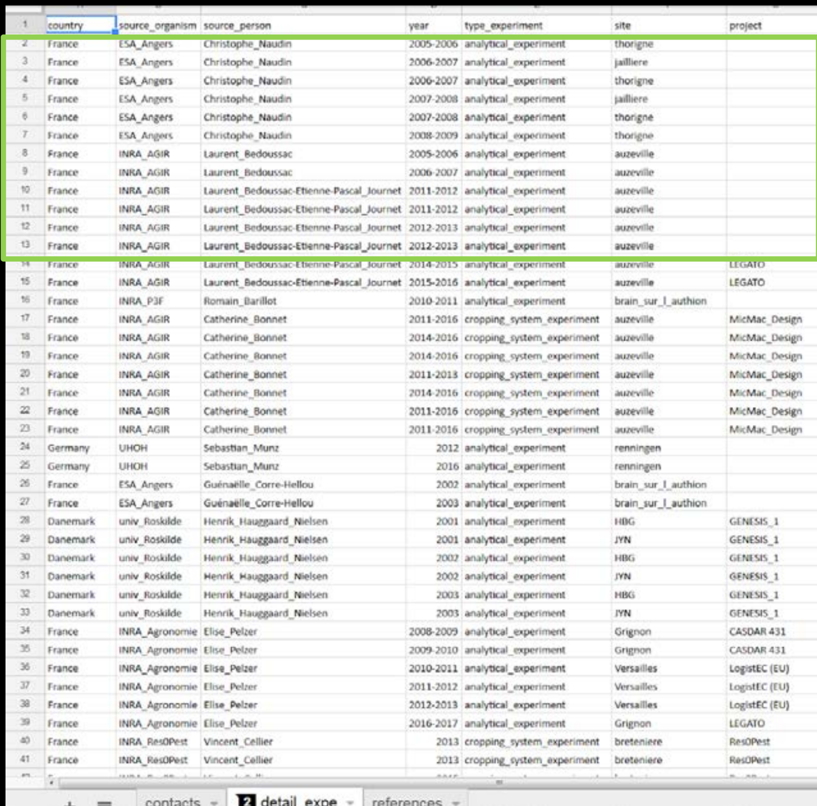
↓

Data-driven models (empirical)

"intelligent": driven by ecological concepts

= mobilize agronomic and ecological knowledge to define integrative variables that are considered important for the performance of the modeled system

Preliminary results on a data subset



	country	source_organism	source_person	year	type_experiment	site	project
2	France	ESA_Angers	Christophe_Naudin	2005-2006	analytical_experiment	thorigne	
3	France	ESA_Angers	Christophe_Naudin	2006-2007	analytical_experiment	jailliere	
4	France	ESA_Angers	Christophe_Naudin	2006-2007	analytical_experiment	thorigne	
5	France	ESA_Angers	Christophe_Naudin	2007-2008	analytical_experiment	jailliere	
6	France	ESA_Angers	Christophe_Naudin	2007-2008	analytical_experiment	thorigne	
7	France	ESA_Angers	Christophe_Naudin	2008-2009	analytical_experiment	thorigne	
8	France	INRA_AGIR	Laurent_Bedoussac	2005-2006	analytical_experiment	auzeville	
9	France	INRA_AGIR	Laurent_Bedoussac	2006-2007	analytical_experiment	auzeville	
10	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2011-2012	analytical_experiment	auzeville	
11	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2011-2012	analytical_experiment	auzeville	
12	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2012-2013	analytical_experiment	auzeville	
13	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2012-2013	analytical_experiment	auzeville	
14	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2014-2015	analytical_experiment	auzeville	LEGATO
15	France	INRA_AGIR	Laurent_Bedoussac-Etienne-Pascal_Journet	2015-2016	analytical_experiment	auzeville	LEGATO
16	France	INRA_P3F	Romain_Barillot	2010-2011	analytical_experiment	brain_sur_l_authion	
17	France	INRA_AGIR	Catherine_Bonnet	2011-2016	cropping_system_experiment	auzeville	MicMac_Design
18	France	INRA_AGIR	Catherine_Bonnet	2014-2016	cropping_system_experiment	auzeville	MicMac_Design
19	France	INRA_AGIR	Catherine_Bonnet	2014-2016	cropping_system_experiment	auzeville	MicMac_Design
20	France	INRA_AGIR	Catherine_Bonnet	2011-2013	cropping_system_experiment	auzeville	MicMac_Design
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22	France	INRA_AGIR	Catherine_Bonnet	2011-2016	cropping_system_experiment	auzeville	MicMac_Design
23	France	INRA_AGIR	Catherine_Bonnet	2011-2016	cropping_system_experiment	auzeville	MicMac_Design
24	Germany	UHOH	Sebastian_Munz	2012	analytical_experiment	renningen	
25	Germany	UHOH	Sebastian_Munz	2016	analytical_experiment	renningen	
26	France	ESA_Angers	Guénaëlle_Corre-Hellou	2002	analytical_experiment	brain_sur_l_authion	
27	France	ESA_Angers	Guénaëlle_Corre-Hellou	2003	analytical_experiment	brain_sur_l_authion	
28	Danemark	univ_Roskilde	Henrik_Hauggaard_Nielsen	2001	analytical_experiment	HBG	GENESIS_1
29	Danemark	univ_Roskilde	Henrik_Hauggaard_Nielsen	2001	analytical_experiment	JYN	GENESIS_1
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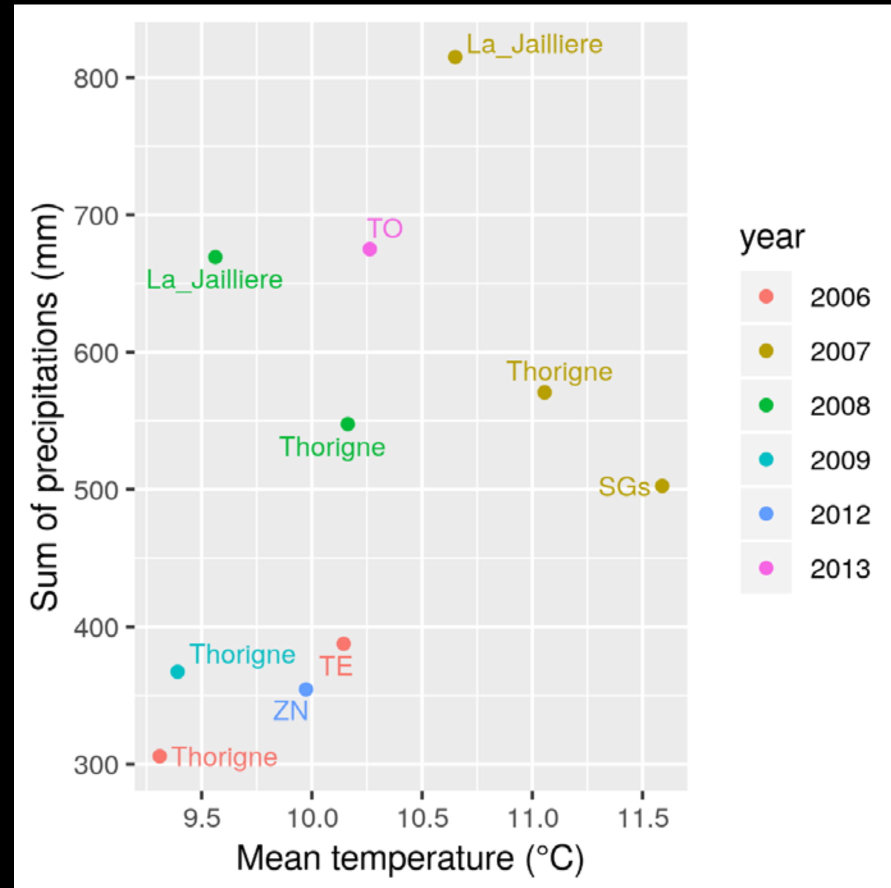
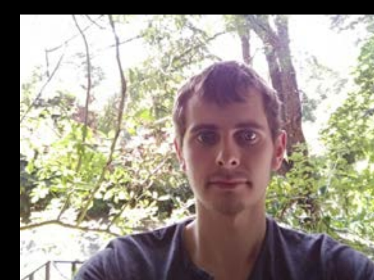


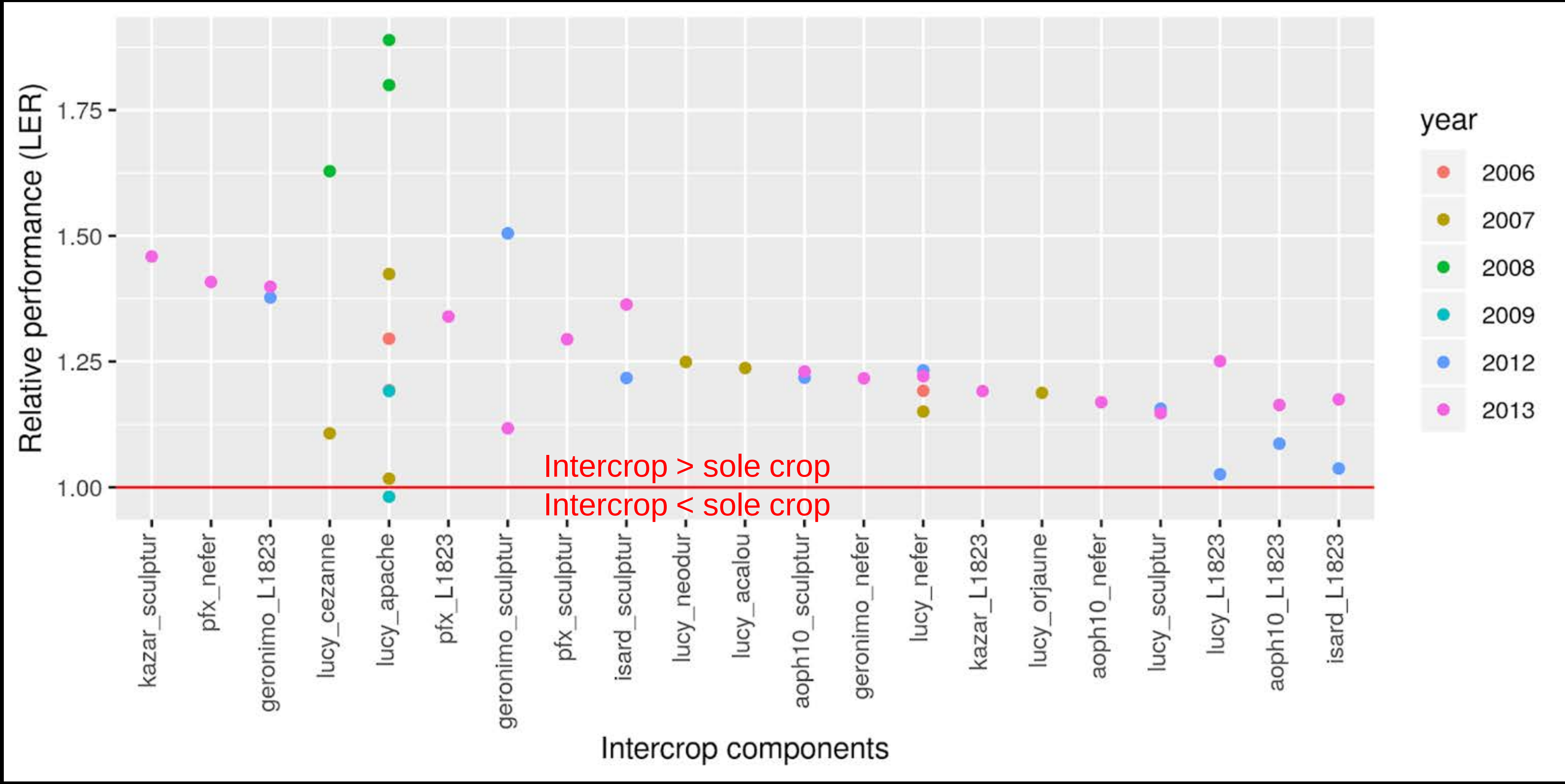
Data subset:

- 10 experiments in France (two sites: INRA AGIR, ESA Angers)
- 6 years
- 40 intercrops combinations of wheat and pea



Rémi Mahmoud
(internship Master 2, 2018)

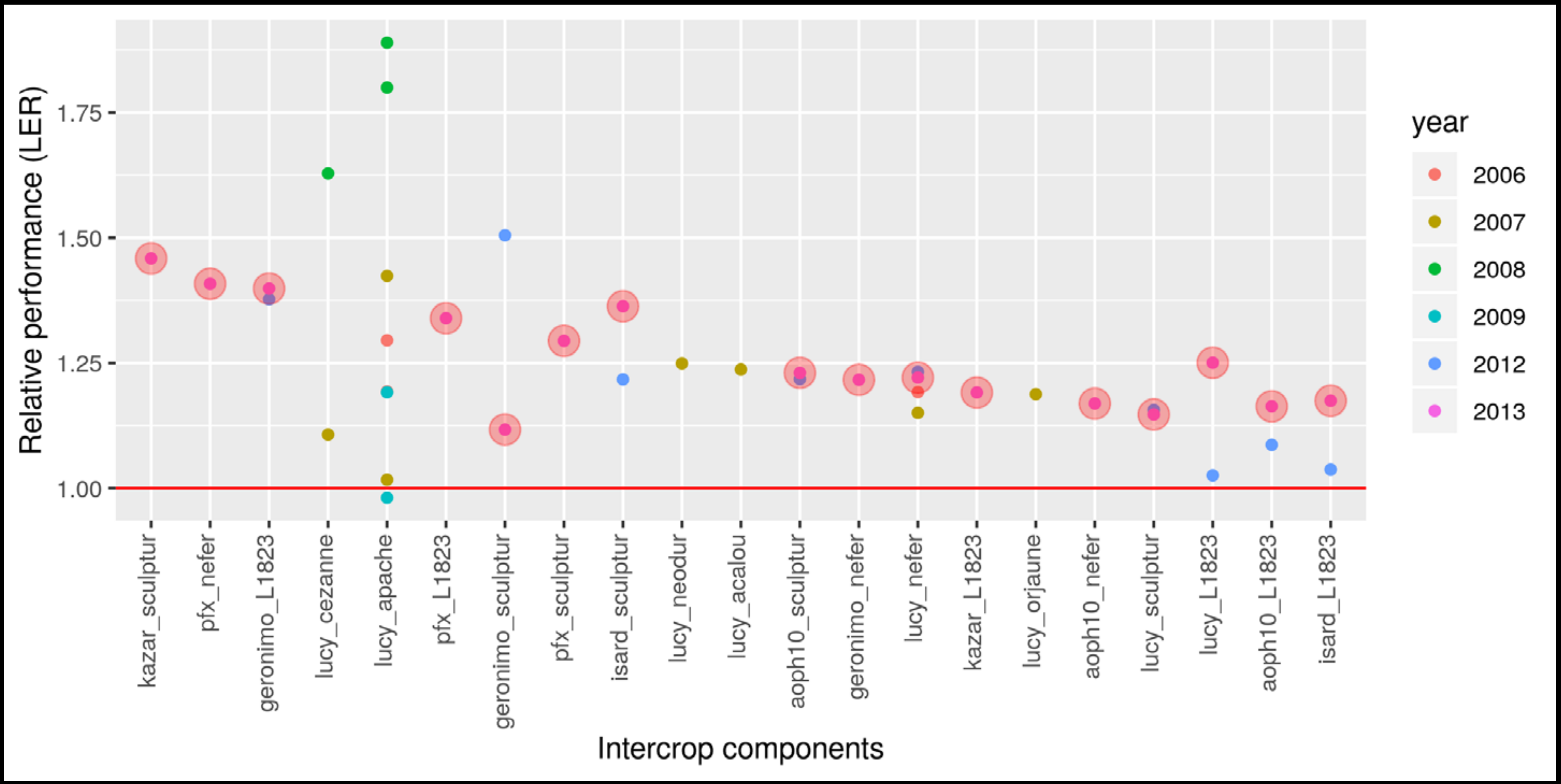
Successful but variable performance of intercrops in low input contexts



$$LER_{trait} = \frac{trait_{ICi}}{trait_{SCi}} + \frac{trait_{ICj}}{trait_{SCj}}$$

SC, sole crop
IC, intercrop

Successful but variable performance of intercrops in low input contexts



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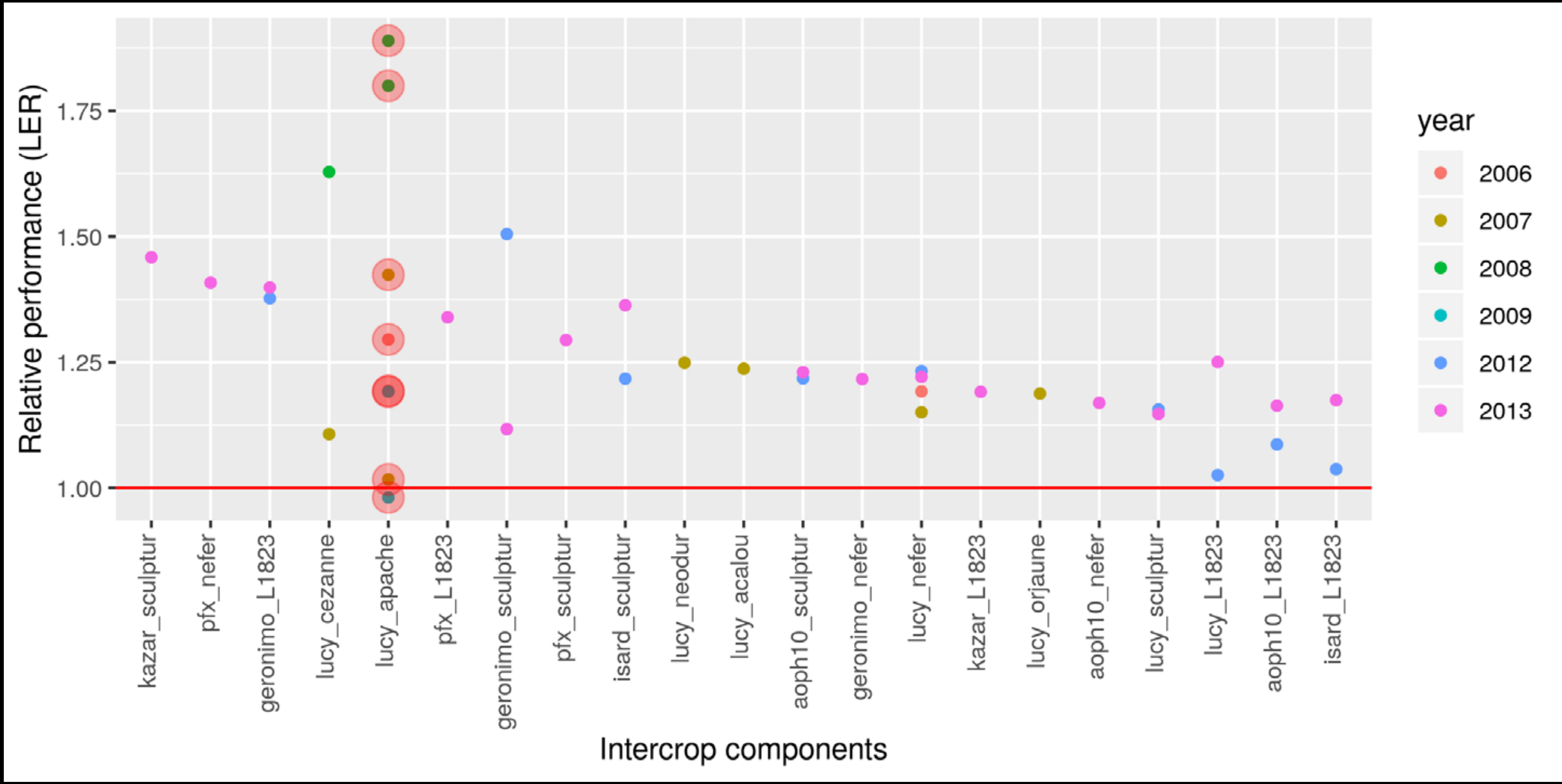
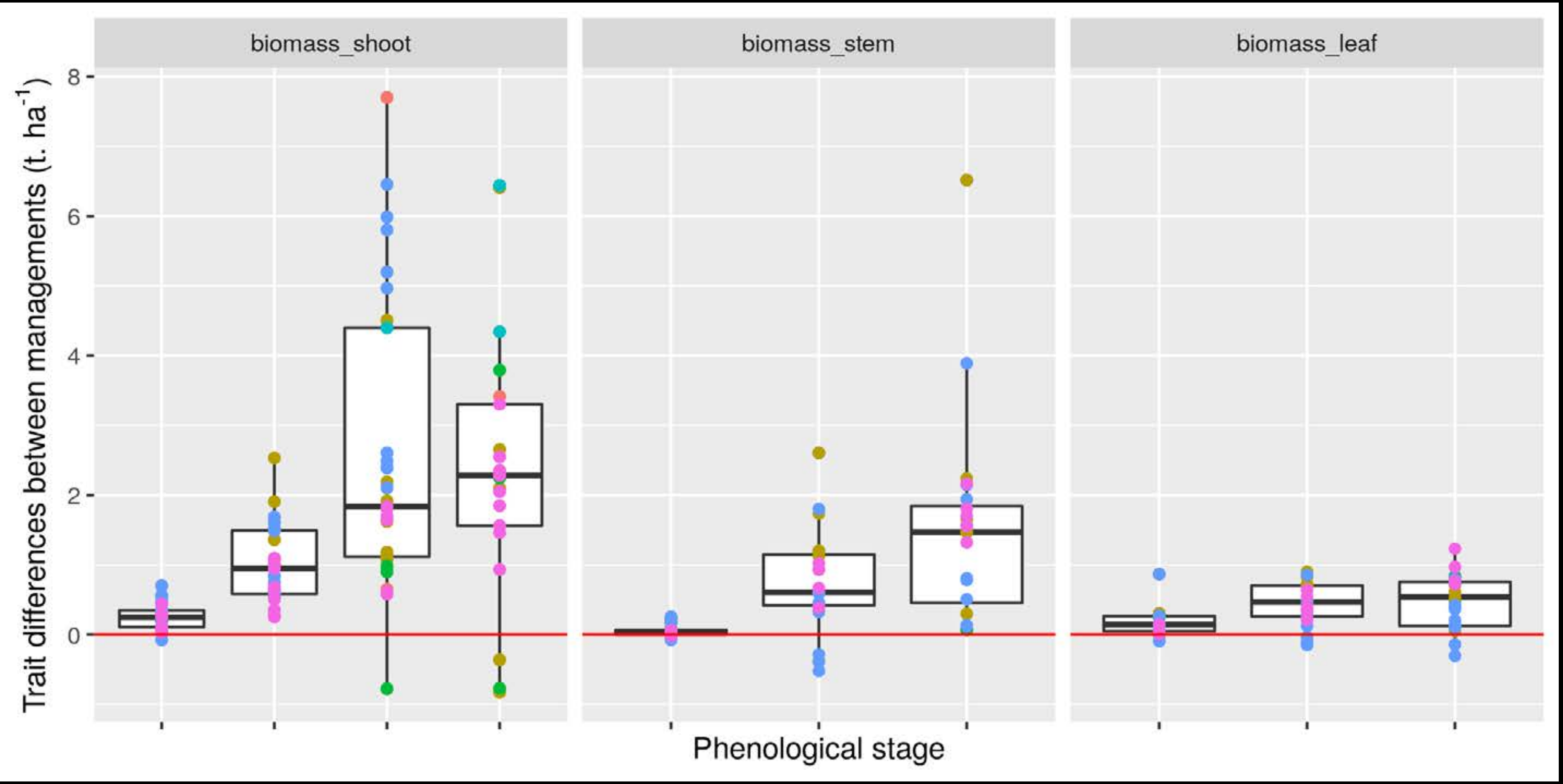


$$LER_{trait} = \frac{trait_{ICi}}{trait_{SCi}} + \frac{trait_{ICj}}{trait_{SCj}}$$

SC, sole crop
IC, intercrop

Effect of mixtures on species characteristics (plasticity)

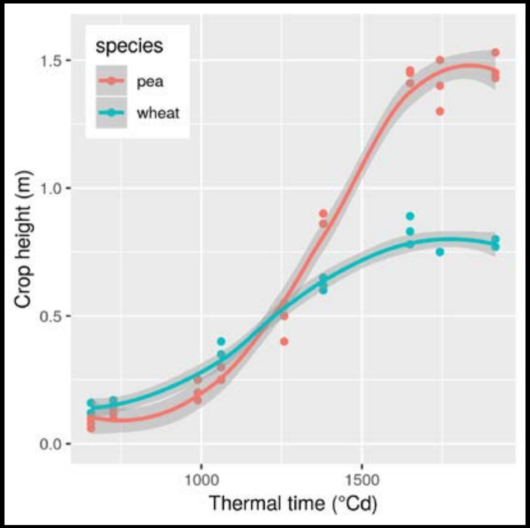
Species adapt strongly when growing in intercrop (illustration for wheat)



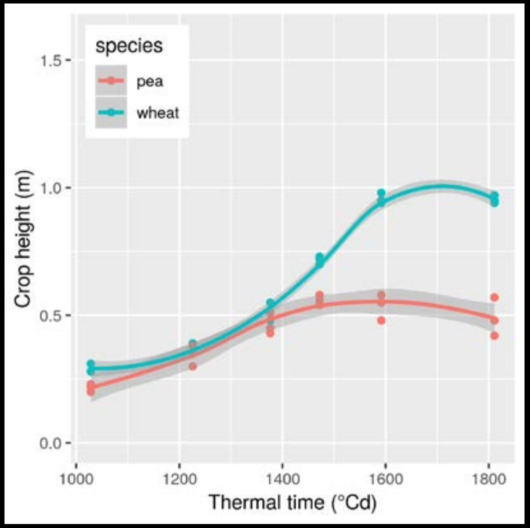
$$\Delta trait_{(intercrop, sole\ crop)} = trait_{intercrop} - trait_{sole\ crop}$$

Differences between species within intercrops (inter-specific divergence)

pea > wheat



pea < wheat



Differences between species within intercrops (inter-specific divergence)

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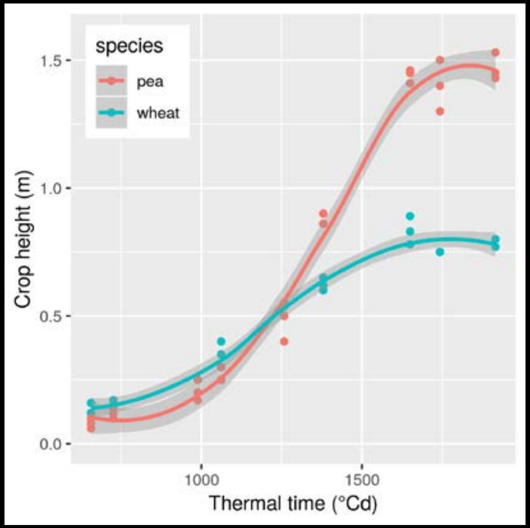
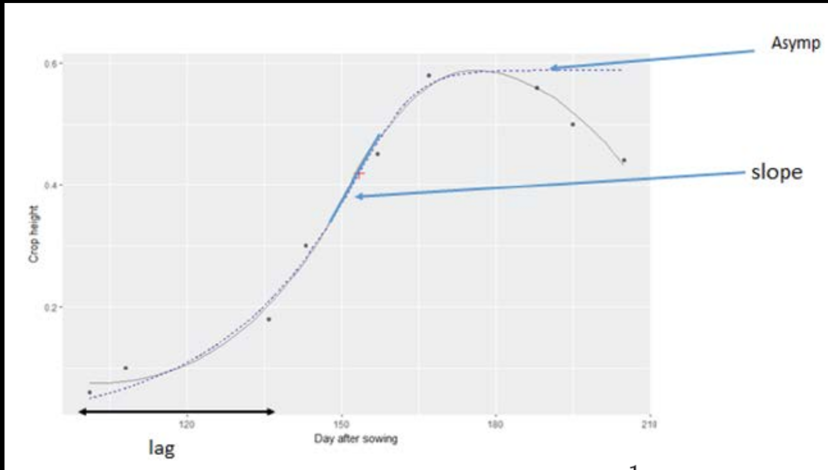
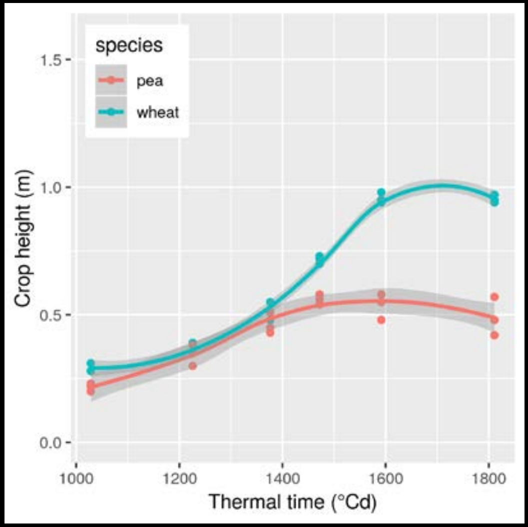


curve parameters



$$f(t) = \text{Asymp}\left[1 + v e^{1+v+\frac{\text{slope}}{\text{Asymp}}(1+v)^{1+\frac{1}{v}}(\text{lag}-t)}\right]^{-\frac{1}{v}}$$

pea < wheat

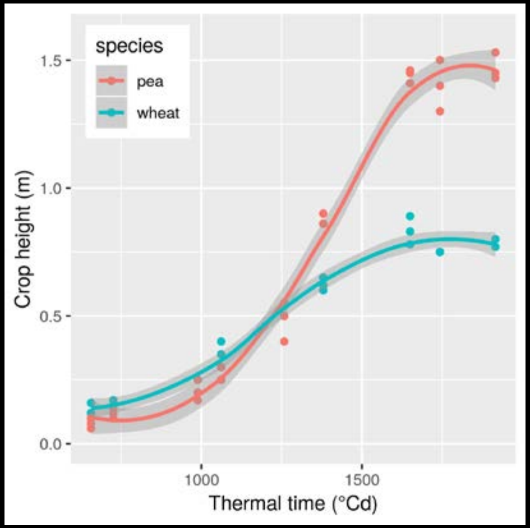


$$\Delta trait_{(wheat,pea)} = trait_{wheat} - trait_{pea}$$

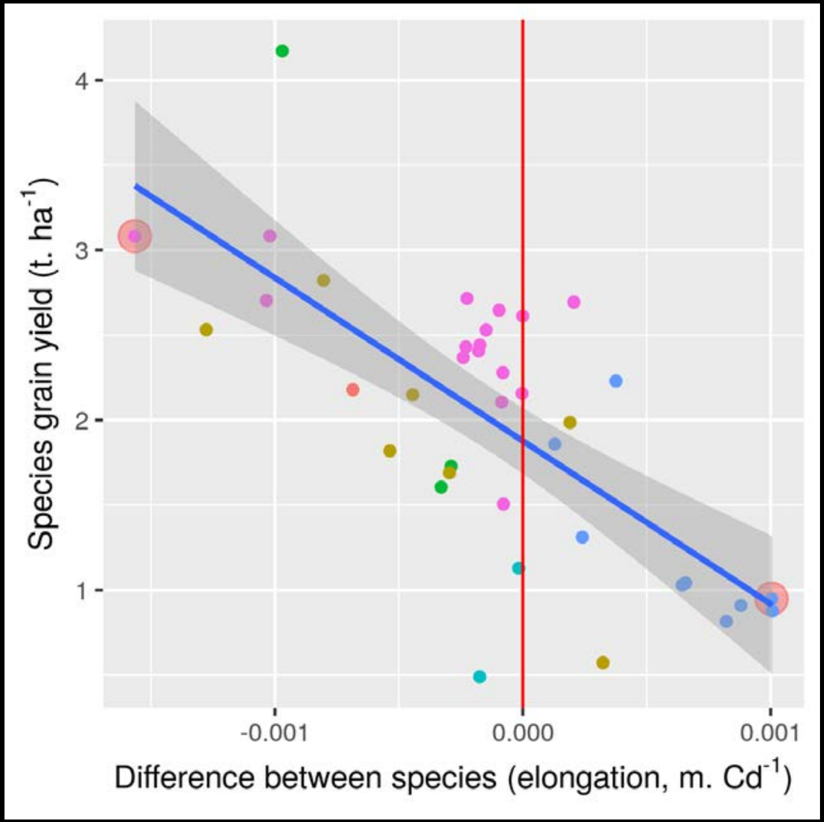
Performance of a species according to the difference between species

In intercrop, pea performance is linked to growth strategies (predictors)

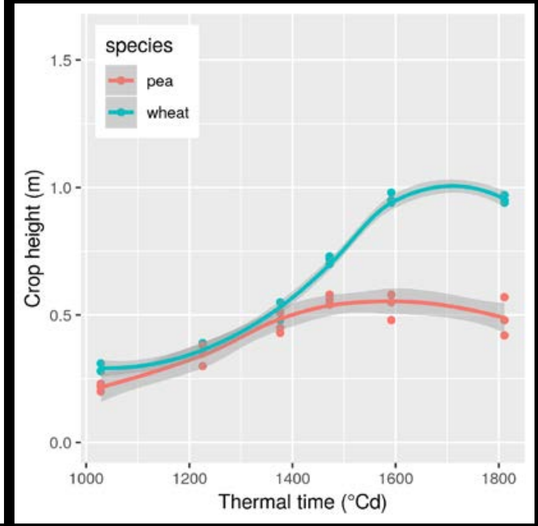
pea > wheat



pea yield



pea < wheat

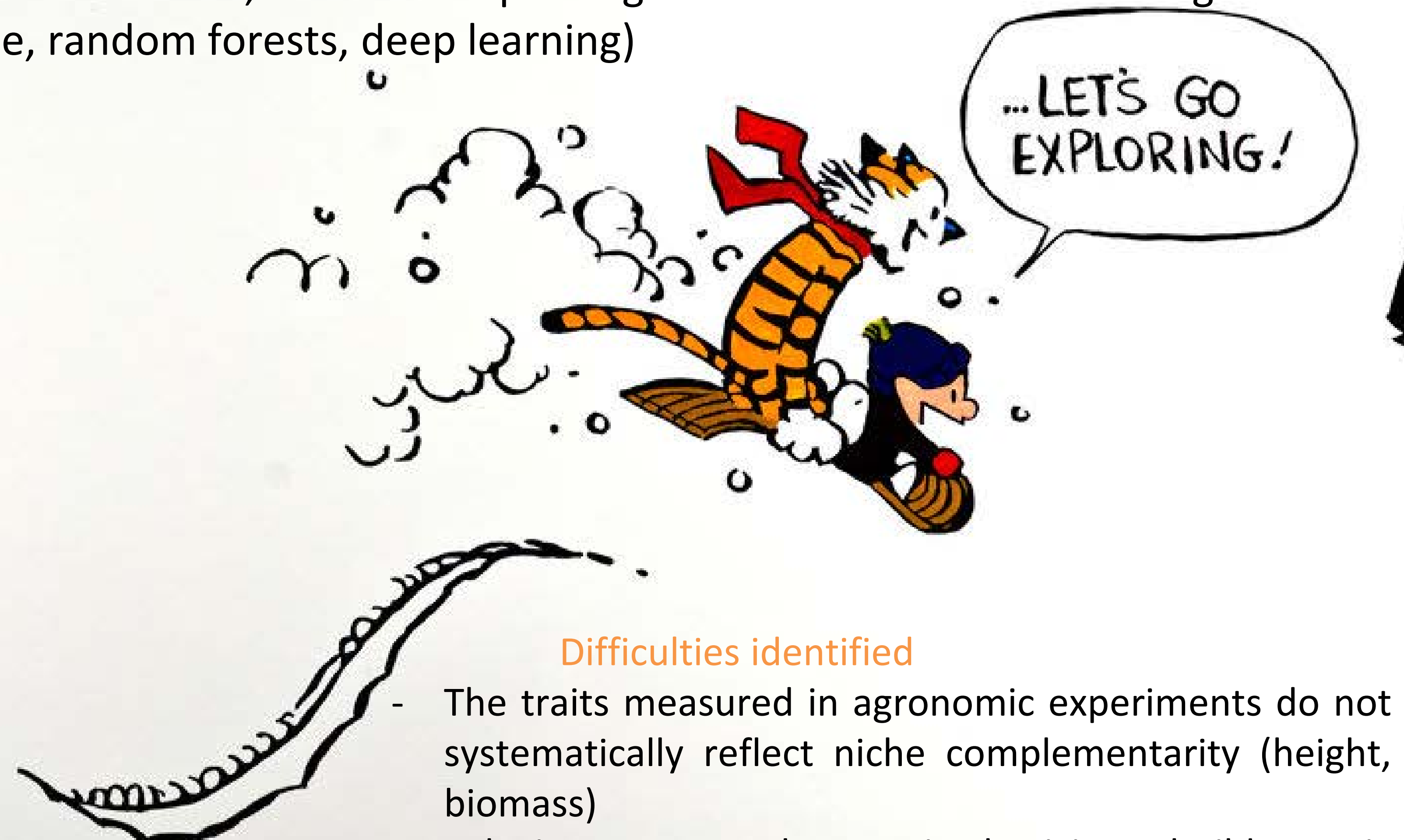


$$Yield_{pea} = f(growth\,rate_{wheat} - growth\,rate_{pea})$$

Still a lot of work

Identify other variables linked to the cover functioning + other mixtures

→ Develop the models, from multiple regression to machine learning (decision tree, random forests, deep learning)



Difficulties identified

- The traits measured in agronomic experiments do not systematically reflect niche complementarity (height, biomass)
- Take into account phenotypic plasticity to build generic assembly rules for different cropping conditions

Perspectives

Still a lot of work

Identify other variables linked to the cover functioning + other mixtures

→ Develop the models, from multiple regression to machine learning (decision tree, random forests, deep learning)

For the photographs, thanks to G Corre-Hellou, J Evers (univ. Wageningen), C Bonnet (INRA), L Bedoussac

Difficulties identified

The traits measured in agronomic experiments do not systematically reflect niche complementarity (height, biomass)

Take into account phenotypic plasticity to build generic assembly rules for different cropping conditions