The use of models at field and farm level for the *ex ante* assessment of new genotypes in pea (*Pisum sativum* L.)

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Pea is an important crop for European agriculture:
→ Source of proteins for animal feeding
→ Many positive environmental impacts

Yet, dramatic decrease of area since 1993

Mainly due to highly variable grain yields and no trend of increase in the past 20 years
spring cultivars = 90% of the peas grown in France

<table>
<thead>
<tr>
<th>Growth cycle in the paris basin</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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<td>High temperature and water stress</td>
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- High risk of high temperature and water stress during yield formation
- Frequent risk of soil compaction due to wet soil at sowing, after winter

➡ VARIABLE YIELDS
Winter cultivars exist!

+ Lower risks of high temperature and water stress during yield formation
  - Frequent risk of soil compaction due to wet soil at sowing,
  - High risk of frost during winter (low resistance)

=> VARIABLE YIELDS
New Hr winter peas: an interesting alternative?

Growth cycle in the Paris basin

Spring peas

Winter peas

Hr winter peas (under breeding)

+ Lower risks of high temperature and water stress during yield formation
+ Lower risk of soil compaction at sowing
+ A longer duration of frost resistance

MORE STABLE YIELDS are expected
New Hr winter peas: an interesting alternative?

Growth cycle in the Paris basin:

<table>
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<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May-Jun</th>
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<td>Spring peas</td>
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<td>Hr winter peas (under breeding)</td>
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</table>

Which performances if not sown in optimal conditions?

Competition among activities at the farm level.
AIMS

1= Which genotypes for Hr peas (which characteristics of genotypes) should be built in order to improve the grain yield level and stability of pea crops?

2= Do the constraints of work organisation at the farm’s scale modify the relative performance of the target genotypes?

⇒ Use of modelling

⇒ Interaction with breeders to:
(1) identify the range of genotype characteristics to consider
(2) Analyse and discuss the simulated results
AIMS

1. Which genotypes for Hr peas (= which characteristics of genotypes) should be built in order to improve the grain yield level and stability of pea crops?

2. Do the constraints of cropping systems and work organisation modify the relative performance of the target genotypes?
Which genotypes for Hr peas?

The pea crop model AFISOL
(adapted from the model AFILA, Biarnès et al., 2004; Lecoeur & Sinclair, 1996)

Genotype
Sowing date
Soil structure
Weather
Soil

AFISOL

Yield
Nitrogen budget
Frost risk

Model at field scale, without disease and weeds
Model assessment allows to be confident in it and to use it with breeders.

- Comparison with observed data:
  \[ \text{RMSEP} = 0.7 \text{ t/ha} \]

- Comparison with expert knowledge:
  correct simulation of the effects of sowing date and soil structure on yield level and stability
Simulations with AFISOL to identify the better virtual Hr genotypes

→ 3 locations in France:
  Mons (cold and wet), Chartres (oceanic),
  Toulouse (warm and dry in summer)
→ 2 soil depths per location: shallow and deep
→ with and without irrigation
→ 2 sowing dates per location (early and late)
→ 28 climatic years per location

■ 6 virtual Hr genotypes:
  ➢ 2 values of mean seed weight (0.125 g gr\(^{-1}\); 0.280 g gr\(^{-1}\)) (linked with the number of flowering nodes: indeterminate and determinate)
  ➢ 3 dates of beginning of flowering (20/04, 10/05 et 30/05)

■ in comparison with a spring pea and a winter pea
Which genotypes for Hr peas?

Grain yield of the Hr genotypes

Mean values of all the agricultural conditions simulated

- Effect of the Hr genotypes on both yield level and variability
- The best Hr genotypes have
  - An early beginning of flowering
  - Small seeds and an indeterminate habit

New information for breeders

Beginning of flowering:
- BF1: 20/04
- BF2: 10/05
- BF3: 30/05

Mean weight per seed:
- MWS1: 0.125 g gr⁻¹, indeterm
- MWS2: 0.280 g gr⁻¹, determ
Aims

AIMS

1= Which genotypes for Hr peas (= which characteristics of genotypes) should be built in order to improve the grain yield level and stability of pea crops?

2= Do the constraints of work organisation at the farm’s scale modify the relative performance of the target genotypes?
Coupling models of pea crop, soil structure, work organisation

Effect of work organisation

Farm characteristics

Dates of the different operations

Works not realised

Sowing date for pea

Compacted soil

Soil water content for each operation and crop of the rotation

SISOL

% compacted volumes in the soil after each operation and crop

Grain yield, N in straw, frost risk

Soil water content model

AFISOL

Characteristics of the machines for soil tillage

Weather

OТЕLO
Effect of work organisation

Conditions of simulations

A group of 4 real farms, 500ha

- Site 1
  - farm 1
    - 150 ha
  - farm 2
    - 150 ha

- Site 2
  - farm 3
    - 135 ha
  - farm 4
    - 65 ha

Oilseed rape, durum wheat, soft wheat, spring pea, winter barley, maize, grassland

- 100 ha of pea,
- autumn: a lot of activities to do (300 ha cereals to sow)
- 2 persons work on the 4 farms
- same machines for the 4 farms
- decision rules identified by farmer’s survey
- simulations based on 28 climatic years
Results of simulations

- weather conditions
- competition among activities
- choice of pea genotype
- Variable dates of sowing for pea (sometimes not optimal) and soil compaction

Analysis of the simulations:
- comparison of the performances of the three types of cultivar (spring, winter and Hr)
- with and without taking into account the constraints of work organisation in the farm and the decision rules of the farmer, thus with optimal and non optimal sowing dates for Hr peas, and soil structure for spring and winter peas.
<table>
<thead>
<tr>
<th>Grain yield variability</th>
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<tr>
<td>Coefficient of variation between years</td>
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<tr>
<td>Spring peas</td>
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<td>Winter peas</td>
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<tr>
<td>Hr winter peas</td>
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</table>

- Lower variability for Hr winter peas, in comparison with spring and winter peas, in agricultural conditions

- The genotype assessment gives different results whether the agricultural conditions are taken into account or not, mainly for spring peas
Conclusions

Originality of the study:

- This work allowed to integrate the effects of crop management, soil and climatic conditions and work organisation within the farm for the assessment of genotypes under breeding.
- The levels of the farm and of the rotation have been considered for the genotype assessment.
- But some effects, that might differ among genotypes, have not been considered: diseases, weeds, easiness of harvest.

Main results:

- Important information on the virtual genotypes have been produced and were discussed with breeders, contributing to the breeding strategy.
- The model appears as an interesting tool for a productive dialogue between researchers from different disciplines and partners.
Thank you
Which genotypes for Hr peas?

Results from experiments allow to identify the effects to take into account in the model

Exp in 2 locations (Grignon and Mons), during 2 crop cycles (2002-03 and 2003-04)

Yield is higher for autumn sowings than spring sowings, due to the longer crop cycle

Crop Nitrogen uptake is reduced when soil is compacted

![Graph showing Grain Yield (q/ha) for November and February sowings.]

- 8 q ha⁻¹

![Graph showing Crop N uptake in non-compacted soils (kg/ha) vs. Crop N uptake in compacted soils (kg/ha).]

Y = X
Effect of work organisation

Risk of soil compaction at sowing

Higher risk of soil compaction for spring and winter peas than for Hr winter peas, even with non optimal sowing dates
Grain yield: loss due to bad conditions of sowing linked with constraints of work organisation, in comparison with optimal sowing conditions.

Lower loss of grain yield for the Hr winter peas than for the spring and winter peas, when sown in non-optimal conditions.
Model assessment based on expert knowledge allows to be confident in it and to use it with breeders

- RMSEP = 7 q/ha
- Grain yields for winter peas are less variable than for spring peas

Model also shows some experts observations:

- The level and stability of grain yield are reduced when sowing is late in autumn (because of frost risks).
- Grain yield is increased and variability is decreased when irrigation on shallow soils is applied
- Grain yield are higher for spring peas in North France, and higher for winter peas in South France

Which genotypes for Hr peas?
Octobre : une période déjà chargée pour certaines exploitations agricoles

Risque de concurrence avec d’autres chantiers....
3ème étape : b) Intégration des contraintes d’organisation du travail

Etat structural : évolution à l’échelle de la rotation

Pour cette rotation, état structural moins tassé avec pois d’hiver hr et Hr que pour le pois de printemps,

Forte influence des conditions climatiques au moment de l’opération technique sur l’évolution de la teneur en mottes $\Delta$. 

Colza / Blé tendre / Pois / Blé tendre / Orge d’hiver

Teneur en mottes $\Delta$ moyenne :
- pois de printemps : 41%, pois d’hiver hr : 30%, pois d’hiver Hr : 33%
Les modifications apportées à AFILA

- Prise en compte du tassement dans un module enracinement,

Une culture de pois n’est pas toujours bien alimentée en azote et en eau (Crozat et al., 1991; Doré, 1992)

- Module de nutrition azotée de la culture (Crozat et al., 1991, 1994; Ney et al., 1997; Jeuffroy et Recous, 1999; Voisin et al., 2002)

- Effets du tassement sur le système racinaire en utilisant le pourcentage de zones tassées du sol (cf 1ère partie)

Différences entre variétés et types de pois en termes de croissance et de développement (Dumoulin et al., 1994; Lecoeur et Ney, 2003)

- Identification et estimation des principaux paramètres variétaux

Importance du risque de gel pour le développement du pois d’hiver dans de nouvelles zones de culture (Etévé et Derieux, 1982)

- Calcul du nombre de jours avec risque de gel

- Insertion d’un module N (fixation et minéralisation du sol; utilisation par la crop)
Tassement et racines

1ère étape : Acquisition de connaissances...

Si TASSLEMENT

de la profondeur maximale de sol explorée par les racines

Vocanson et al. (Plant & Soil, sous presse)
2ème étape : Mise au point et évaluation d’AFISOL

**Les modifications apportées à AFILA**

- Insertion d’un module foliaire pour prédir la biomasse
  \[
  \text{MS} = f(\varepsilon_i) \quad \text{(Monteith, 1977)}
  \]
  \[\varepsilon_i : \text{efficience d’interception du rayonnement lumineux}\]

  **Initialement dans AFILA**
  \[\varepsilon_i = f(T^\circ, P)\]

  **Finalement dans AFISOL**
  \[\varepsilon_i = f(\text{LAI}) \text{ et } \text{LAI} = f(\text{N absorbé})\]

\[\text{Semis d’automne, Semis de printemps}\]
Les modifications apportées à AFILA

- Identification et estimation des paramètres variétaux

Relation Ngunit – P1G (fig II-7)
1ère utilisation d’AFISOL : à l’échelle de la parcelle

Quel est le type variétal le mieux adapté aux conditions de culture ?

**Itinéraire technique**
- Variété
- Date de semis
- Irrigation
- Profondeur de sol

**Pédo-climat**
- Climat

**AFISOL**
- Rendement
- Bilan azoté
- Risque de gel
Which genotypes for Hr peas?

Rendement et risque de gel

- Rendement pois H > pois P
- Ecart-type pois H < pois P
- Rendement - élevé que pois P
- Rendement - élevé que pois P
- Rendement - stable que pois P
- Rendement + stable que pois P

Pois P : pois de printemps
Pois H : pois d’hiver
Results

Influence de l’irrigation (sol superficiel)
Influence du climat

Results
Influence de la date de semis

Précoce

Tardif
Model assessment based on expert knowledge allows to be confident in it and to use it with breeders

- RMSEP = 0.7 t/ha
- Simulated grain yields for winter peas are less variable than for spring peas *(simulations without frost risk)*

Which genotypes for Hr peas?

Simulations for 3 locations, 28 climates, 2 soil depths, and irrigation or not