Intercropping cereal and grain legume:10 years of experiments from field to plate

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Intercropping cereal and grain legume

10 years of experiments from field to plate

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International Workshop of Intercropping for Agronomy and Ecology

19-21th August 2015 ; Xi'an ; China

An evolution of ours questions, objectives and positionning

Evaluating the functionning and the efficiency of intercrops	2006	Ecological intensification ???
Designing intercropping management	2008	
Designing cropping systems	2009 2010	Agrecological ingeniering ???
Designing sustainable supplychain	2011	
Towards a mobilisation of different actors, scales and disciplines	20XX	Agroecologie in action ???

PART 1 : Evaluating intercropping with an agronomic point of view

Analysing the functioning and efficiency of intercropping as an application of natural ecosystems ecology principles to a better use of ressources in time and space





Intercropping species to produce low input durum wheat and grain legumes

- Durum wheat : an important crop in south-west France
  - Traditional crop adapted to the climate
  - Important supply chain (farmers, collectors, industrials)
  - Needing large amounts of inputs (fertilizers and/or pesticides)

How to produce durum-wheat in a sustainable way ?

- Grain legumes : a strong deficiency in Europe
  - About 70% of protein deficit in Europe
  - No need for N fertilizer
  - Sensitive to pests needing pesticides

How to increase legume production to reduce N use ?

Is intercropping an « innovative » solution ?

IC = Simultaneous growth of two or more species in the same field for a significant period without necessarily sowing and harvesting them together (Willey 1979)





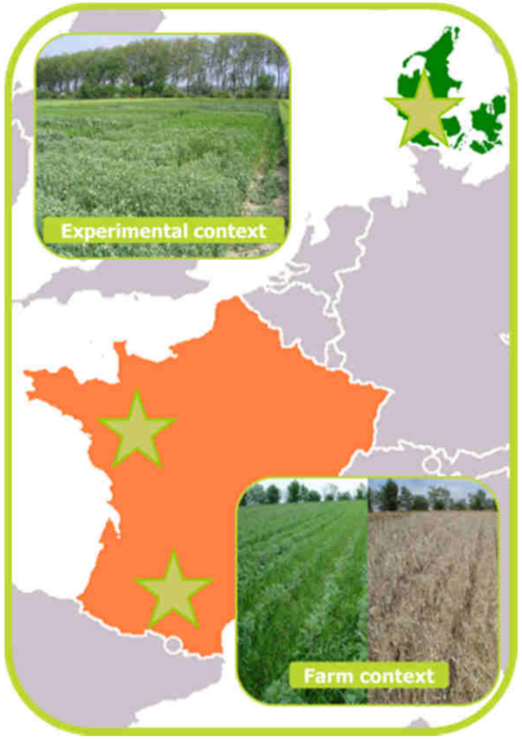
Interests of intercrops for low input systems

- Improve **cereal grain quality** (grain protein content)
  (Jensen, 1996; Hauggaard-Nielsen &al 2001a; 2009, Bedoussac & Justes, 2010a)
- Increase **global yield** (compared to low input sole crops)
  (Hauggaard-Nielsen &al 2001a; Zhan &al, 2010; Bedoussac & Justes, 2010a)
- Reduce **weeds** (compared to legume)
  (Hauggaard-Nielsen &al 2001b, Corre-Hellou &al, 2011)
- Potentially reduce **pests** (e.g.pea aphids) and **diseases**
  (hypothesis widely cited, e.g. Vendermeer, 1989; but no demontration published)
- Reduce the **nitrate leaching risk** (compared to sole legumes)
  (Hauggaard-Nielsen &al 2003; 2009, Bedoussac & Justes, 2010b)
- Increase **yield stability** (compared to sole crops)
  (hypothesis widely cited, e.g. Vandermeer, 1989; but no demonstration published)
- Increase or stabilise over years the farmer **gross margin**
  (Bedoussac, 2009; Pelzer &al, 2012)

Lots of references for cereal-legume IC (except winter crops)
Few limits highlighted by the scientific community

10 years of experiments

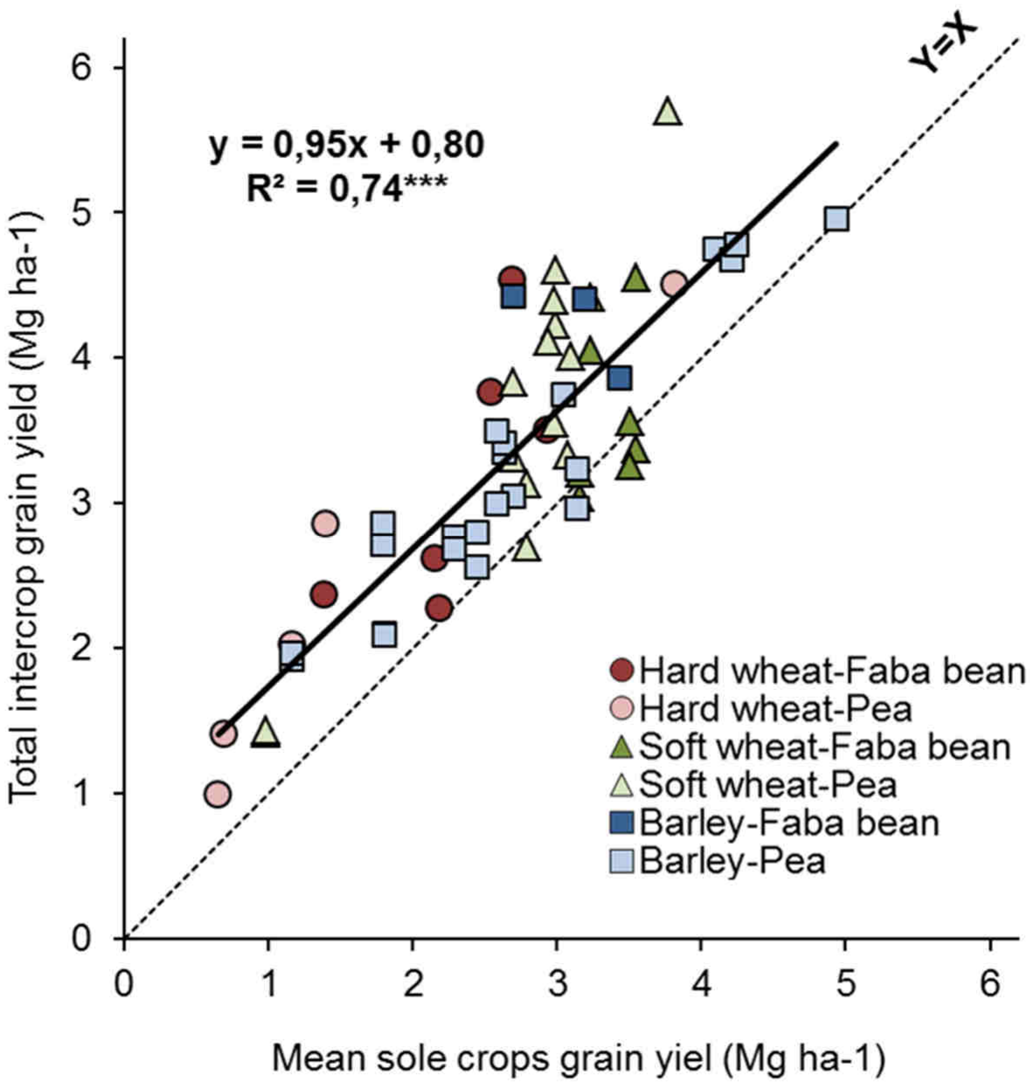
- 10 years of experiments in Toulouse but also in others pedoclimatic situations (NW, SE, Denmark)
- Conventional and organic farming
- Experimental station and farm
- Spring and Winter crops
- Large range of practices
  - Cultivars
  - Densities
  - Sowing paterns
  - Fertilization N or P
  - Pest management
- Different aims :
  - Evaluate the potential advantages of intercrops for grain yield, grain protein concentration, weed and pests control
  - Analyze the functioning of cereal-grain legume intercrops to further propose optimized intercropped systems



From : Bedoussac et al. Agr. Sus. Dev. 2015

IC improve yield (compared to low N SC)

(Hauggaard-Nielsen et al. 2001; Bedoussac and Justes 2010)



- Total intercrop grain yield higher than the mean sole crops (3.3 vs 2.7 Mg ha^{-1})

  → **Highest efficiency for low N**

- Total IC grain yield more stable compared to each sole crop

  → **Higher resiliency**

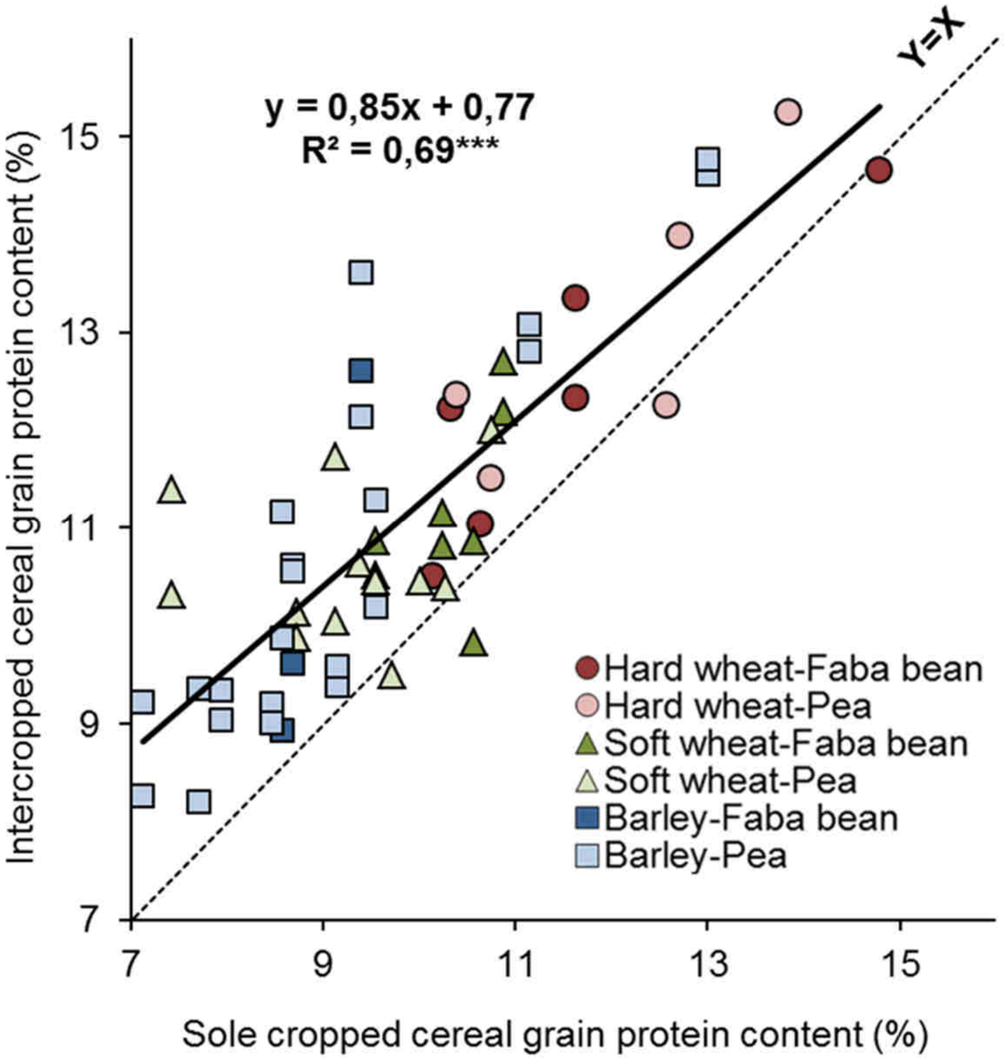
- Proportion of cereal > 50%

→ **Cereal more competitive and increased with N supply**

From : Bedoussac et al. Agr. Sus. Dev. 2015

IC improve grain quality

(Jensen 1996; Hauggaard-Nielsen et al. 2001, 2009; Bedoussac and Justes 2010)



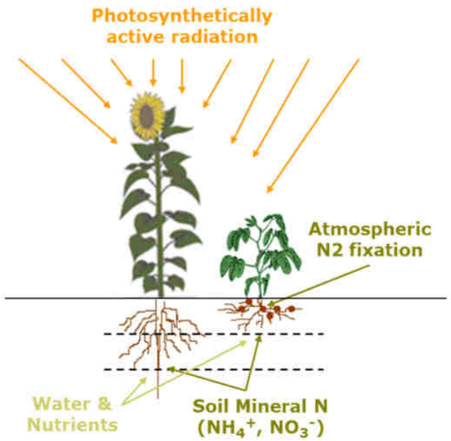
- Cereal grain protein concentration higher in IC (11.1% vs. 9.8% in SC)
- The lowest the SC protein the higher the increase

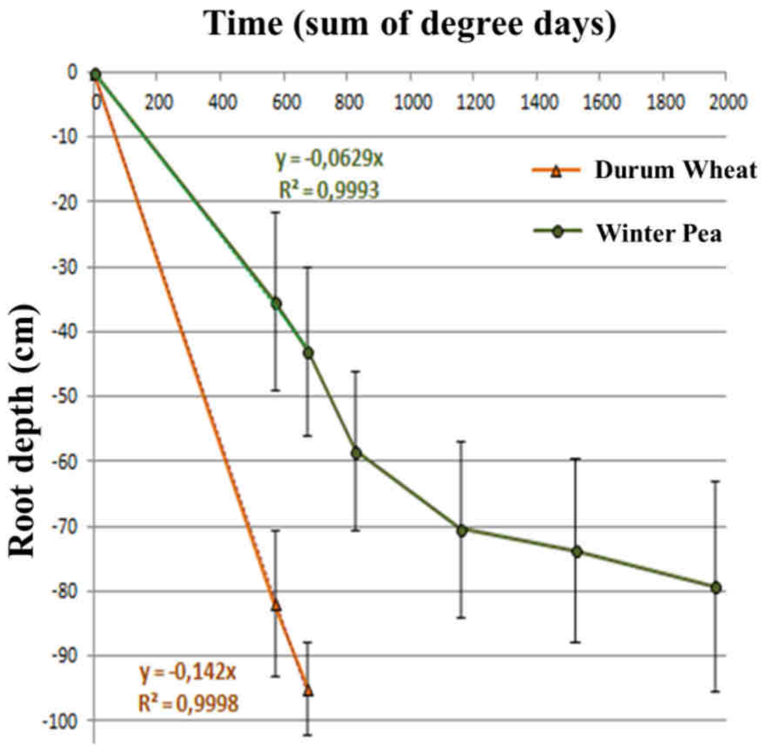
→ **Highest efficiency for low N**

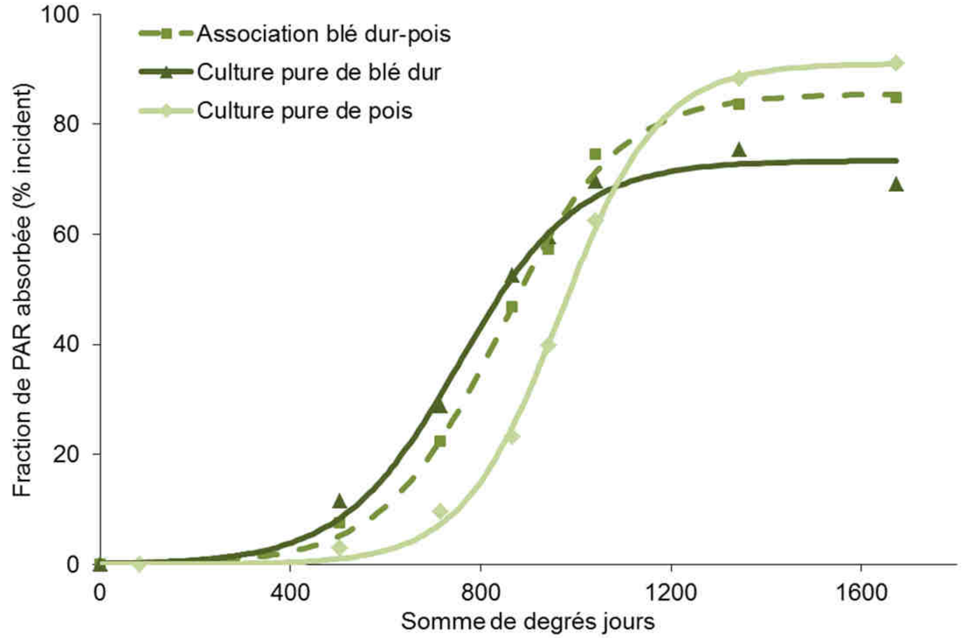
- Due to :
  - lower cereal grain yield
  - low use of soil mineral N by the legume (75% of Ndfa)

→ **More N available per plant, tiller & grain in IC**

Species complementarity for light and soil ressources (nutrients and water)







- Wheat roots deeper than those of the legume

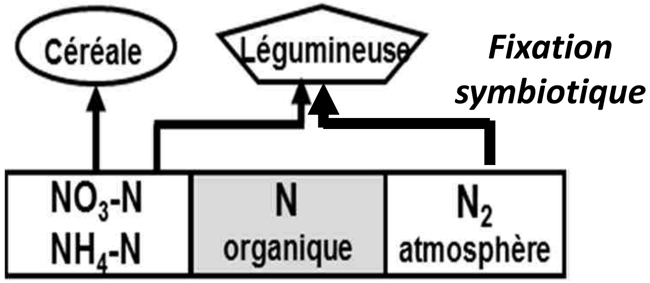
  → **Deep nutrients only available for the cereal**

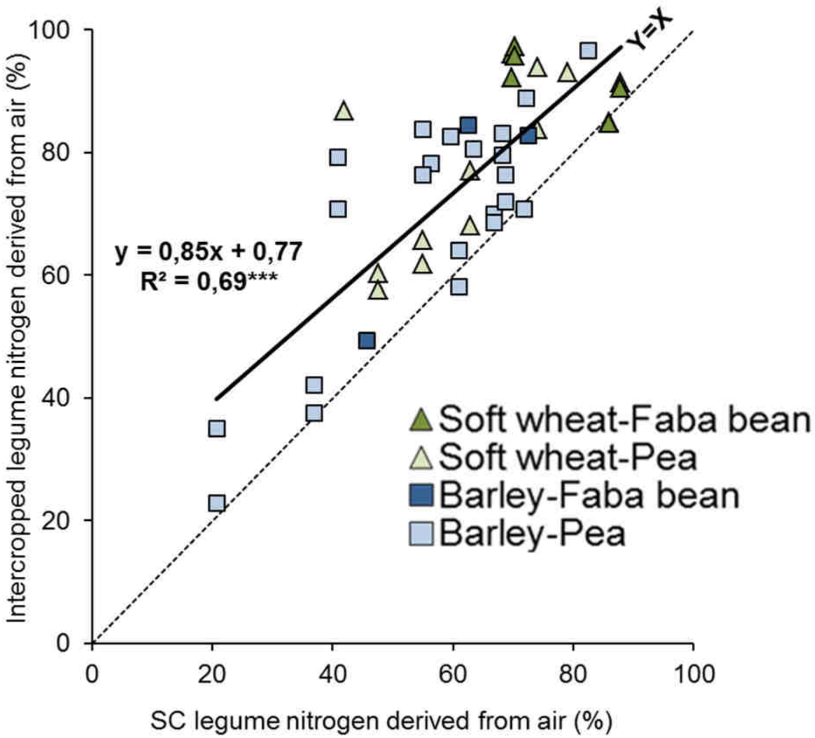
- Higher light use in IC

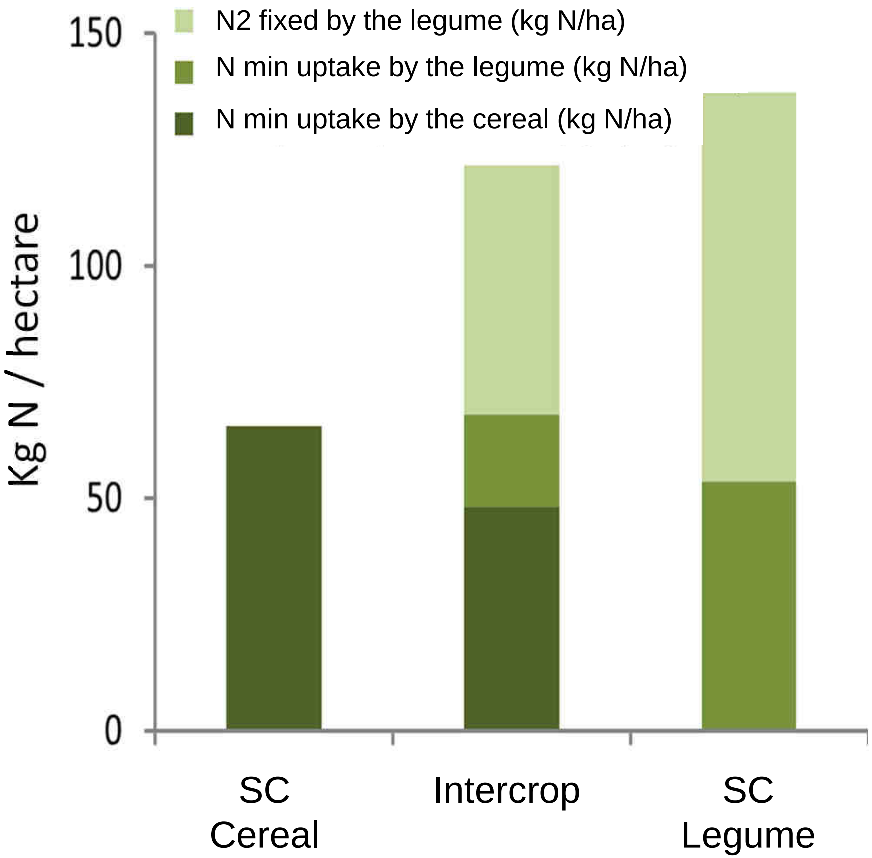
  → **Species complementarity allow a better use of available ressources in time and space**

From : Bedoussac et al. Agr. Sus. Dev. 2015

Species complementarity for N sources (soil mineral N and N_2 from air)







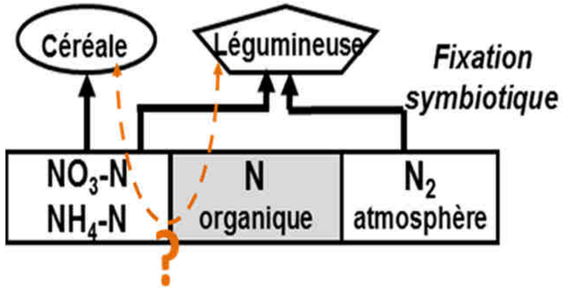
- Higher legume N2 fixation rate in IC (75% vs. 62%)

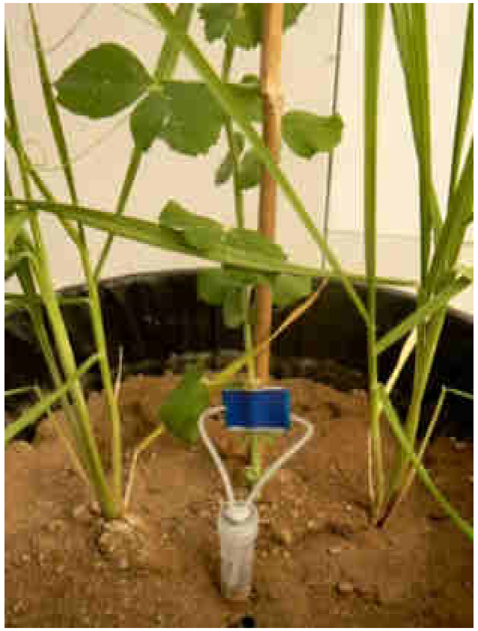
→ **Most of soil N mineral available for the cereal**

→ **Niche complementarity for N sources combined with competition for soil N mineral**

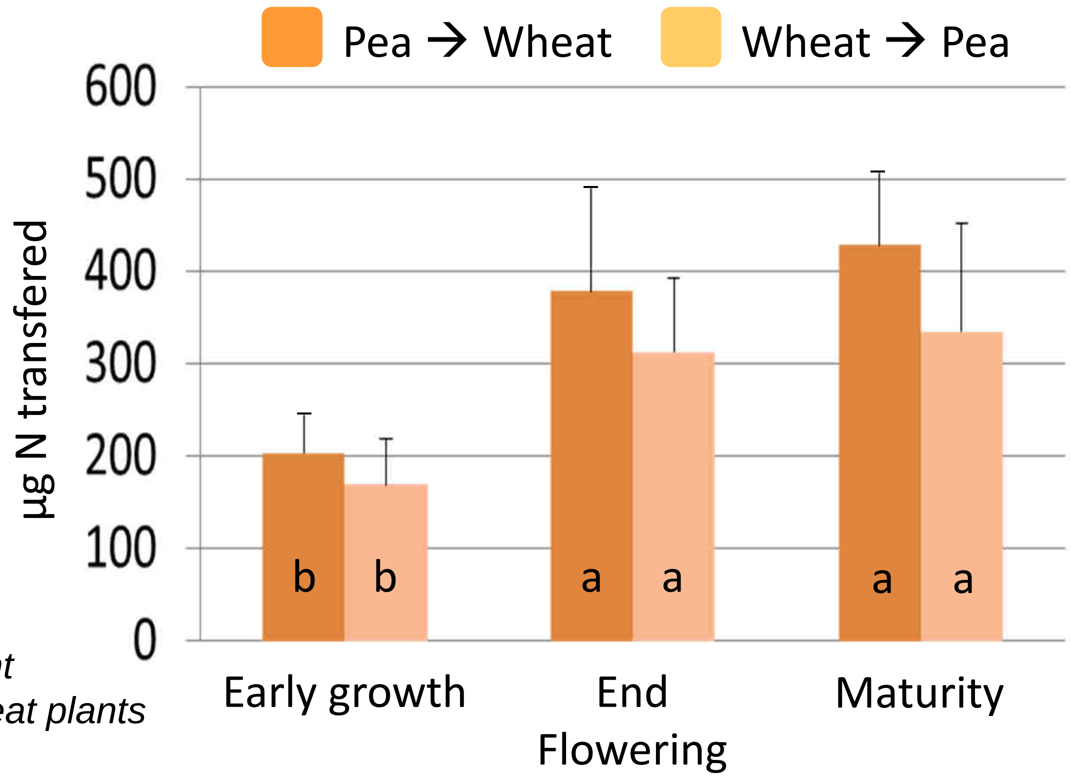
From : Fustec J, Malagoli P, 2012, Ecole chercheurs - Montpellier

N transfers limited between plants (at least for anual crops)





- *Soil from INRA Melgueil*
- *10L pots*
- *^{15}N leaves labelled*
- *1 pea plant with 2 wheat plants*

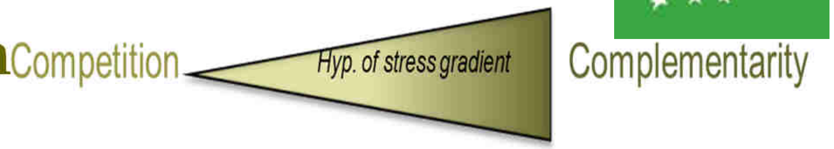


- There is N transfered between intercropped plants
- N amounts are limited (<1% of plant N content)

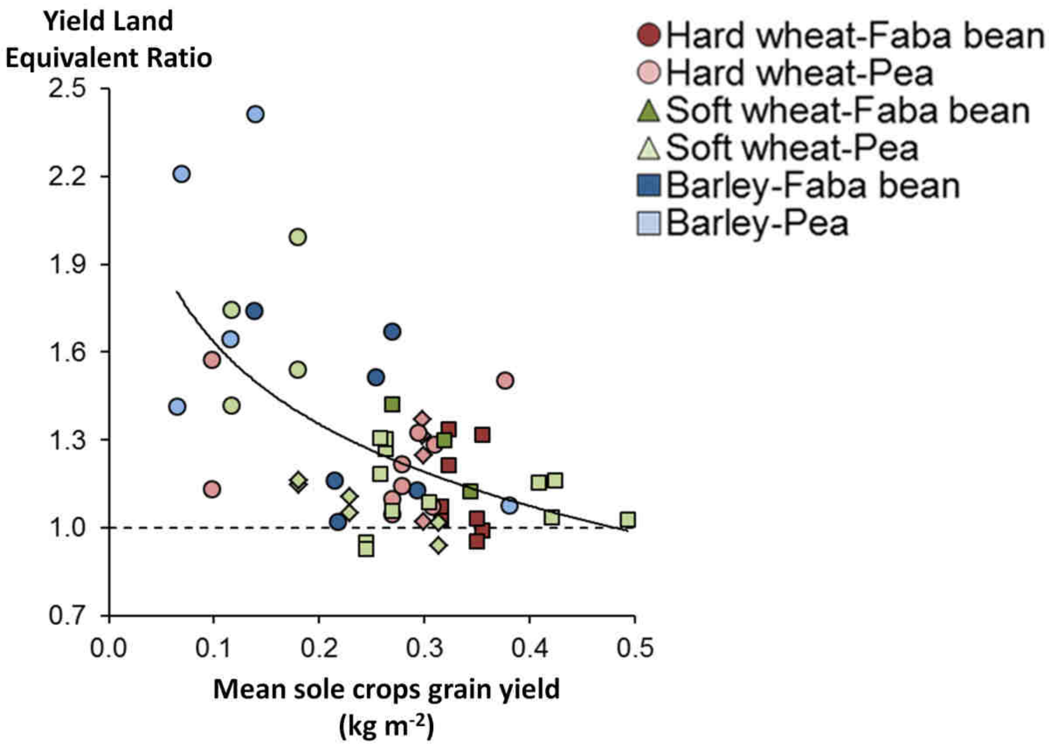
→ **For anuals crops the balance is almost nul and could not explain IC efficiency**

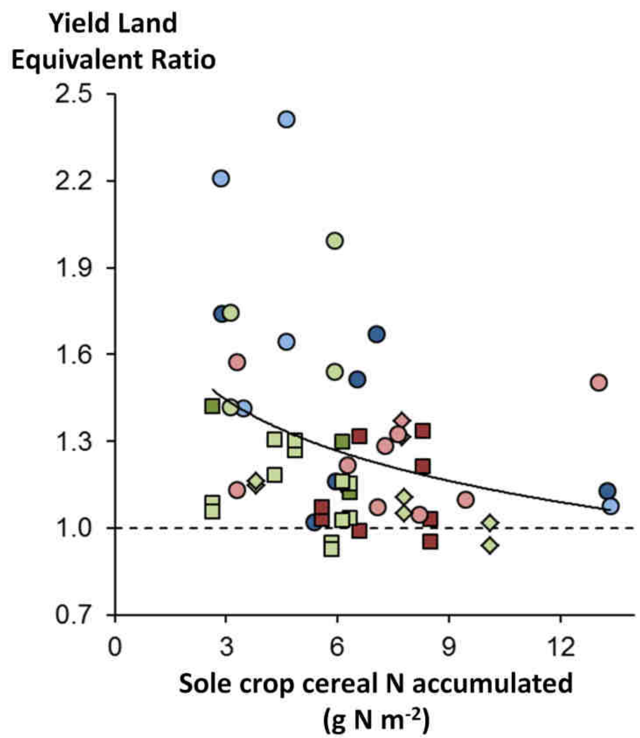
From : Bedoussac et al. Agr. Sus. Dev. 2015

Complementarity & facilitation mostly in limited conditions



From: Bertness et Callaway, 1994





- Land Equivalent Ratio higher when SC yields low
- Or when N available low

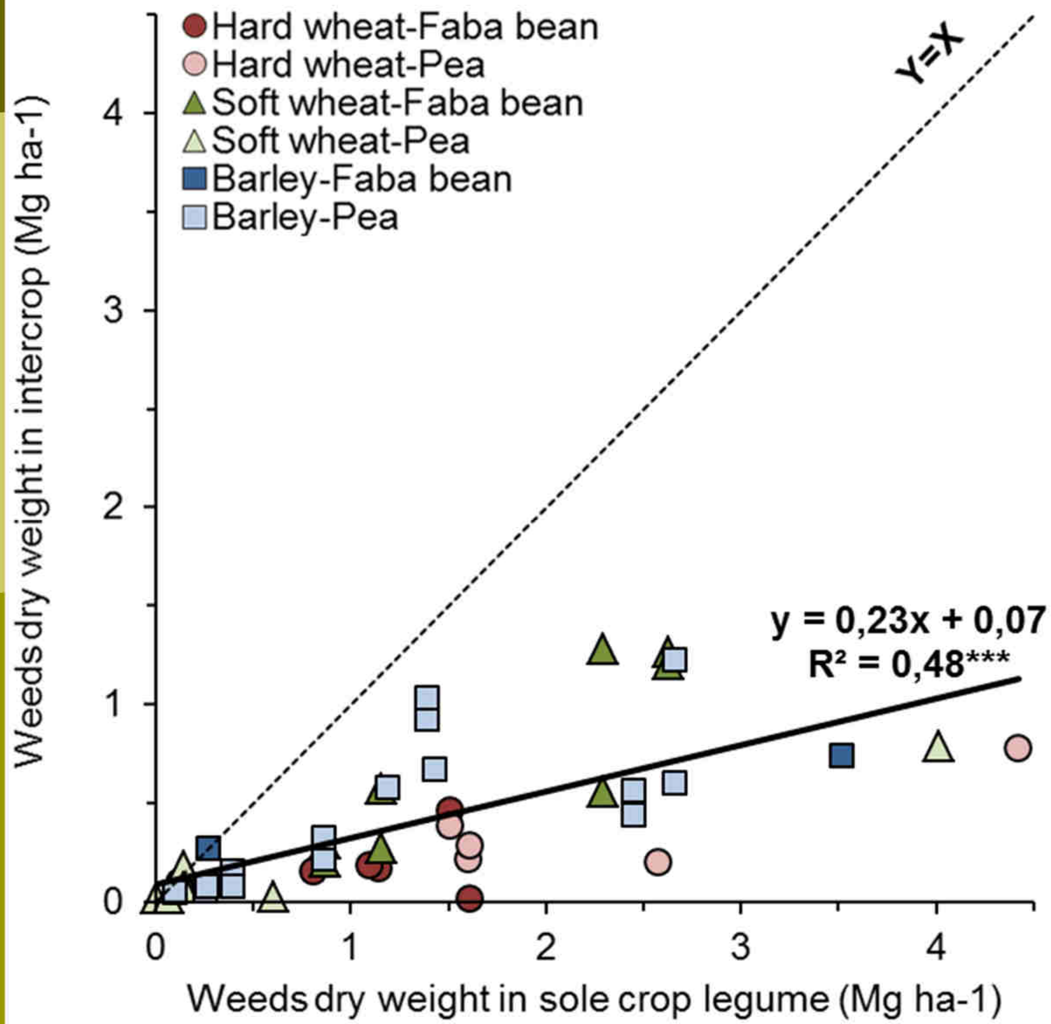
→ Niche complementarity for N sources in low N

→ IC is a kind of “insurance” of production for farmers

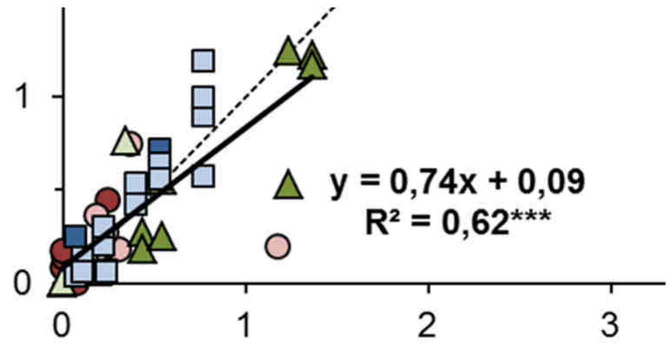
From : Bedoussac et al. Agr. Sus. Dev. 2015

IC reduce weeds

(in comparison of legume)



- Less weeds than the SC legume (0.40 vs. 1.38 Mg ha-1)
- But similar to SC cereal

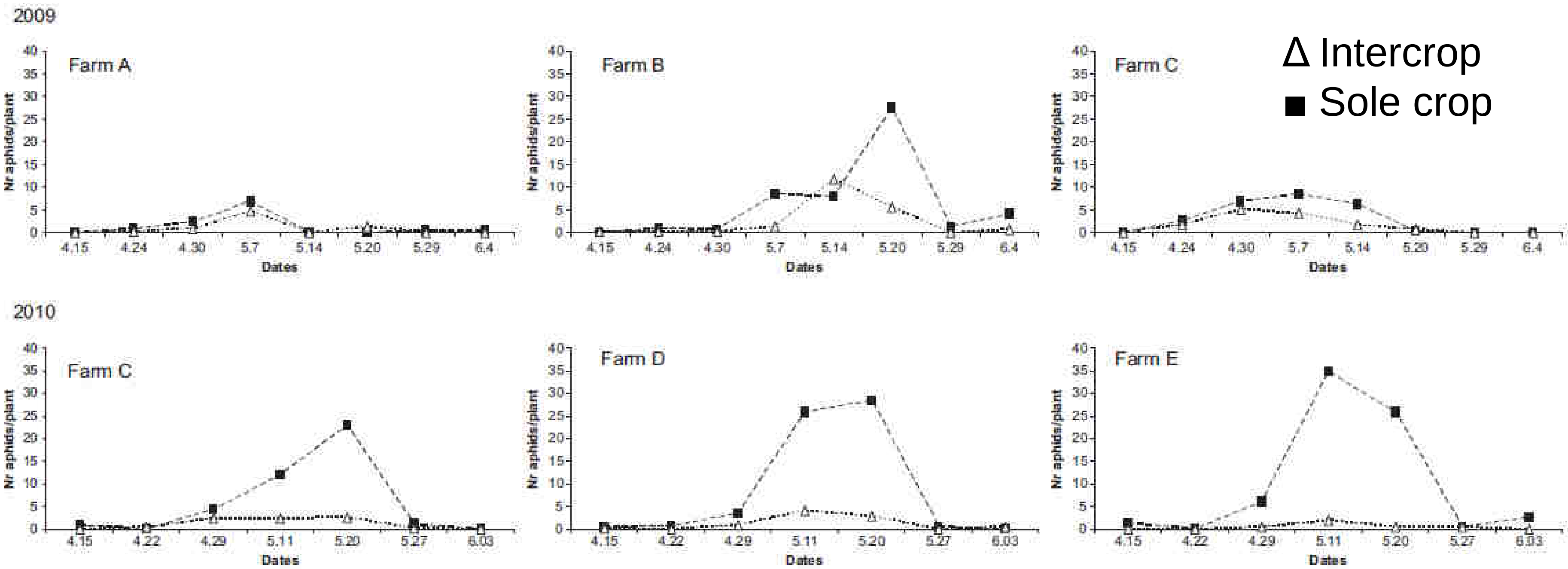


→ Weeds mostly controlled by the cereal and due to less light and N available

From : Abanda et al. J. Applied Entomology 2014

IC reduce aphids

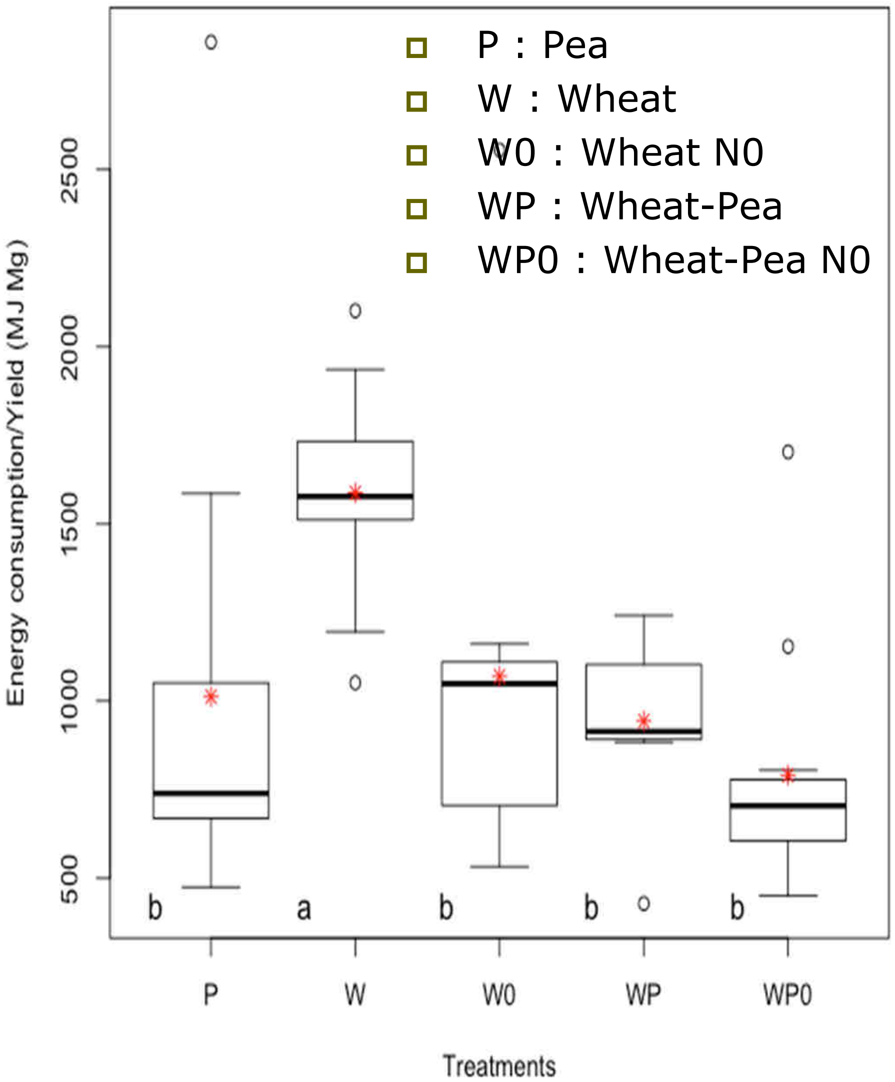
(at least those of pea)

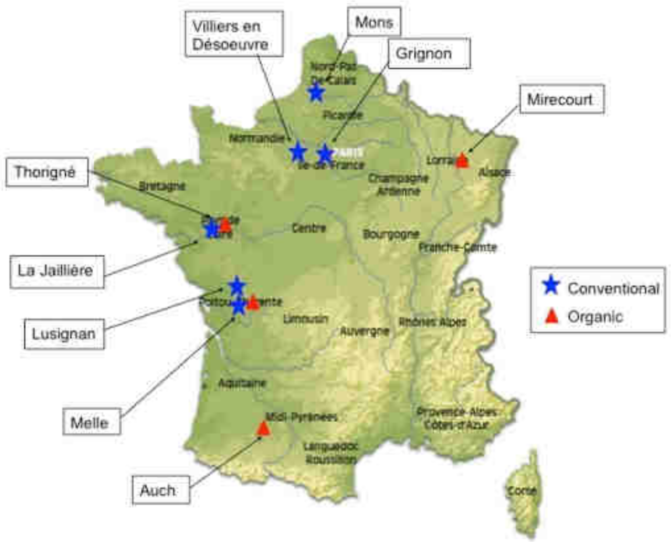


Acyrthosiphon pisum

- **Less green aphids in IC than in SC pea**
  - Physical barrier ?
  - Modification of plant recognition (shape, color, odor..) ?
  - Modification of habitat quality (temperature, humidity, sap quality …) ?

Intercropping reduce environmental impacts (Pelzer et al. 2012)





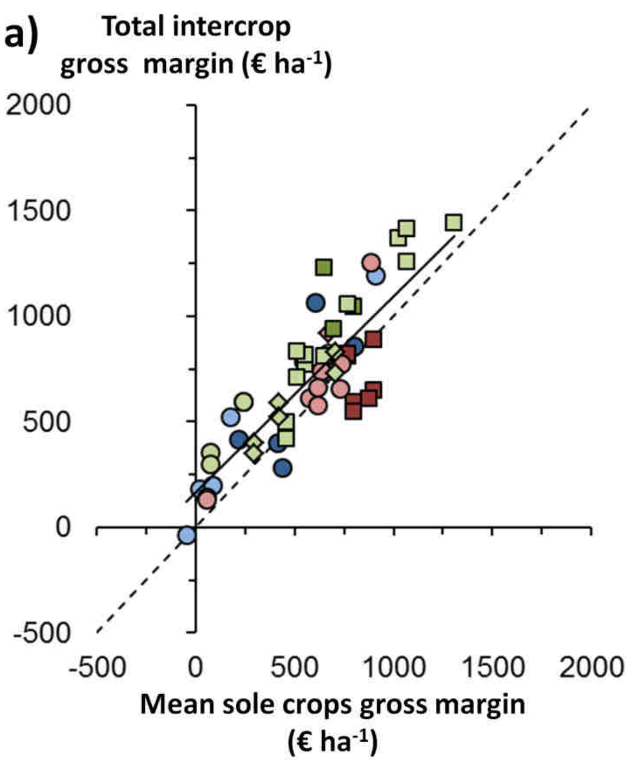
CASDAR associations (2005-08 ; 16 sites-years)

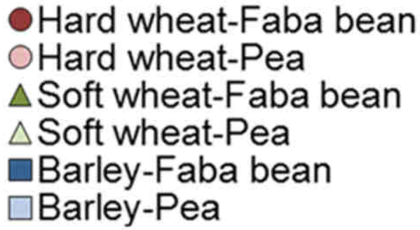
- Lower energy consumption per kg of grain produced due to lower use of N fertilizer and also less N_2O emissions…

From : Bedoussac et al. Agr. Sus. Dev. 2015

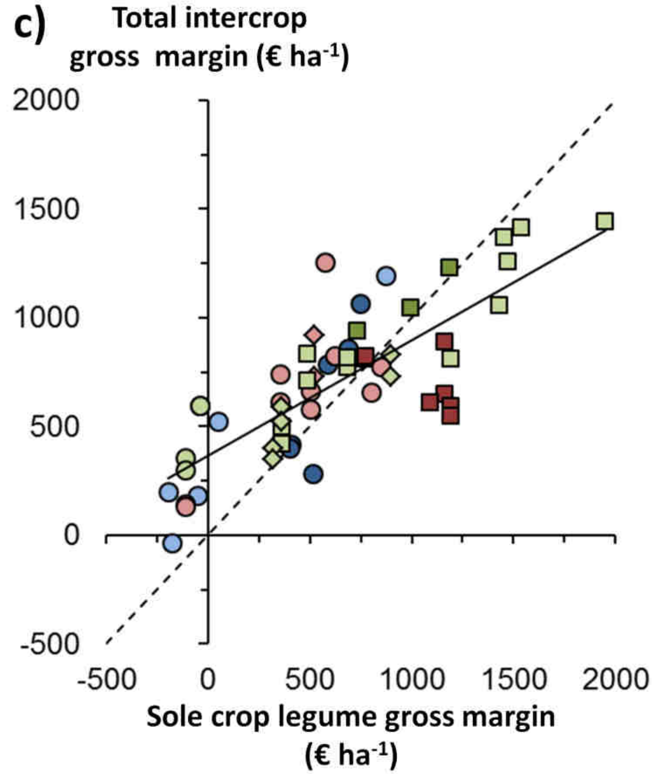
Intercropping improves margin

(notably when that of sole crop is low)





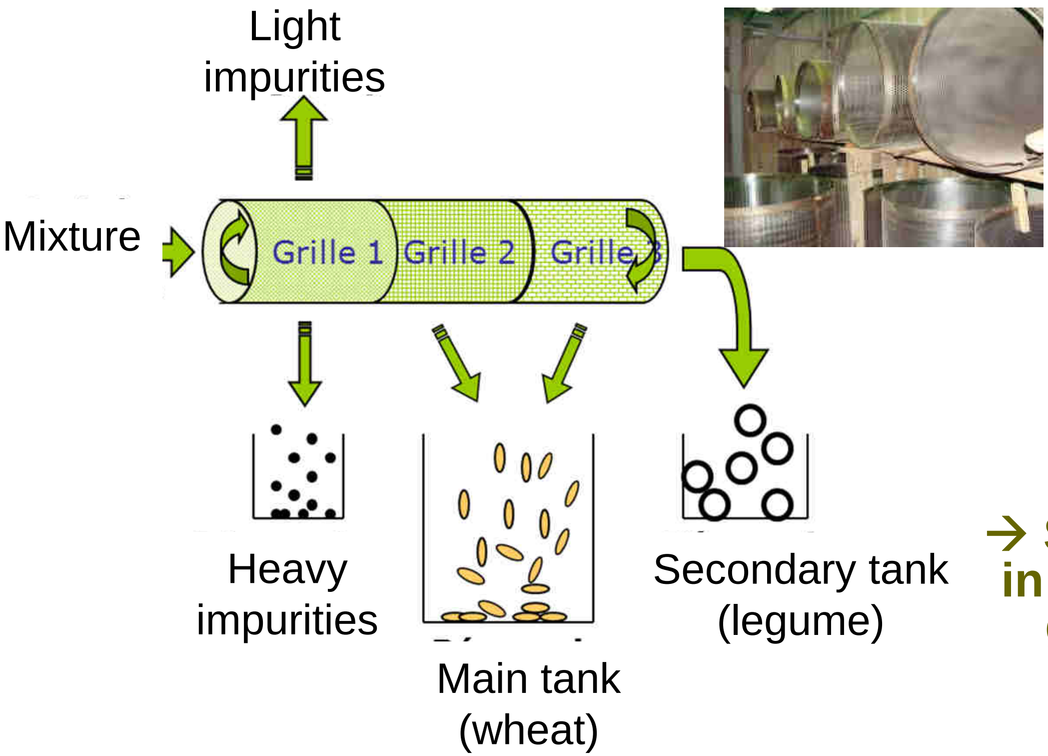
- Including sorting out
- Without subsidies
- Premium depending on protein content



- Total intercrop gross margin mostly always higher than the mean SC
- The lower the SC margin the higher the benefit in IC

→Effectiveness of grain separation determine whether it can be sold at a potentially high price representing the main obstacle to the development of intercrops

Effectiveness of grain separation determine the gross margin efficiency



	D. Wheat (%)	Pea (%)	Impurities (%)	Broken peas
Initial mixture	65.4	22.5	6.6	5.5
Clean Wheat	85	0	6.5	8.5
Clean pea	1.5	97	1.5	0

→ Sorting out grains is difficult and in that case insufficient for selling grains to human consumption but there is solutions…

- Sorting out grains at farm ?
- Using a more efficient machine ?
- Creating a double harvest machine ?
- Using wheat cultivars easy to harvest and peas not sensitive to splitting ?
- Diluting the impurities with sole crop wheat ?
- Accepting not to sort out all the grains ?

Conclusion and perspectives

- **Intercropping is an efficient way to improve yield, quality and reduce weeds when**
  - Competition for similar ressources (in time, space or chemical forme) are limited
  - Facilitation process occurred (e.g. P) or niche complementarity (e.g. N)

  → **Intercropping advantages mostly occured in limited conditions**

- **N transfers between species are limited** for annual crops

- **Interspecific complementarities depend on** species, cultivars, fertilisation…

→ Modelling intercropping systems could be helpful to optimize them and to determine varietal characteristics suited to mixtures

PART 2 : Agricultural innovative practices & impacts of the supply chain

An ex-ante study of the logistics of agricultural cooperatives to estimate the acceptability of durum wheat-grain legumes intercrops

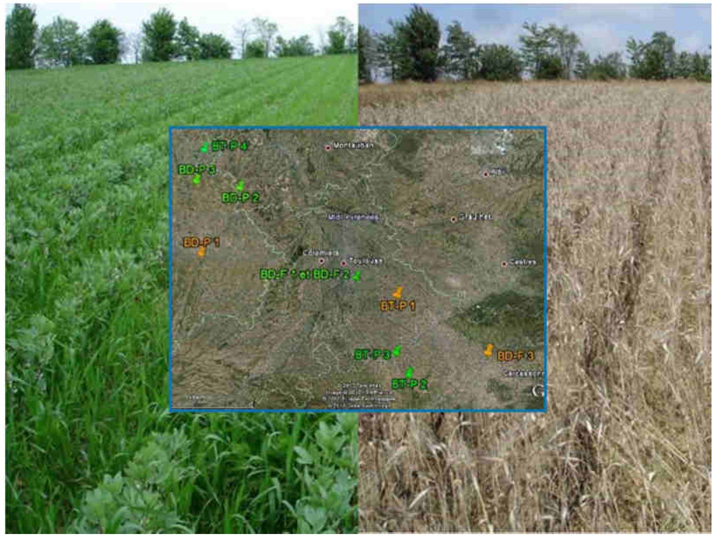




Some difficulties to adopt intercrops

- **For farmers:**
  - Species and cultivars
  - Sowing (densities, date…)
  - Fertilization (amount, fractioning…)
  - Pesticides use (products, doses…)
  - Harvest (adjustments, when ?…)
  - How to declare them for subsidies ?

→ Many levers and a potential to reach



- **For commercialization:**
  - Intercrops still not well accepted by collectors
  - Necessity to sort out grains at harvest (human)
  - Risk of contamination by other specie

→ Understanding their point of view to propose further solutions efficient and acceptable

__Cowan, R. & Gunby, P. (1996)__ « Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies », The Economic Journal ; __Vanloqueren, G. & Baret, P. V. (2008)__ « Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural "lock-in" case study », Ecological Economics ; __Vanloqueren, G. & Baret, P. V. (2009)__ « How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations », Research Policy

How does lock-in effect work ?

SELF-REINFORCING MECHANISMS

- Increasing returns
  - Economies to scale
  - Network/Learning effects
- Supply chain organization
- Switching costs
- Knowledge state
- Uncertainty
- Government Support
- Property Rights…

PATH DEPENDENCY

Earlier choice of a technology A at t_0

QWERTY design invented in 1870 (Sholes & Glidden) to prevent typebars clashes

Earlier choice of A prevails in t_0+t_1

QWERTY prevails even with electronic

&

Alternative B could be preferred but is not chosen

More efficient Drovak's keyboard not chosen

"A technology is not chosen because it is the best one but it became the best one because it has been chosen" → SUBOPTIMAL CHOICE

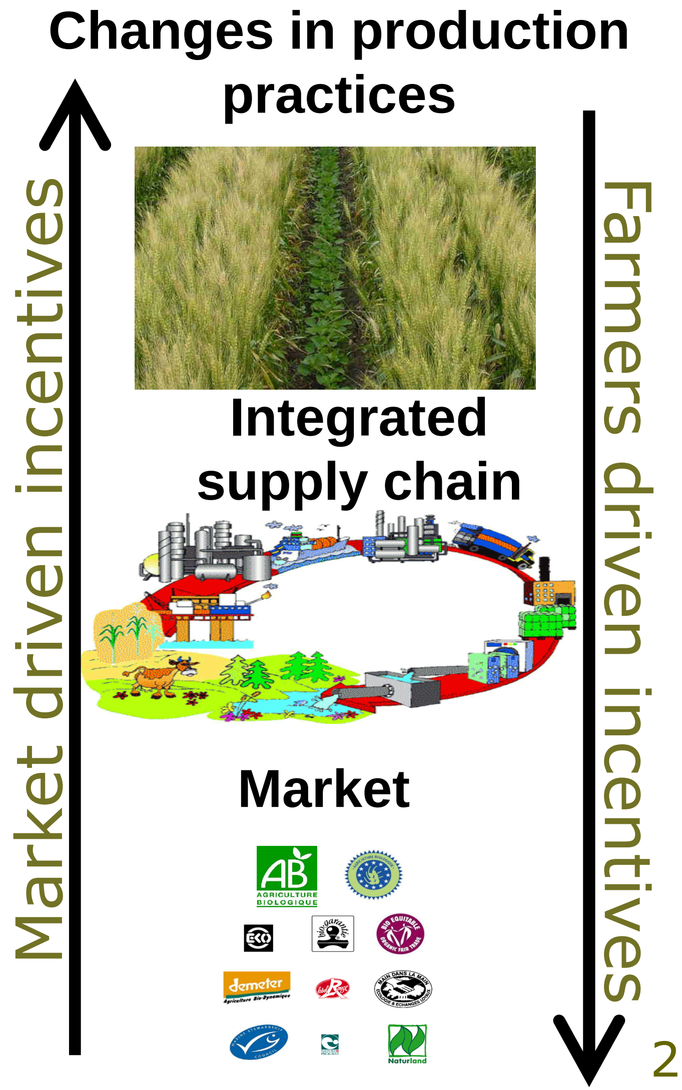
"Once a solution is reached, it is difficult to exit from" → LOCK-IN PROBLEM

Arthur (1994)

Can Agroecological practices be adopted ?

Context and questions

- **Context:**
  - There is efficient innovative solutions for low input systems
  - There is a social request to set up these solutions
  - Actors of the supply chain slightly integrate these innovations due to structured and stable organization of the supply chain around the conventional technological paradigm
- **Questions ?**
  - Are farming systems lock-in ? Why ?
  - Which acceptability of these alternatives by the supply chain ?
  - Which evolution for farming systems ?
  - How to switch from conventional to agroecological paradigm ?



Organizational design of durum wheat supply chain: *a concentrated downstream one leading to lock-in*

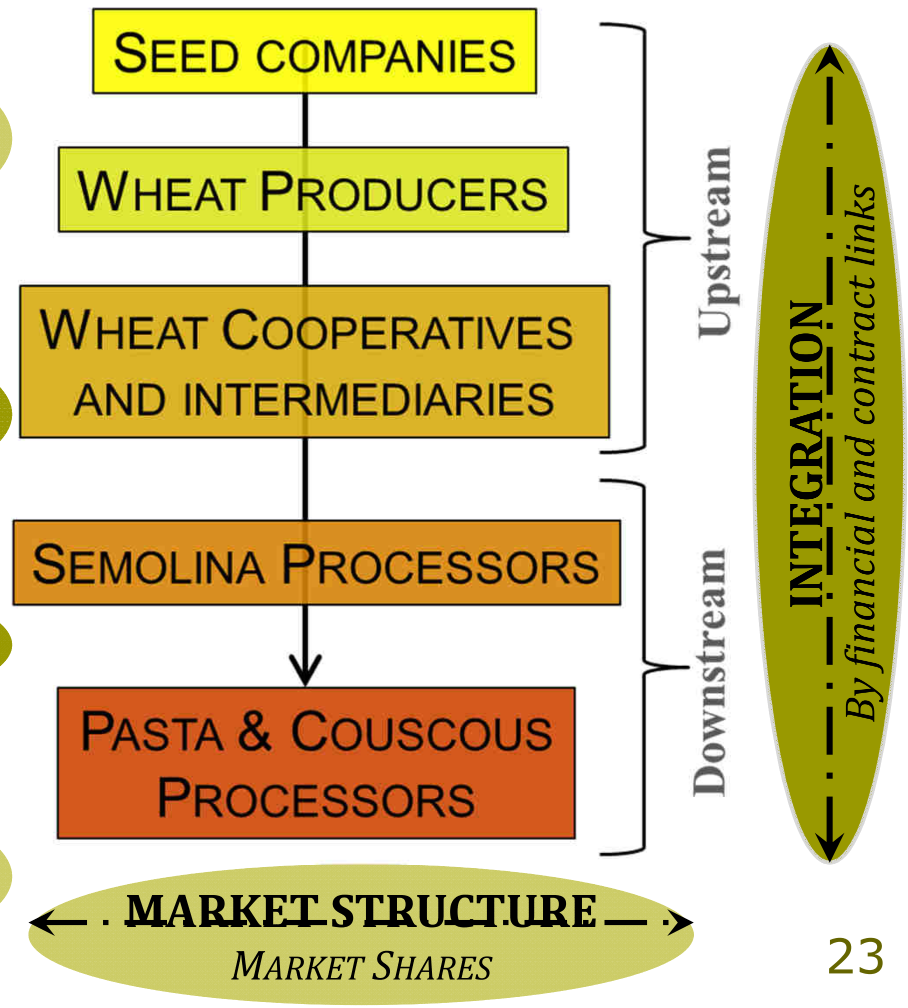
- Organizational design of supply chain
- Identification of main actors

MARKET CONCENTRATION AT REGIONAL LEVEL
Quality heterogeneity depending on the area & no national collect

NO INTEGRATION OR QUASI-INTEGRATION
(No ownership link & no long term contract link)

MATURE MARKET
(No entrance of new actors)

HIGH CONCENTRATION OF MARKET (OLIGOPOLISTIC)
(Semolina process = key point)



Can intercrops be adopted by farmers?

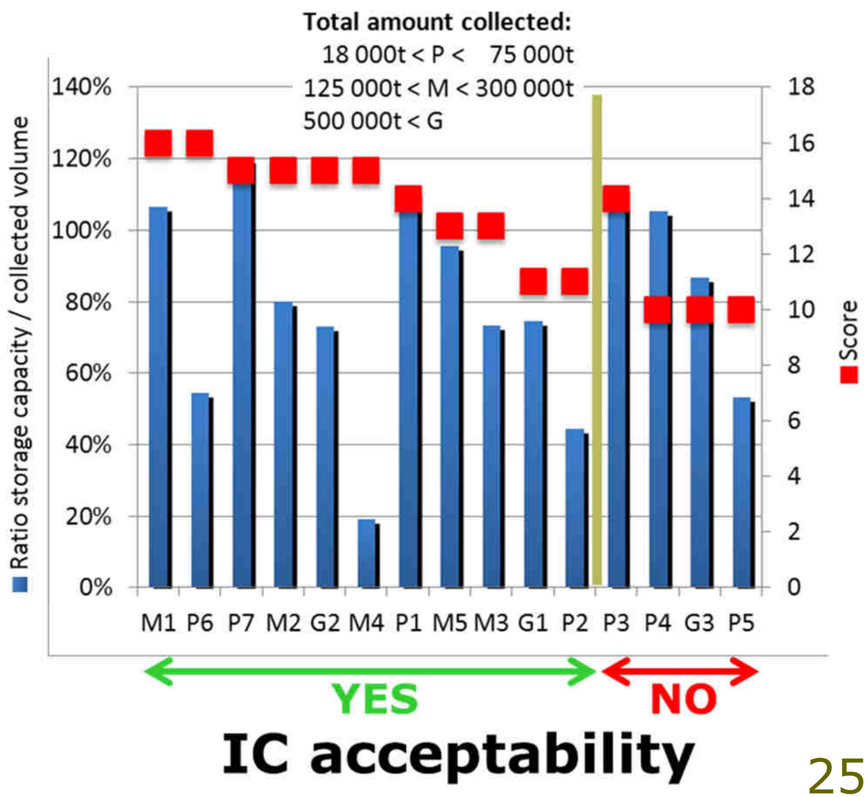
The cooperative's logistic

- **Adoption of intercrops by farmers must be compatible with cooperative's logistic** (ex: abilities to the collection, grading and marketing of the two species)
- The **logistic of cooperatives can be an obstacle but also a competitive advantage** (in a context of products differentiation by quality)
- **Analyzing the diversity of cooperatives** in the SW France region with an indicator of resiliency of cooperatives logistic
  - Size (number of species, volumes)
  - Flexibility (storage capacity, ability to sort out grains)
  - Importance of durum wheat and quality strategy
  - Dynamic (investments perspectives)

- **Assess ex-ante the characteristics of the logistics of coop.** likely to promote the adoption of new practices such as intercropping

Conclusion: links between cooperative's logistic and intercrops acceptability

- **Intercrops acceptability depends on quality strategy:**
  - Competencies and technical means (material, grading…)
  - Number of durum wheat classes
- **Size and flexibility seems not discriminant**
- **Needs for the development of intercrops:**
  - Sufficient volumes
  - Homogeneous species choice
  - Commercialization capacity of the 2 species
  - Capacity to sort out grains



PART 3 : New questions, new actors and others works integrating intercrops

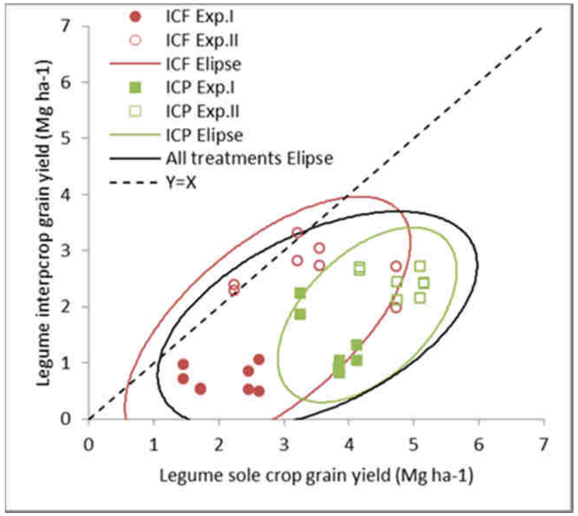
Still working on IC optimisation in order to include them in cropping systems notably as cover crops to promote sustainable supply chain



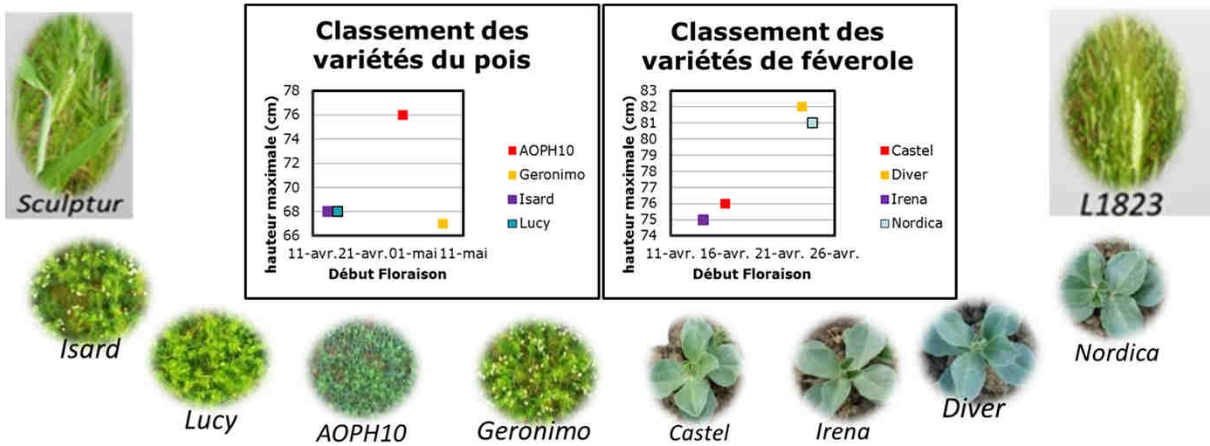


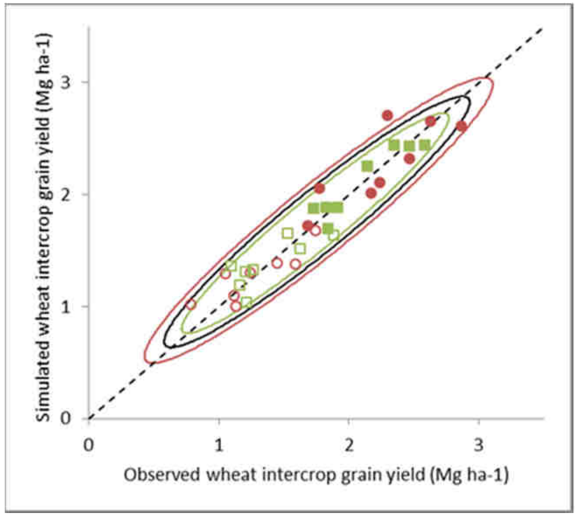
From : Kammoun et al. (under review)

Which cultivars are the most suited for intercropping



B. Kammoun PhD (2011-2014) :
Analysis of genotype x cropping systems interaction in durum wheat-grain legumes intercropping in order to define cultivar choice





- The best intercrop is not the intercrop of the best sole crops cultivars

→ **Which caracters make a cultivar suited for intercropping ?**

→ **Is that possible to predict IC yield from SC yields and sensitivity to interactions ?**

Intercropping species for both catch crops and green manure effect

Mixtures	Auzeville catch crop effect	Auzeville green manure effect	Bignan catch crop effect	Bignan green manure effect
bristle oat_faba bean	87%	67%	74%	111%
bristle oat_wild lentil	93%	70%	85%	39%
bristle oat_forage pea	81%	67%	90%	56%
bristle oat_crimson clover	79%	60%	73%	20%
bristle oat_purplevetch	83%	77%	113%	45%
foxtail millet_faba bean	63%	39%	74%	84%
foxtail millet_wild lentil	79%	45%	80%	36%
foxtail millet_forage pea	74%	42%	92%	48%
foxtail millet_crimson clover	85%	45%	114%	42%
foxtail millet_purplevetch	93%	51%	118%	66%
turnip rape_faba bean	260%	33%	78%	135%
turnip rape_wild lentil	168%	49%	128%	54%
turnip rape_forage pea	218%	34%	71%	67%
turnip rape_crimson clover	258%	9%	111%	41%
turnip rape_purplevetch	154%	56%	87%	69%
phacelia_faba bean	72%	87%	97%	80%
phacelia_wild lentil	71%	73%	78%	32%
phacelia_forage pea	52%	104%	83%	68%
phacelia_crimson clover	84%	89%	88%	39%
phacelia_purplevetch	74%	108%	80%	58%
Italian ryegrass_faba bean	51%	86%	84%	92%
Italian ryegrass_wild lentil	56%	61%	104%	62%
Italian ryegrass_forage pea	57%	84%	96%	78%
Italian ryegrass_crimson clover	64%	65%	103%	52%
Italian ryegrass_purplevetch	81%	87%	79%	68%

Delegation of Scientific Expertise, Foresight and Advanced Studies

The use of cover crops to reduce nitrate leaching

Effect on the water and nitrogen balance and other ecosystem services

H. Tribouillois PhD (2011-2014) :
Functional characterization of species used as cover crops and analysis of their performances in bispecific mixtures to produce ecosystem services of nitrogen management

e.g. of Setaria italica + Trifolium incarnatum to both catch crop and green manure effect

- Intercropping legume and non legume could provide both catch crop and green manure effect

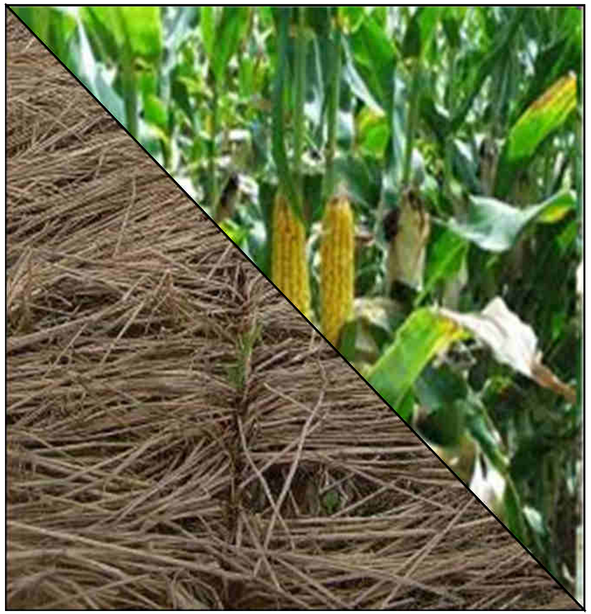
→ **Which species to intercrop ?**

→ **How many ? Which services ?**

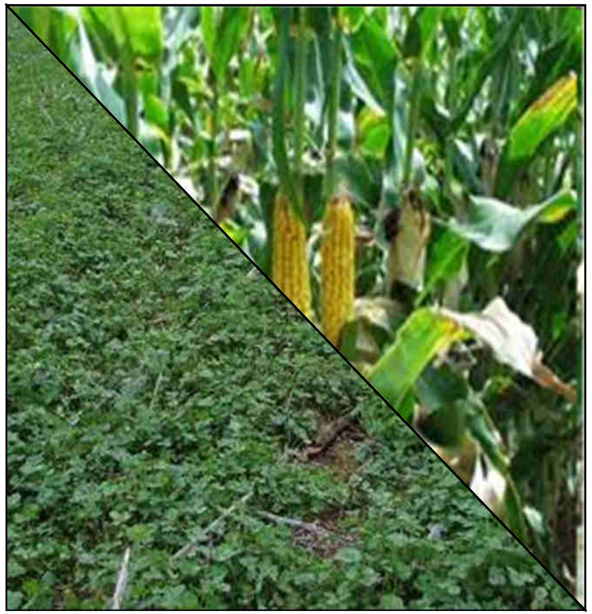
Conception and evaluation of innovative cropping systems

Objectives : Reducing nitrate and pesticides losses by 50 % maintaning economical performance

MM2
Purple trifolium + Ray-grass sown under cover
Plowing + mecanical and chemical weeding



MM3
Avena + Vicia + Phacelia
Mulching + Strip-till + mecanical and chemical weeding



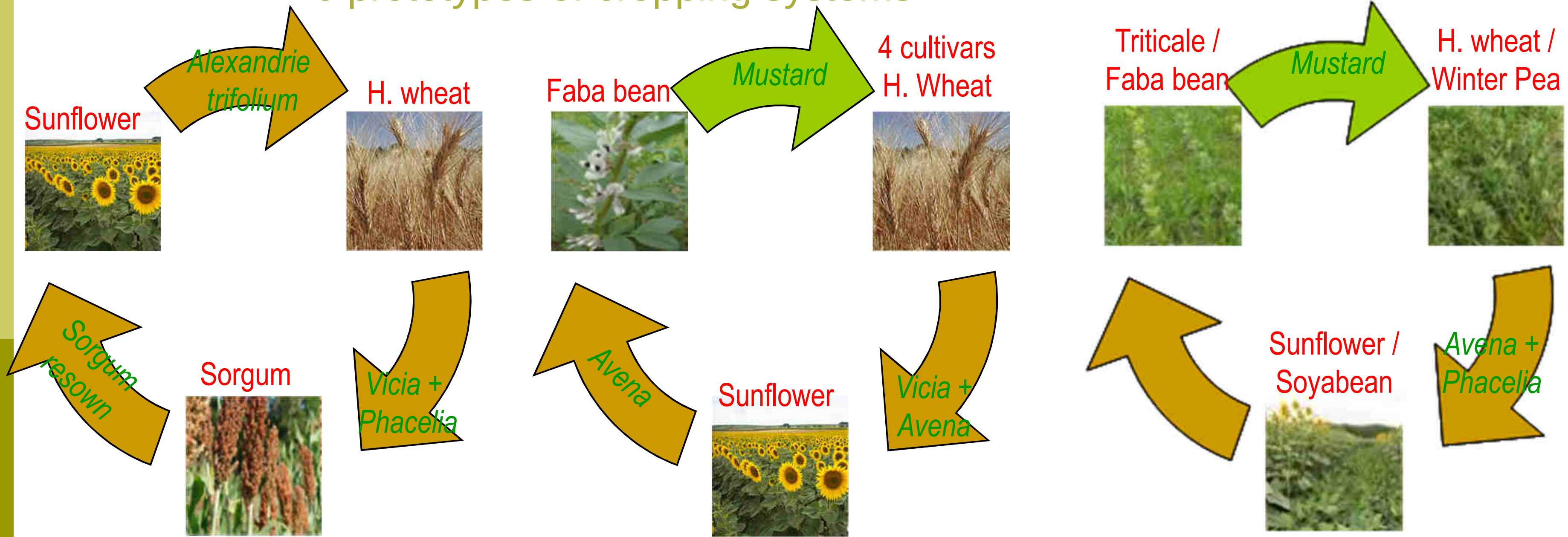
MM4
Permanent white trifolium
Strip-tilling + mecanical and chemical weeding

Conception and evaluation of innovative cropping systems

Hard wheat – sunflower
(our local reference)

Reduce the use of fertilizers and pesticides with the diversification of durum wheat – sunflower roration

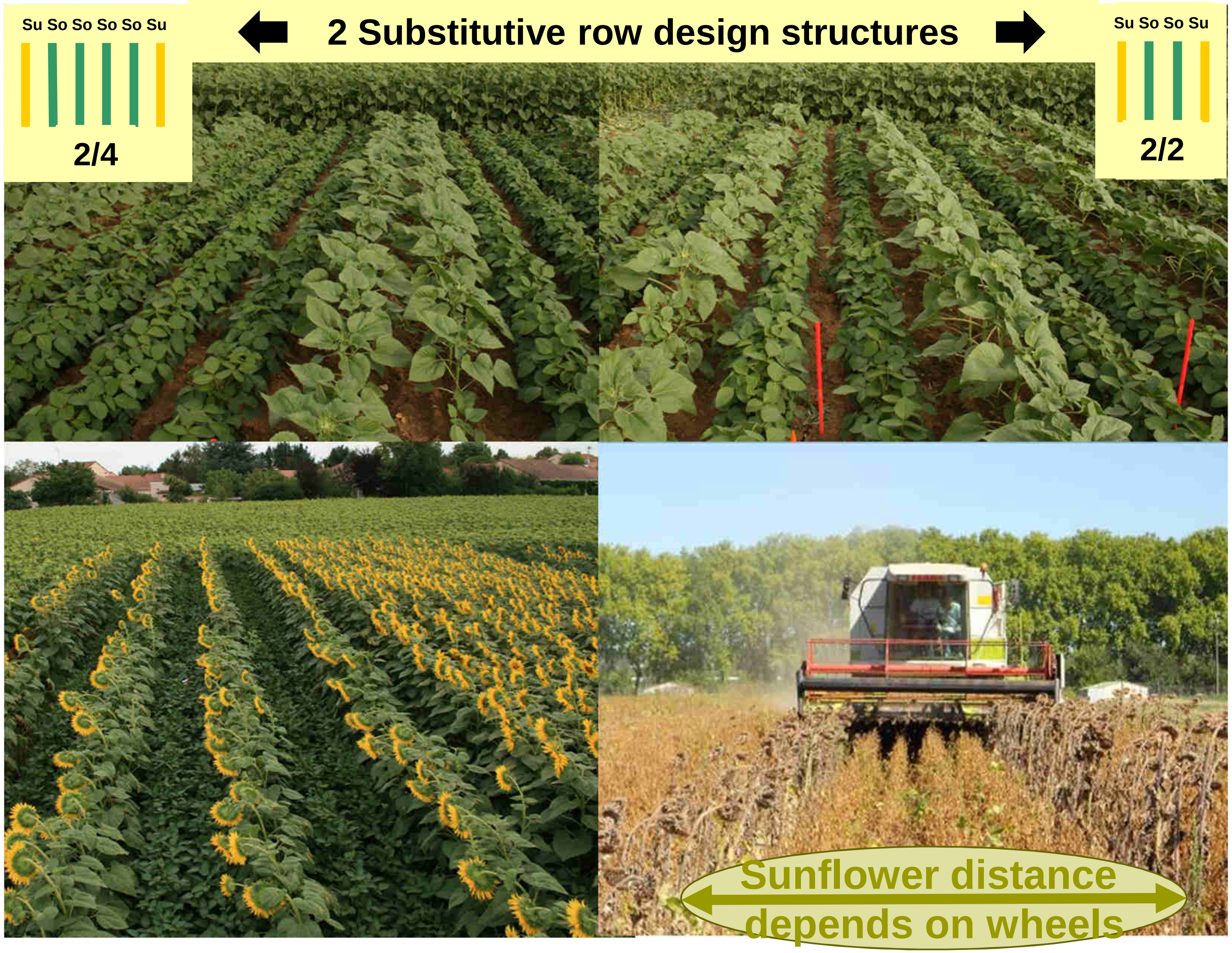
3 rotations : with and without catch crop
= 6 prototypes of cropping systems



Low inputs (LI) :
Reducce by 50% the number of treatments
(Plan ECOPHYTO 2018)

Very Low Inputs (VLI) :
Pesticides only if huge infestation or if there is a long term risk
(≈ reduce by 75% the number of treatments)

Summer IC practical aspects :
Sowing once, harvesting twice

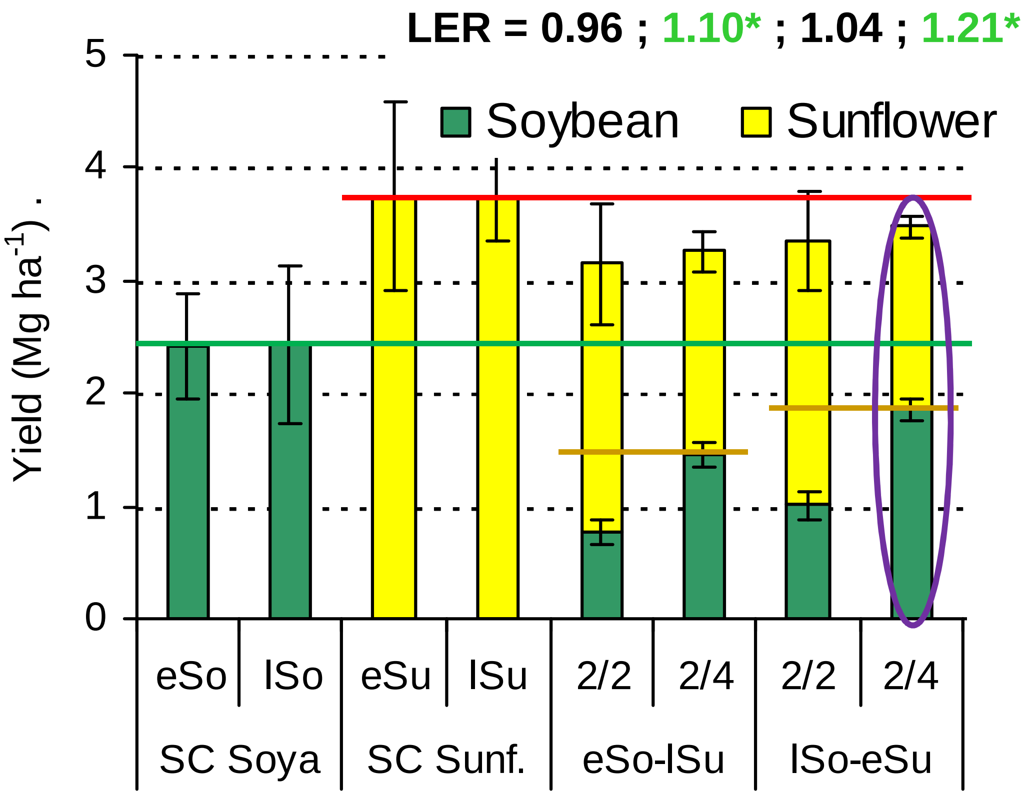


Sowing at the same time :
Early to End of May

Harvesting in two times :
1st Sunflower : Mid-September

2nd Soybean : End-September / beginning of October

Grain yields performance of soybean-sunflower intercrops



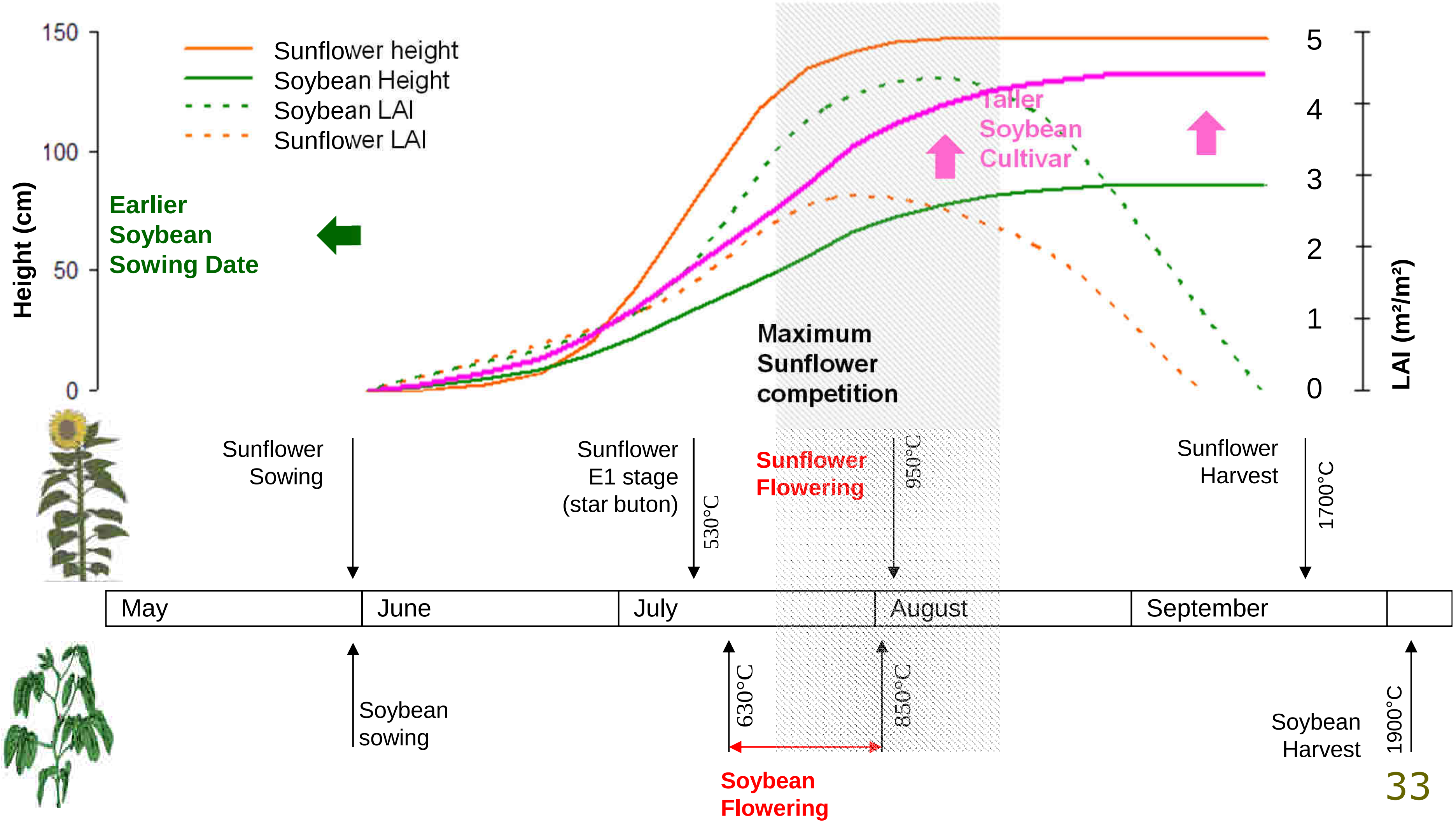
Toulouse ; 2010

- **2 Soybean cv. :**
  Isidor (eSo = **early**)
  Ecudor (lSo = **late**)

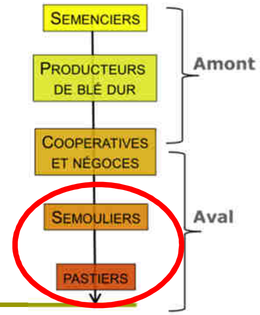
- **2 Sunflower cv. :**
  Fabiola (eSu = **early**)
  Melody (lSu = **late**)

- IC total grain yield > SC Soybean and < SC Sunflower
- More Soybean in the 2/4 and with late soybean cultivar (lSo)
- Always more Sunflower (except 2/4 with lSo)
- LER always ≥ 1 but that don't mean a better gross margin !!!

Adapting cultivar or sowing date to increase complementarity



From field to plate: **industrials and consumers are keys actors**



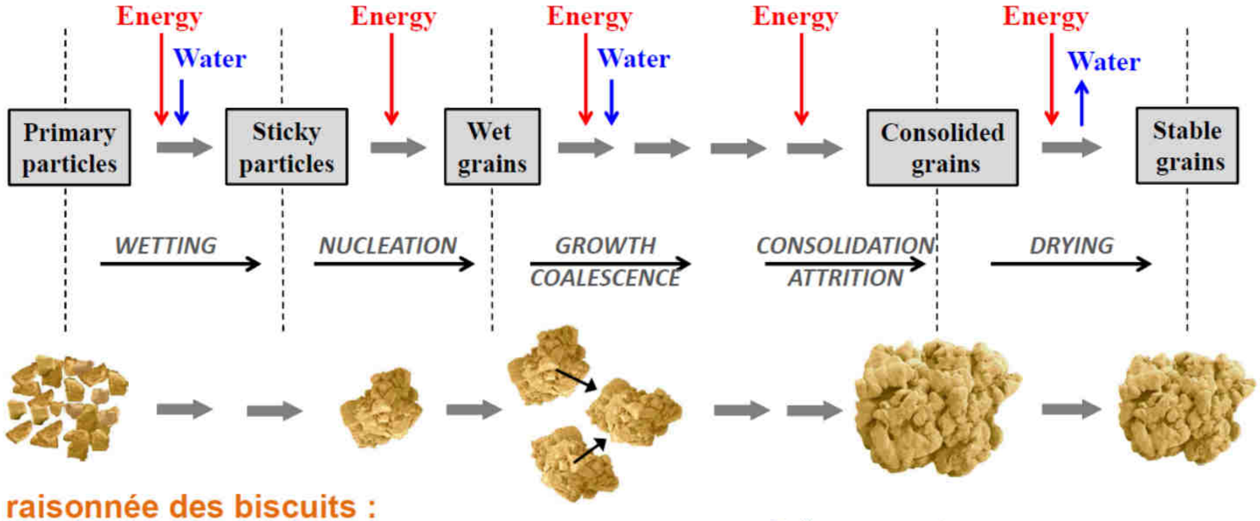
DUR-DUR
Une filière blé dur durable

UMR iAte
Agropolymer engineering & emerging technologies

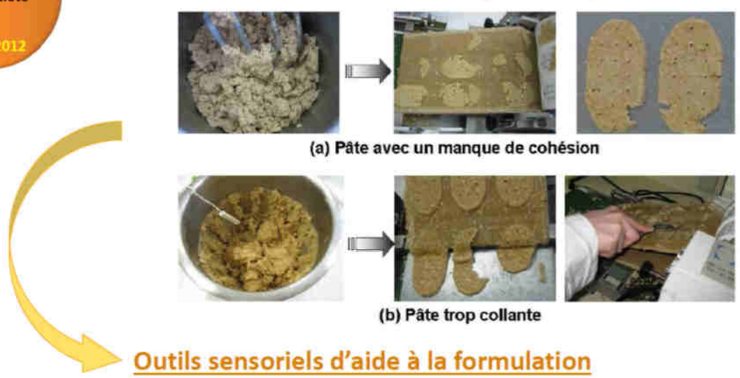
UMR GenIAl

BISENS
BIScuit ENrichi et Satiété
2009-2012

Re-design of durum wheat processing for couscous production



Formulation raisonnée des biscuits :
difficulté d'ajuster l'hydratation

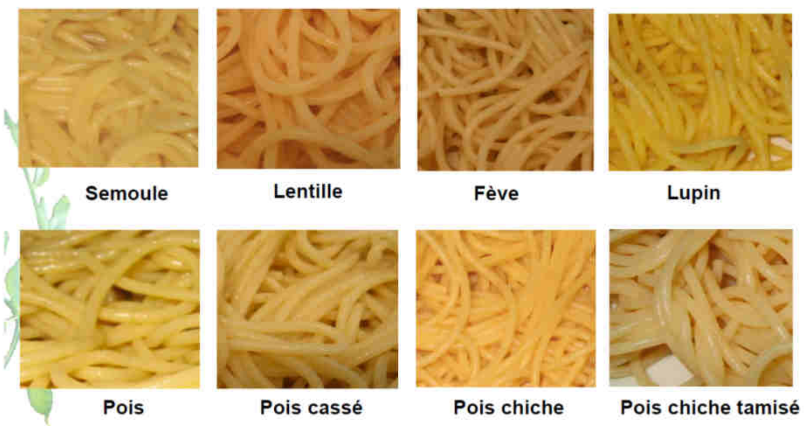


(a) Pâte avec un manque de cohésion

(b) Pâte trop collante

Outils sensoriels d'aide à la formulation
Adhérence au pétrin (4 niveaux), Aspect de la pâte (4 niveaux), Cohésion (4 niveaux), Caractère collant (3 niveaux), Lipidité (3 niveaux)

Pâtes cuites



All the actors are now involved in order to try to develop intercropping practice

谢谢

Bedoussac L., Journet E.-P., Hauggaard-Nielsen H., Naudin C., Corre-Hellou G., Jensen E. S., Prieur L., Justes E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for sustainable development 35(3):911-935

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UMR AGIR INRA-INPT ; Toulouse – France

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19-21th August 2015 ; Xi'an ; China