

Designing and Evaluating Prototypes of Arable Cropping Systems with LEGUME SOLE CROPPING or INTERCROPPED Aimed at Improving N Use Efficiency *in Low Input Farming*

*Justes E., Hauggaard-Nielsen H., Bedoussac L., Corre-
Hellou G., Jeuffroy M-H., Nolot J-M., and E.S. Jensen*

 **INRA** Toulouse, Grignon (France)

 **ESA** Angers (France)

 **RISO** Roskilde (Denmark)

 **SLU** Alnarp (Sweden)



Introduction (1)

- Increasing concern about climate change and environmental impacts require transformation of actual cropping systems focusing on enhanced sustainability (e.g. decrease the use of inputs)
- A solution could consist in increasing the diversification of crops across the European countries, e.g. by implementing more legumes crops (Malézieux et al., 2008)
- In Europe, rotations including legumes and organic sources of N have been largely replaced with synthetic N fertilizers while increasing the benefits from N₂-fixation and rotational break-crop effects for cereal diseases could reduce the use of fossil inputs (Crew and Peoples, 2004)



Introduction (2)

- Needs for **re-designing cropping systems** in order to **increase the proportion of legume crops** in arable cropping systems in Europe
→ How to integrate grain legume for improving the cropping system efficiency in low input farming?
- Growing cereal and legume in **intercrops** could be a solution (rarely cultivated in Europe excepted for animal feed), due to the fact:
 - Spring cereal-legume intercrops enhance global yield compared to sole crops in low input systems (e.g. Hauggaard-Nielsen et al. 2003; Corre-Hellou, 2006) because the species do not compete for the same resource niche and then use N sources in complementary way (e.g. Hauggaard-Nielsen & Jensen, 2001)
 - But, no reference were available for **winter cereal – grain legume intercrops** despite these crops better adapted to Southern European conditions (Bedoussac & Justes 2009)

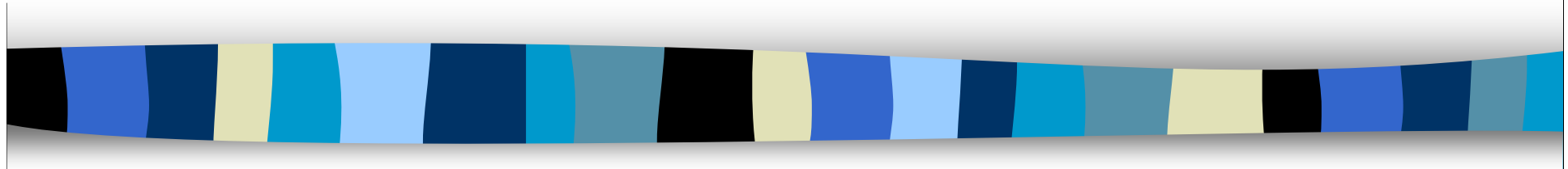


Objectives

- The main objective of our presentation is to propose two ways of research to **re-design cropping systems with the objective of maximizing the benefit from leguminous N₂ fixation** in low N input systems and reduce environmental impacts
- Our presentation will illustrate in 2 parts:
 1. the design and evaluation of **prototypes of arable systems including legumes** using jointly medium-term field experiments together with crop modelling at the rotation time scale
 2. the **potential of intercrops** for improving the global yield (land equivalent ratio) and protein content of durum wheat

Part 1.

Cropping system with grain legumes (sole cropping)



6-yr field experiment was initiated at INRA
Toulouse (SW France) from autumn 2003 to
study the **rotational effects of grain legumes**
and **cover crops** according to N use efficiency
and medium-term soil fertility

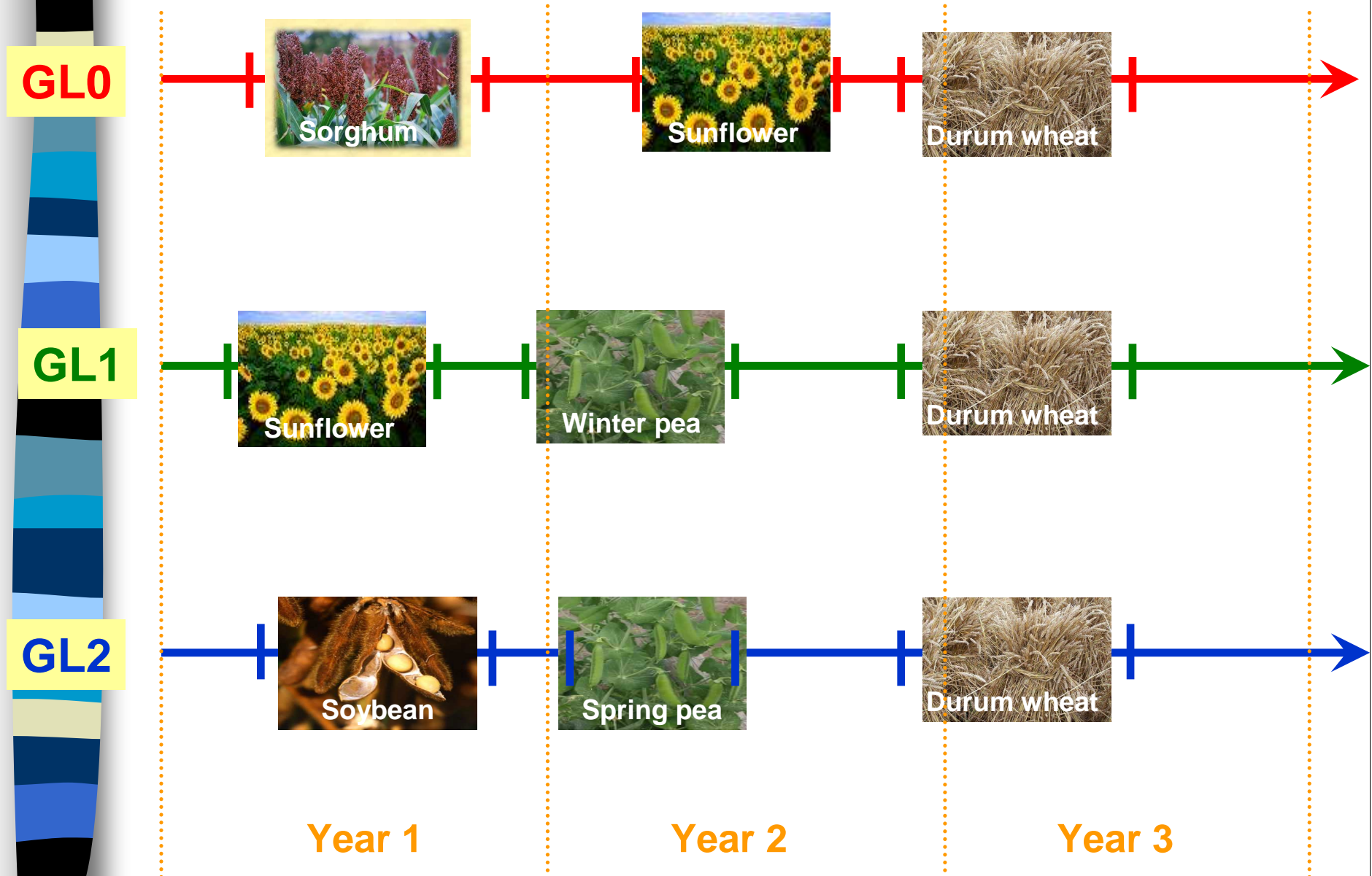


Material and methods (1)

- Cropping system prototypes design was based on a 3-yr rotation in low input system based on the number of grain legume (GL) in the rotation with each crop of the rotation grown each year (“climatic repetition”)
- Cover crop (CC) as green manure or catch crop
- 6 rotations were compared considering the presence or absence of cover crop between cash crops
- Crop management was based on decision rules (Nolot and Debaeke, 2003): i.e. adjustment of technical acts to the soil and crop status (e.g. adjusting N rates to the preceding crop)
- Analyse of dynamical water and nitrogen budgets at the rotation time scale: use of STICS soil-crop (Brisson et al., 1998; 2003; 2009)

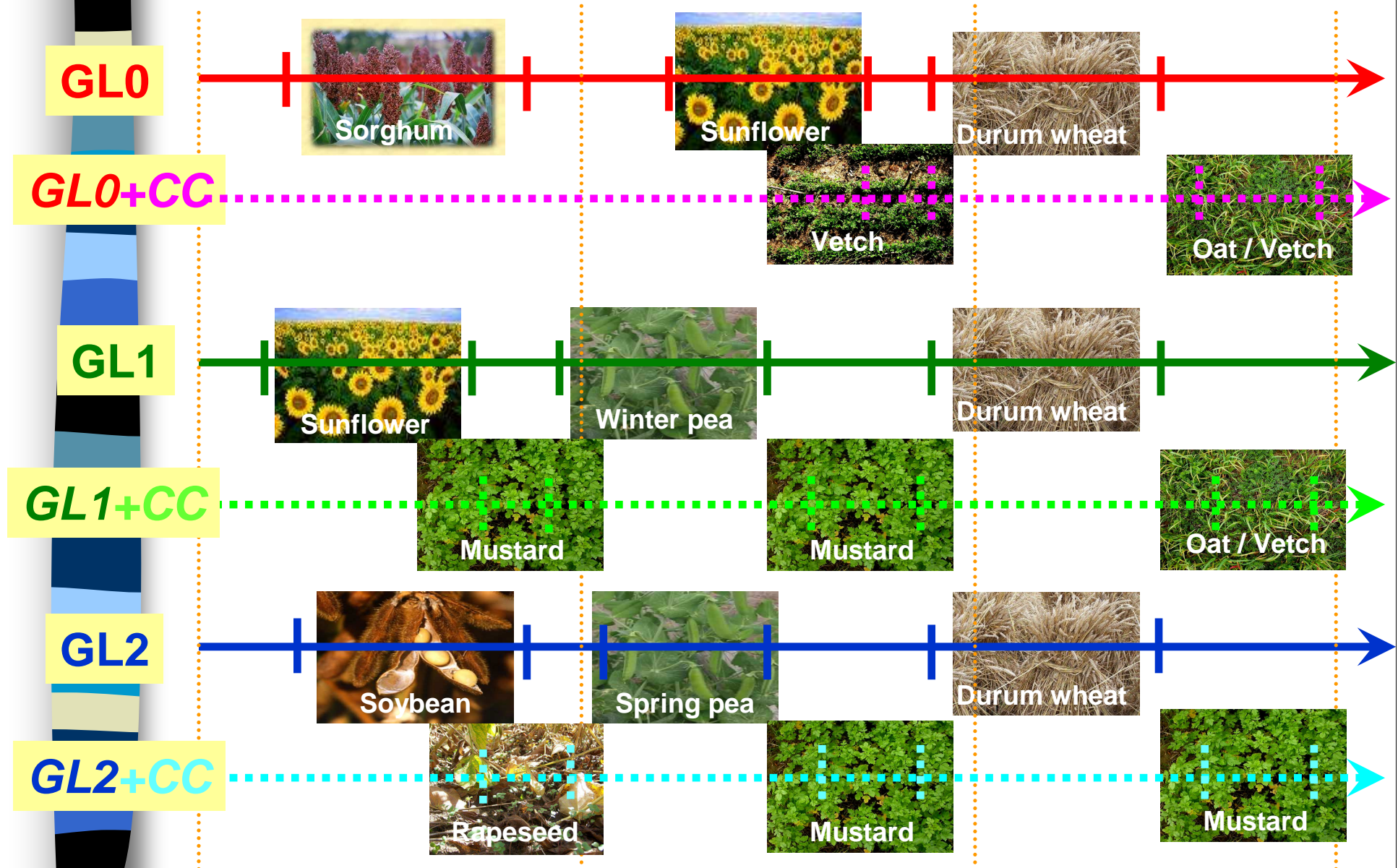
Material and Methods (2)

Cropping system exp. at INRA Toulouse (France)

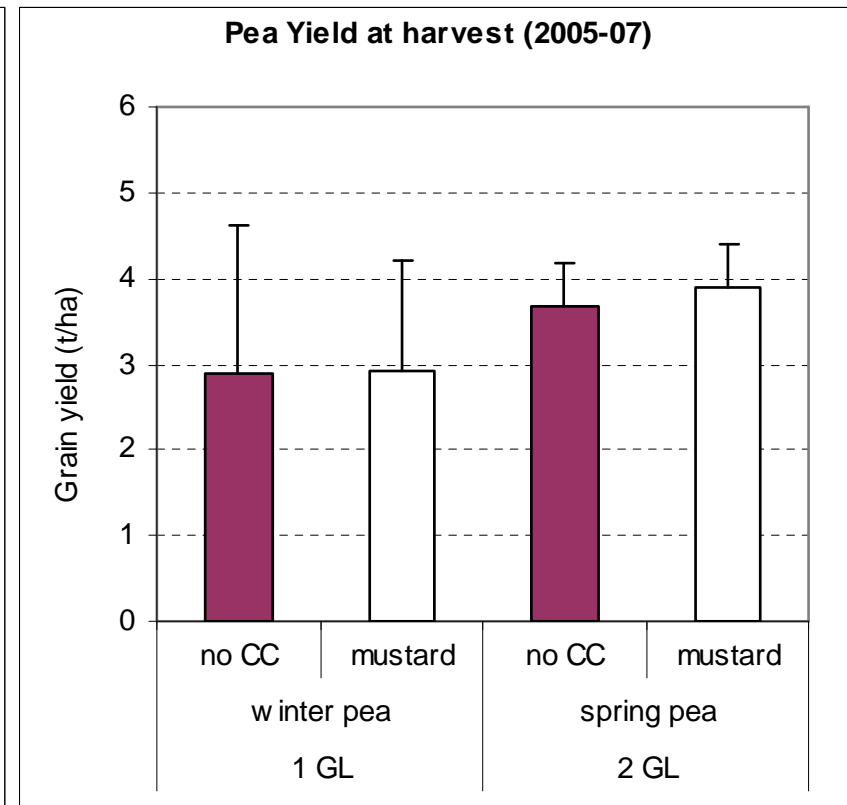
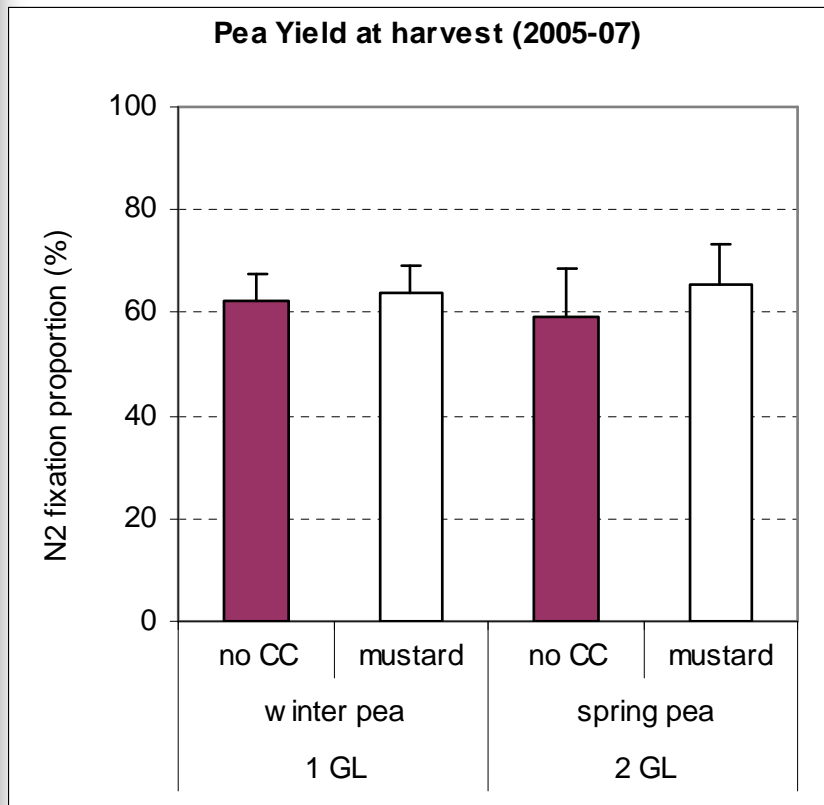


Material and Methods (2)

Cropping system exp. at INRA Toulouse (France)

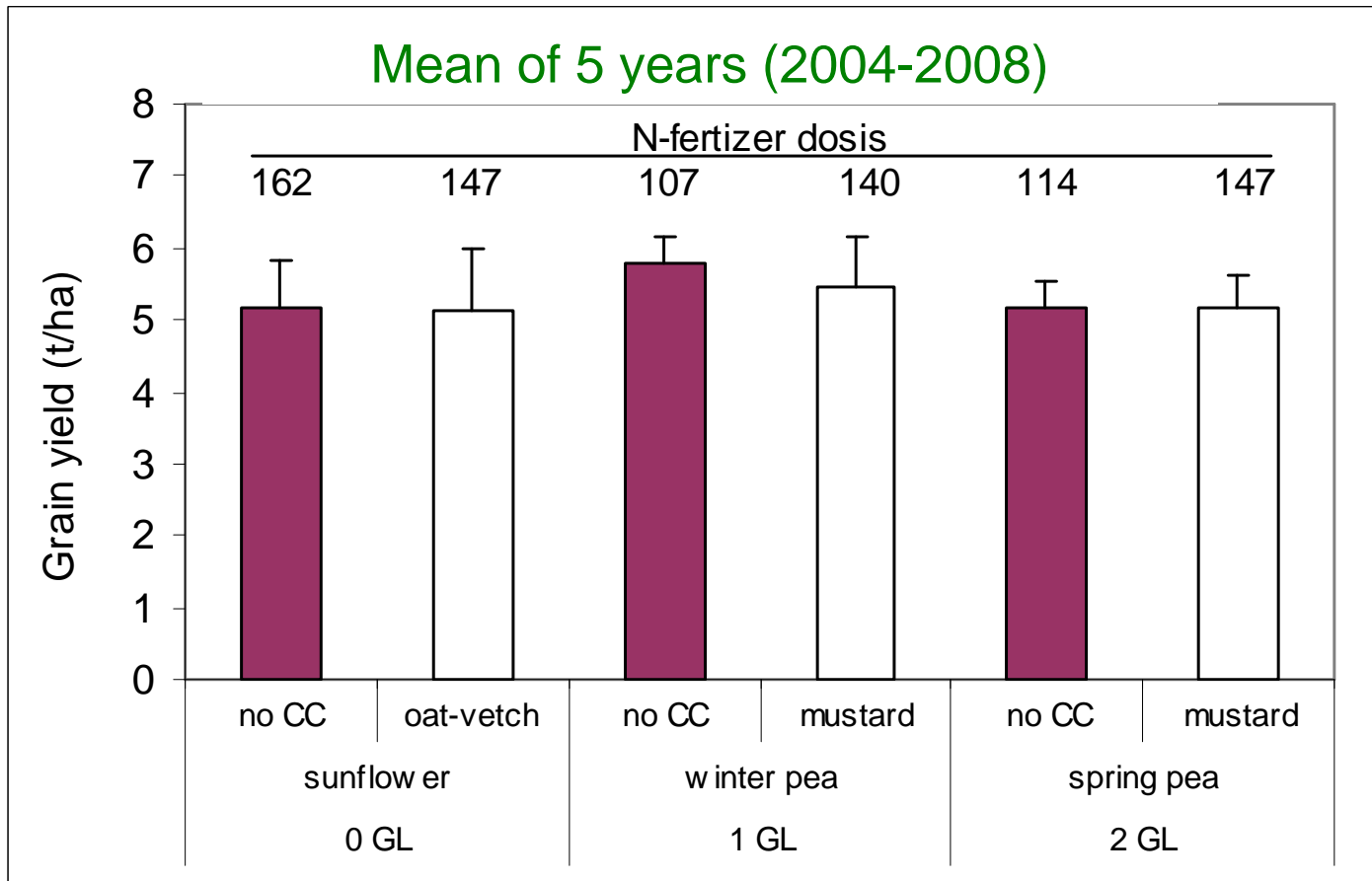


Results (1): Pea N₂ fixation and grain yield



- The N₂ fixation represented 60 to 65% of N acquired without large variation between years
 - Winter pea less efficient (high variability between years) than spring pea: **pests & diseases more detrimental than water stress** after flowering
- Spring pea better adapted to low input farming in Southern France

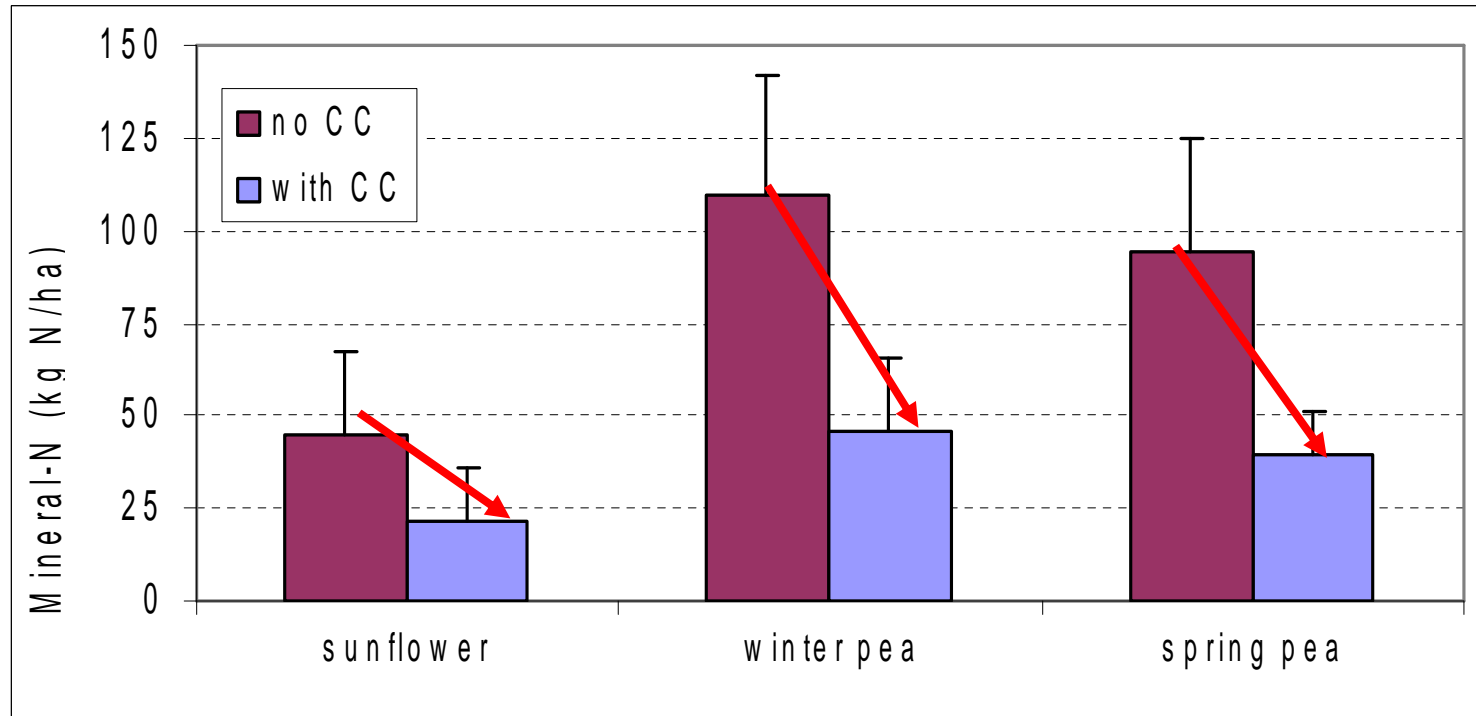
Results (2): Durum wheat yield & fertilizer-N dosis



- Yield of durum wheat was higher after winter pea: **this confirms well known results with grain legume as a preceding crop**
- N release from catch crop residues was not always sufficient to compensate the pre-emptive competition for soil mineral-N when grown between pea harvest and wheat sowing, **so the rate of fertilizer-N must be increased to reach the same target yield...**

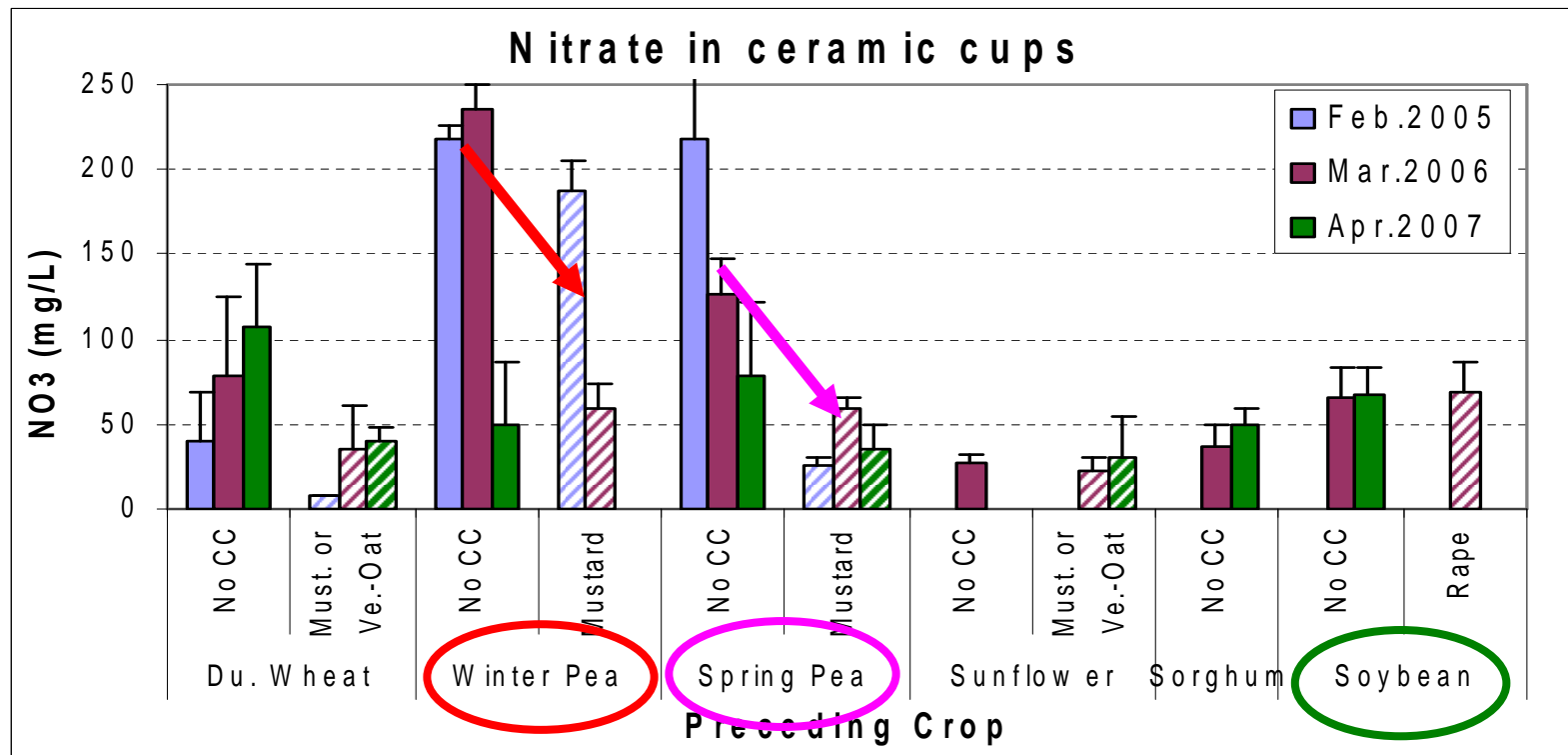
Results (3): Measured mineral-N in soil at wheat sowing (mid-November = start of drainage period)

Effect of catch crop (mean of 5 years exp.)



- **Higher soil N availability after pea: +50 kg N/ha**
- **Significant effect of CC to decrease mineral-N** at the beginning of drainage period in particular after pea crops
- **Mustard very efficient to uptake soil mineral-N** during few weeks (sown end of August and incorporated in November)

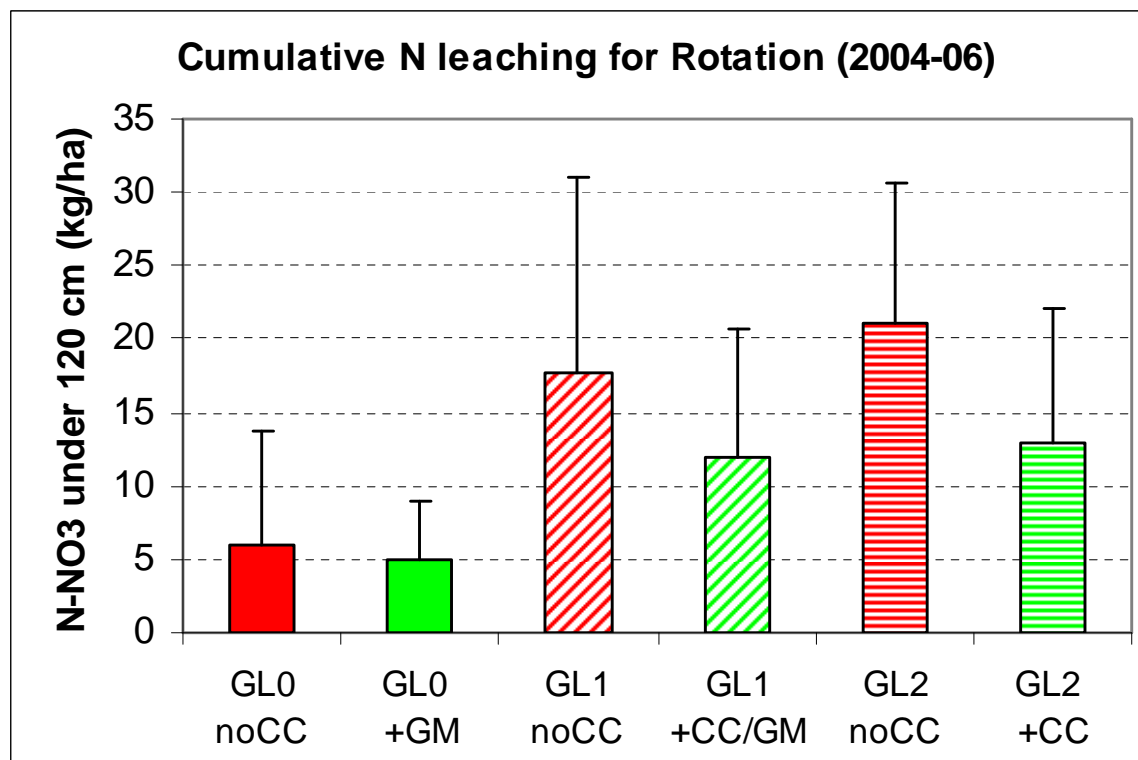
Results (4): Nitrate concentration in soil solution (ceramic cups at 125 cm depth)



- Higher NO₃ concentration after pea crops: *N needed to be managed in order to limit N leaching after GL with catch crops*
- Instantaneous data that needed to be integrated at the rotation level: *use of the STICS soil-crop model*

Results (5): Nitrate leaching

Data coming from STICS simulation (rotation scale)



Bars represent Standard deviation taking into account the 3 crops of the rotation (each crop is represented each year)

- 3 dry winters which lead to low drainage fluxes
- N leaching (and nitrate concentration in water drainage) higher after GL in particular with pea (not after soybean...)
- CC efficient to decrease nitrate losses and green manure did not increase the risk of N losses

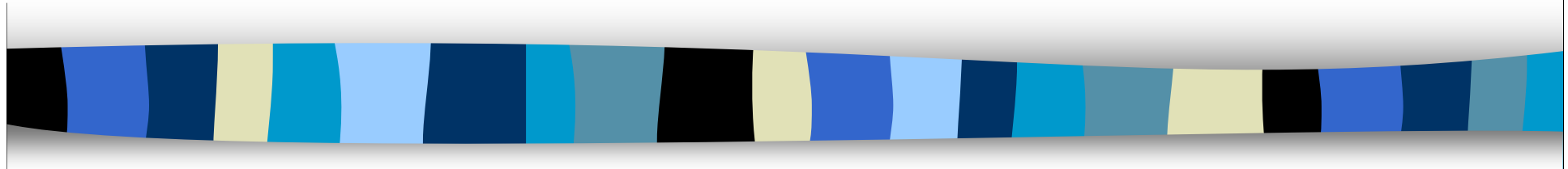


Discussion

- In our conditions, grain legume sole cropping did not always lead to decrease the use of inputs (except for N) due to the sensitivity of pea to pests (aphids, weevils) and diseases (anthracnose) ...
- The higher N availability after pea must be carefully manage to avoid high level of nitrate leaching: **then it is not sufficient to introduce grain legumes in cropping systems but this is a need for adapting the whole cropping system to well valorise N₂ fixation,**
 - Firstly, by reducing the N losses: catch crops are efficient but need to be carefully manage to avoid N pre-emptive competition for the succeeding crop
 - What about N₂O emissions?
 - Secondly, by designing rotations (including cash and cover crops) in order to valorise N availability from N₂ fixation
 - And, by choosing well adapted species and cultivars of GL
 - ...

Part 2.

Cereal – legume intercrops



Experiments with intercrops of various cereals (winter soft wheat or durum wheat **used for human consumption**) and grain legume (winter pea or fababean) were carried out in order to analyse their functioning and understand results with the objective of improving crop management systems of intercrops



Material and methods

- Various winter cereal – legume intercrop experiments carried out in France in different locations (INRA Toulouse & Grignon, ESA Angers, other locations):
 - Durum wheat – Winter pea
 - Durum wheat – Fababean
 - Winter wheat (soft baking wheat) – Winter pea
- Various wheat cultivars
- Various N availabilities (preceding crop, amount and application date of fertilizer-N)
- Analyse of yield, protein content and LER (Land Equivalent Ratio)

Results (1): LER and Protein concentration

Partial and total Land Equivalent Ratio (LER)

	LER _p P	LER _p W	LER _{total}
N0	0.51 (0.09)	0.72 (0.10)	1.23 (0.18)
N100	0.59 (0.03)	0.60 (0.10)	1.19 (0.11)
N180	0.38 (0.00)	0.70 (0.13)	1.08 (0.13)

Protein concentration in grains

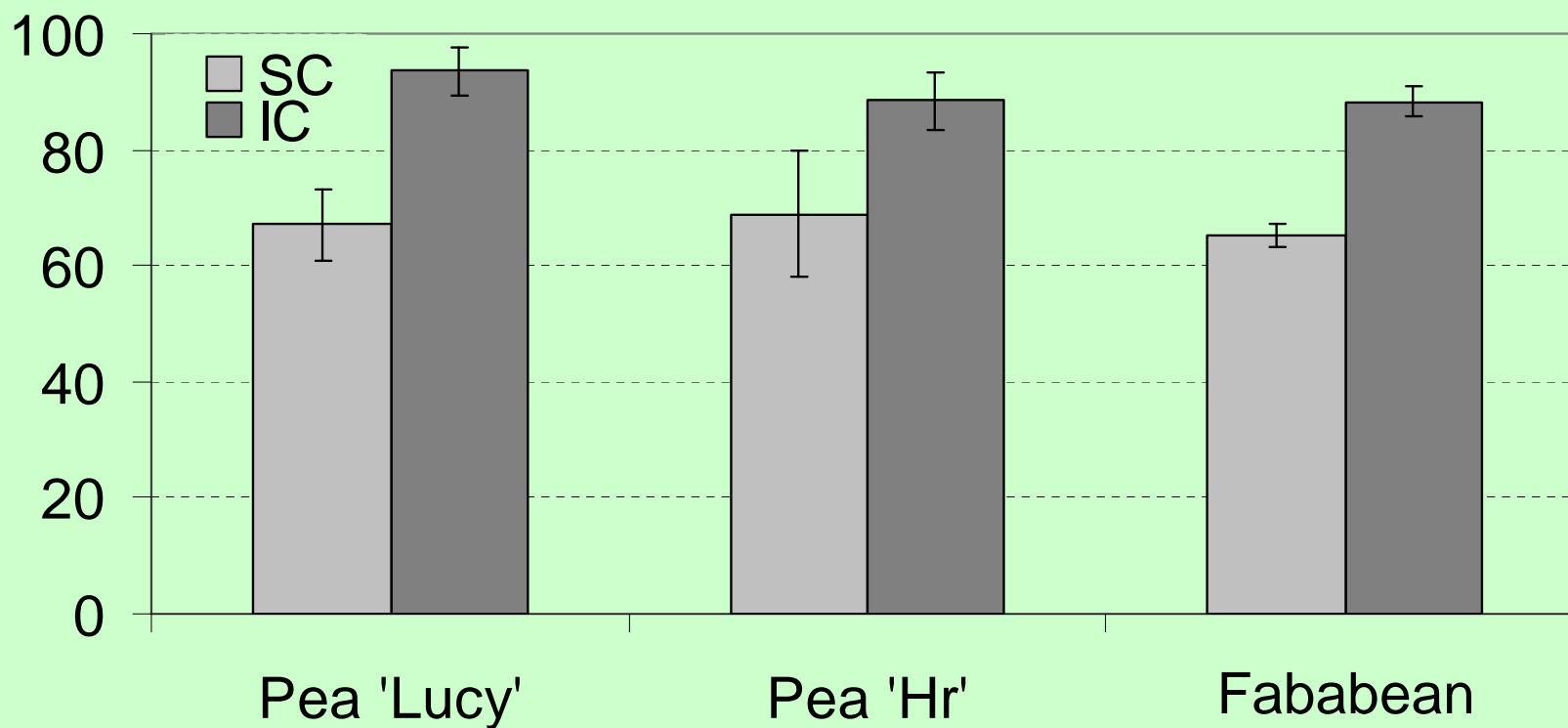
	W Sole Crop	W Intercrop
N0	8.1 (0.3)	10.7 (1.4)
N100	13.1 (0.3)	14.0 (0.7)
N180	13.6 (0.9)	13.4 (0.8)

Bedoussac and Justes (2009)

- Intercropping is more efficient in low N input systems: **the more the N availability at the start of the intercrop, the less the LER** (intercrop use efficiency of resources)
- But late fertilizer-N application (after pea flowering) did maintain the LER and protein concentration increases

Results (2): N acquisition

% Ndfa (N derived from air in % of N acquired) – Treatment N0



% Ndfa was higher in Intercrop than in Sole Crop for all grain legumes evaluated

→ **Complementary use of soil mineral N and symbiotic N₂ fixation sources in InterCrop**



General Discussion and Conclusion

- Further work is needed in order to better exploit sole grain legume advantages in particular to design new cropping systems including grain legumes and then:
 - **Better use N availability due to grain legume by sowing catch crop in order to limit nitrate leaching and increase the N efficiency at the rotation level**
 - **Analyse the potential of intercrops to reduce grain legume pests and diseases damages which are tedious problems in low input farming and organic farming**
- A number of factors still needs to be optimized before the full potential of cereal-grain legume intercropping systems can be appropriately, such as:
 - **Intercrop efficiency according to N availability in dynamics**
 - **Grain legume species and cultivars adaptations**
 - **Sowing practice (alternate rows or mixture within each row)...**
 - **Harvest: adjustment of beating**
 - **Post-harvest: separation between wheat and legume grains**
- **BUT**, the correct rotational position of intercrops need to be analysed in order to propose relevant solutions, without increasing pests and diseases...

Thanks for your attention



Acknowledgments

This work was supported by
EU-GLIP and our research/university institutions:

