Institut National de la Recherche Agronomique
CENTRE DE MONTPELLIER

UMR System
Fonctionnement et conduite des systèmes de culture tropicaux et méditerranéens

Evidences and explanations for the unexpected high productivity of improved temperate agroforestry systems

1rst EURAF Conference,
9 October 2012
Session 1

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INRA, Montpellier, France

Trees and Agriculture : a change of paradigm ?

Trees inside parcels

Trees around parcels

Around parcels

Inside parcels

Innovative Agroforestry

Dual approach :

long-term experiments + models

Controlled Experiments

Agroforestry

Agri-voltaism

The Hi-sAFe model : 2002-2011

Objectives
Hypotheses
Specifications

2002 : Wageningen seminar

2004 : Montpellier Seminar

2005 End of SAFE project

2007

TALBOT Ph.D

2011

Formalisation, développement

Débogage, vérification

Automatisation

Parameters, calibration

Evaluation

Exploration, utilisation

Version 1

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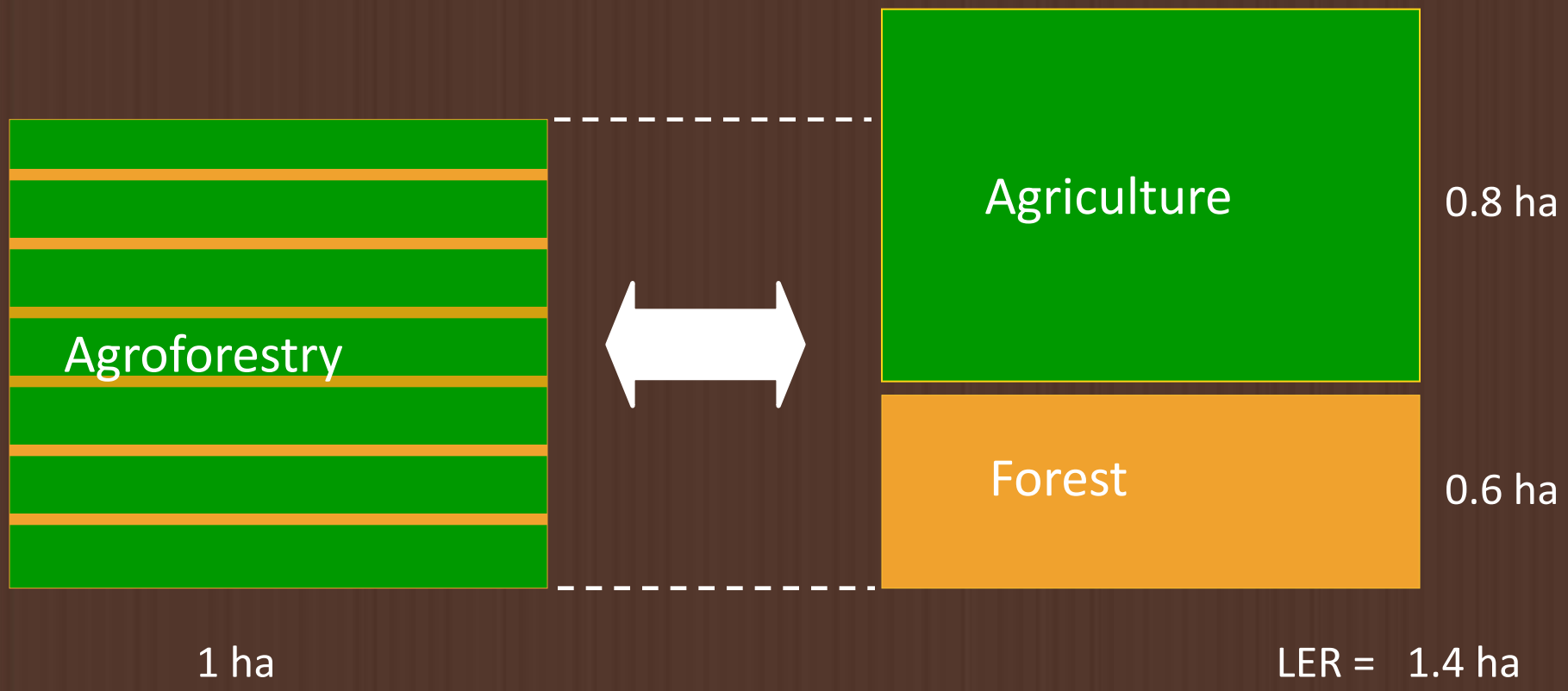
To mix or not to mix : trees and crops/animals…

Mixture

Separation



Land Equivalent Ratio (LER) (Mead and Willey, 1980)


1996


1997

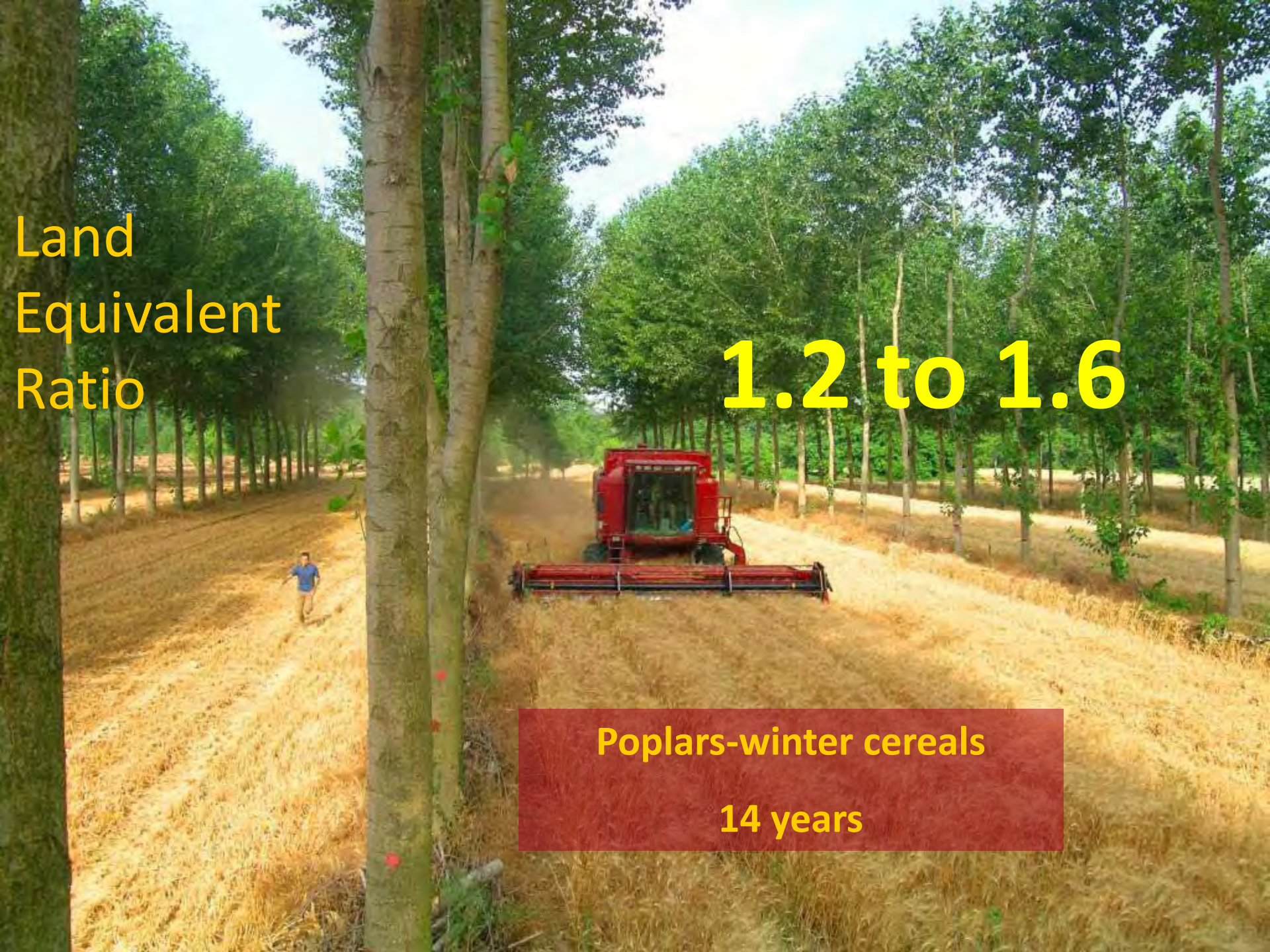

2002


2005


2003


2010


2009


Land
Equivalent
Ratio
1.2 to 1.6
Poplars-winter cereals
14 years

A 1.4 LER means

that a 100 ha agroforestry farms produces as much crop and tree products as a conventional 140 ha farm where trees and crops are separated

Part of a new green revolution

Increased efficiency of natural production factors (light, water, natural nitrogen)

Measured LER for agrivoltaic systems with various densities of PV panels

Dupraz et al, 2011, Renewable Energy 36: 2725-2732

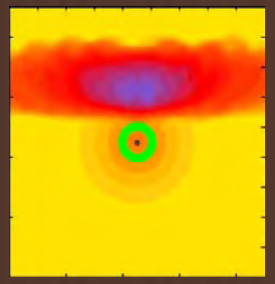
2003

2009

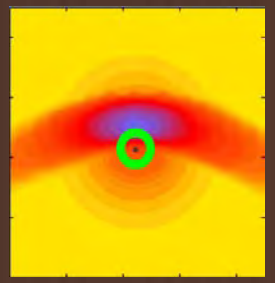
Solving the tree shade shape riddle

Average irradiation under an isolated tree → **Integrated irradiation under a tree stand**

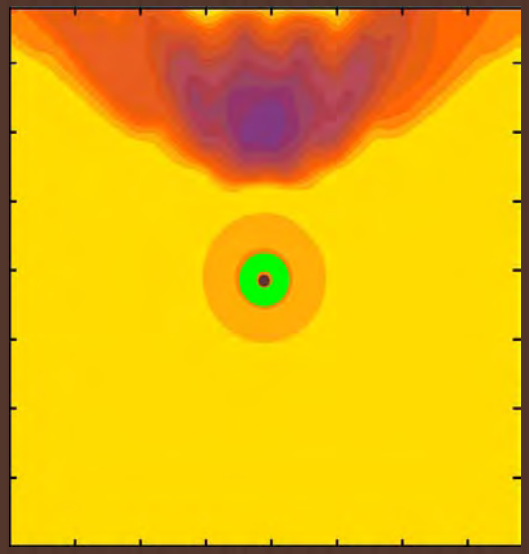
21 March / 21 September

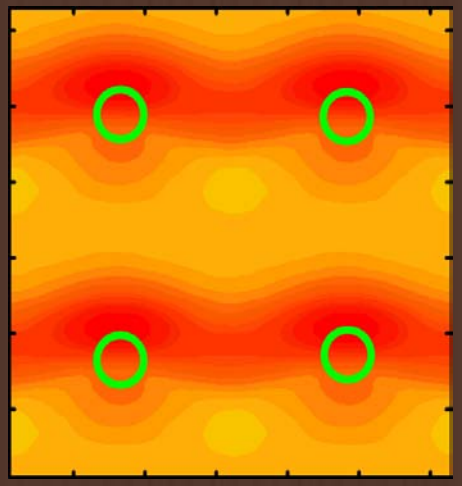


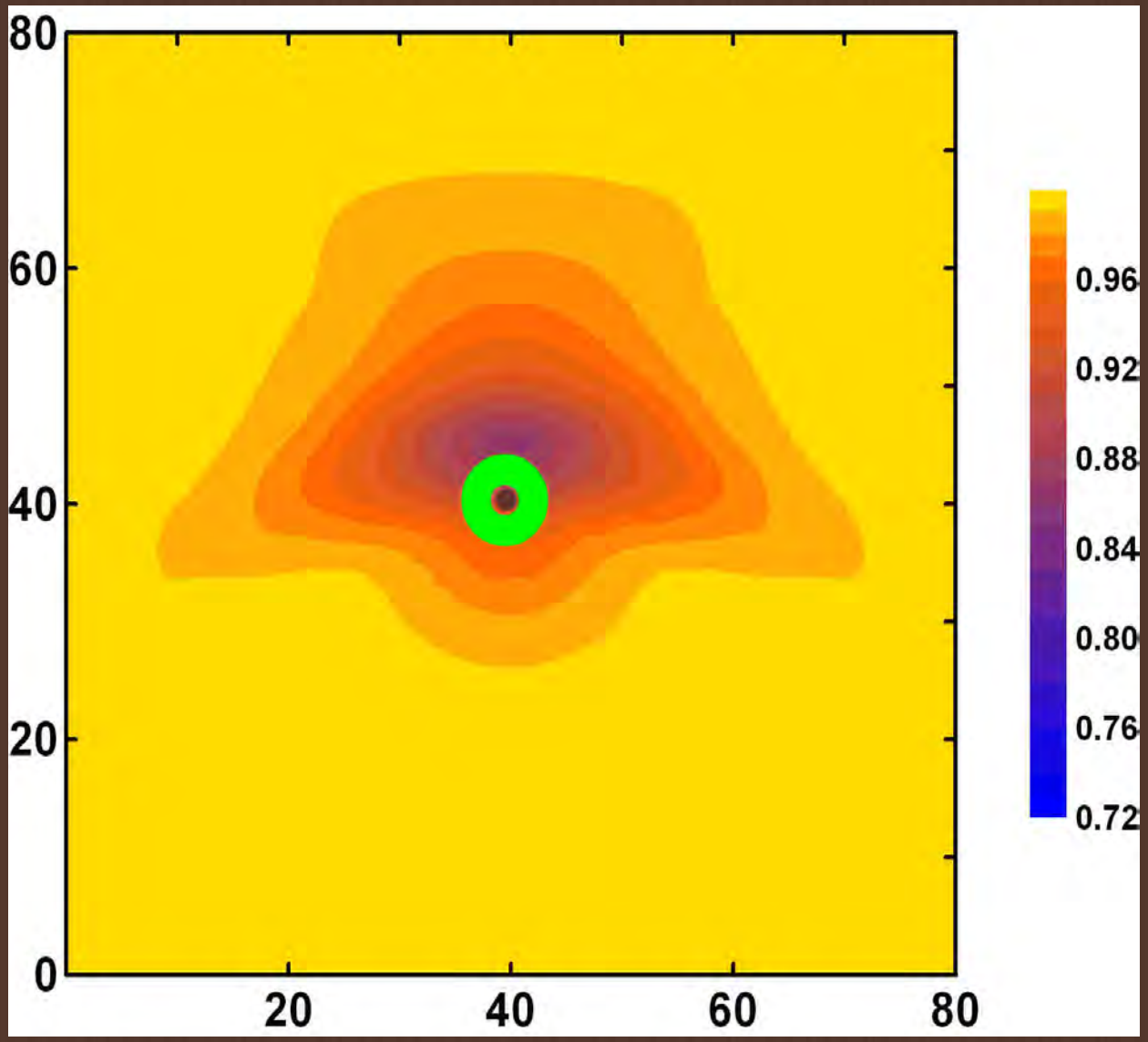
21 June



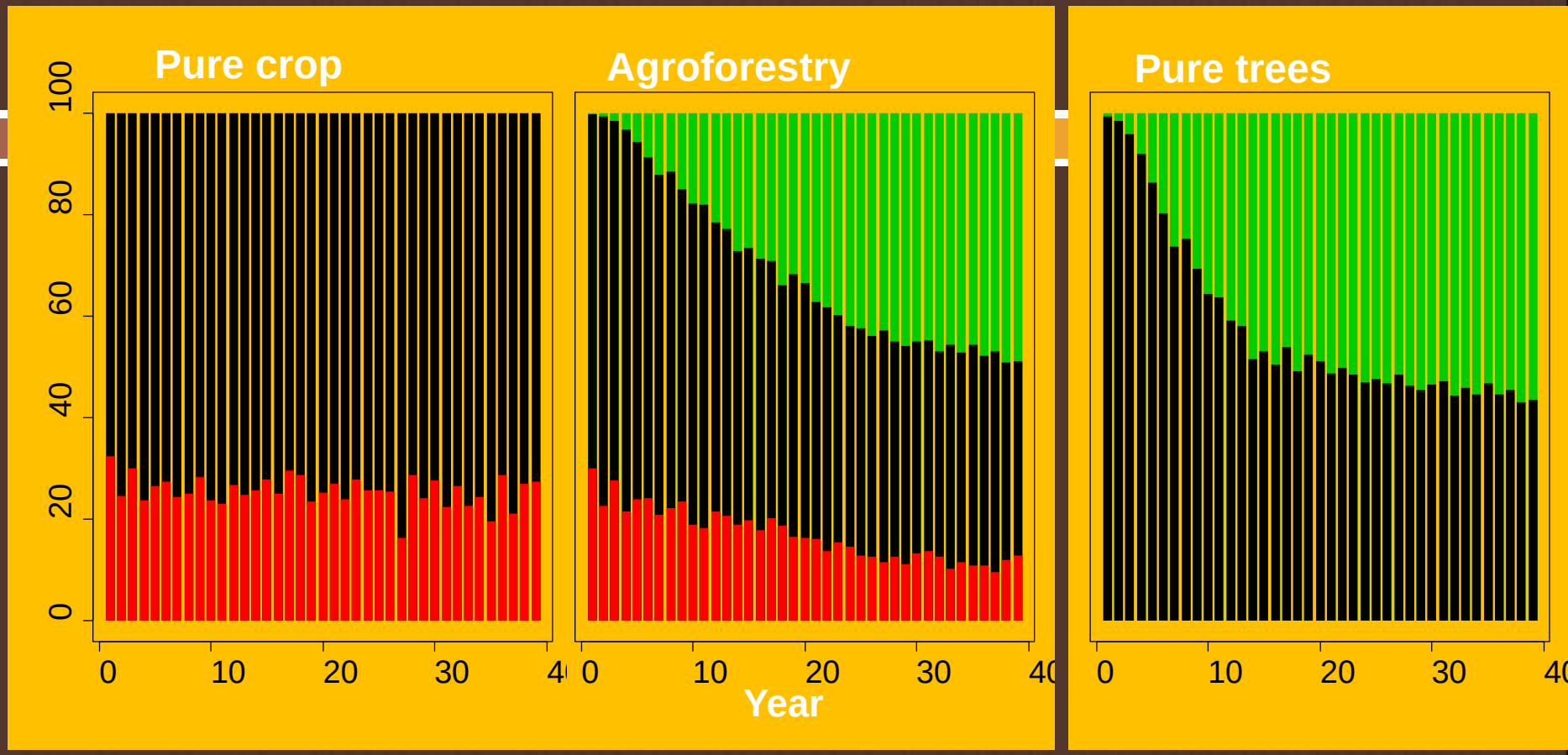
21 December






80
60
40
20
0
20
40
60
80
0.96
0.92
0.88
0.84
0.80
0.76
0.72

Light capture (40 years)

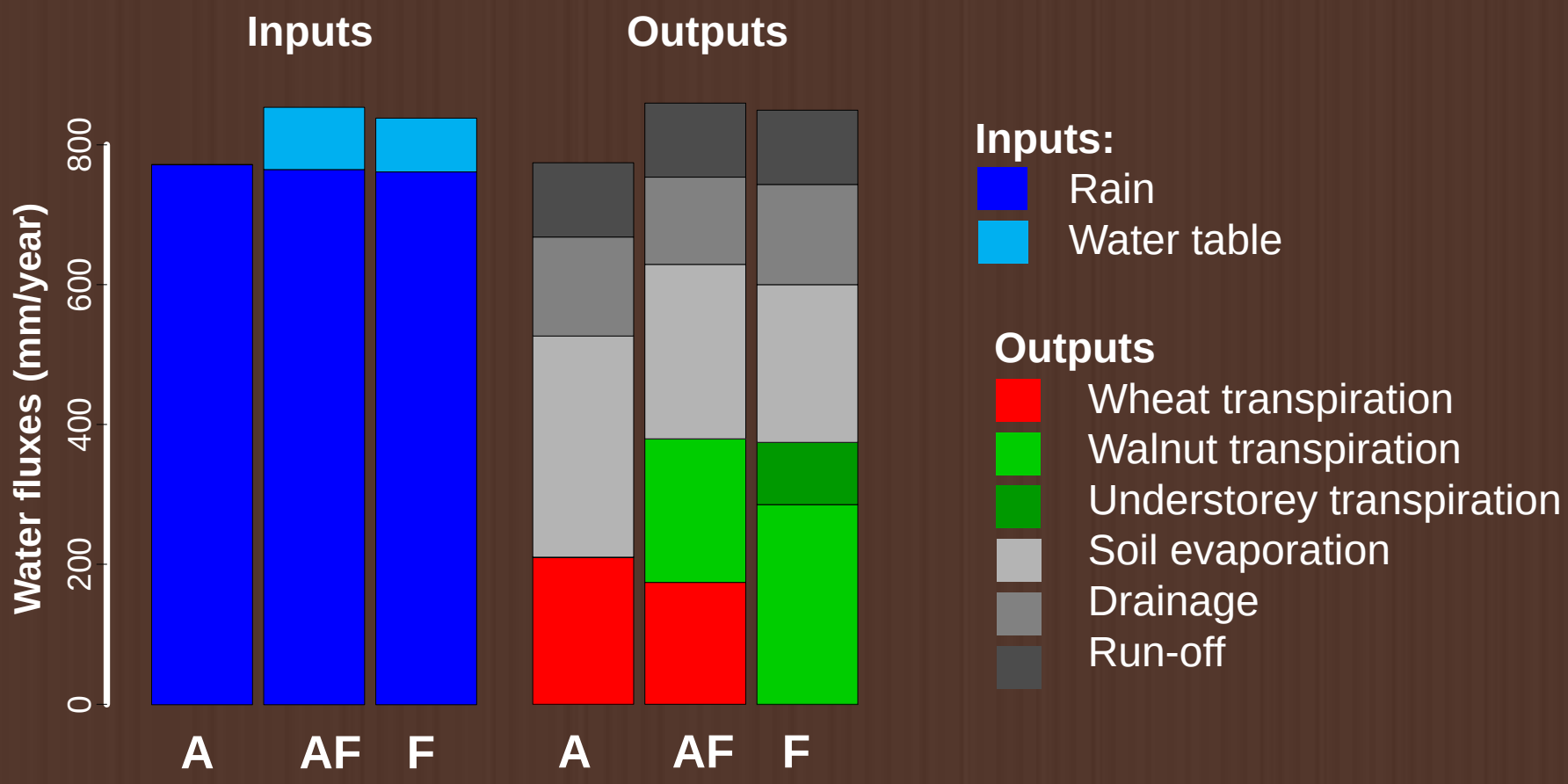


Light interception Land Equivalent Ratio :

Walnut trees : 0.73
Winter wheat : 0.66

Light LER = 1.39

Water budget (40 years)

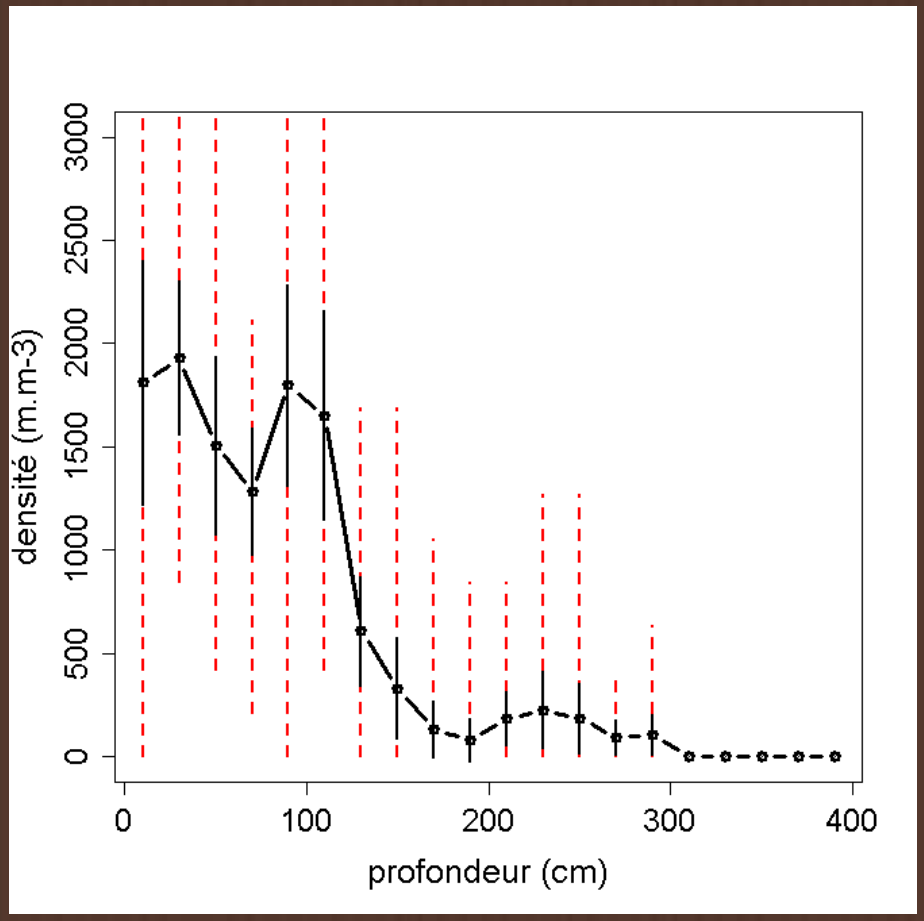


Water capture Land Equivalent Ratio :

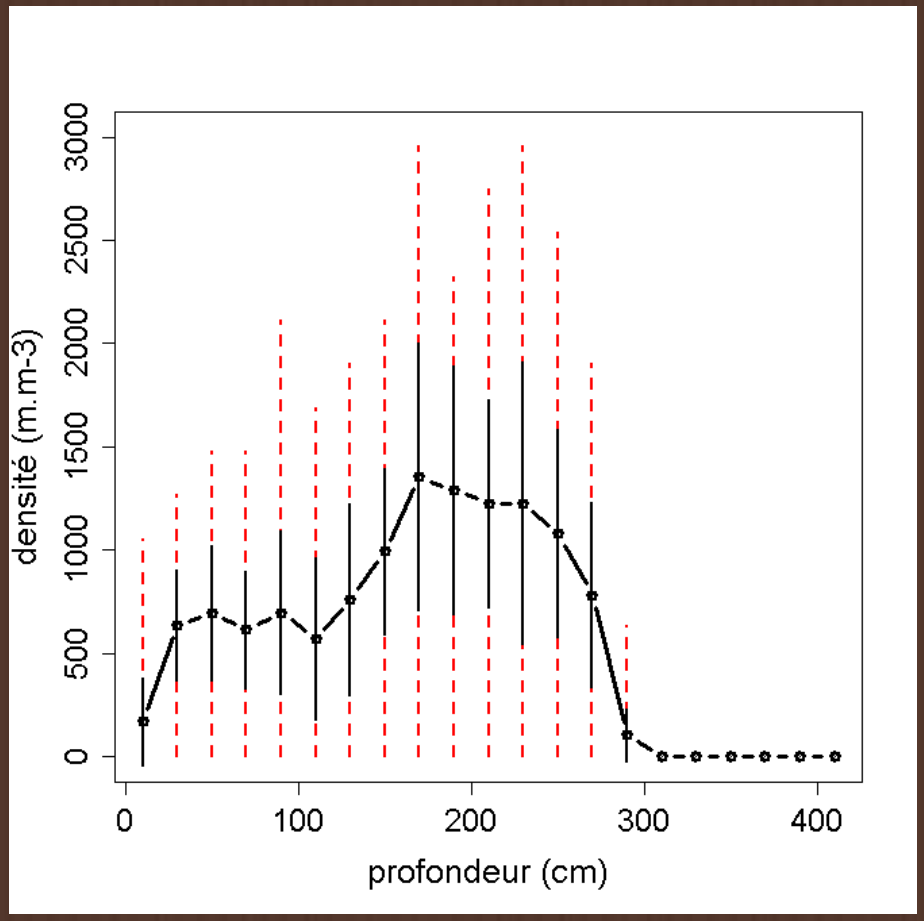
Walnuts : 0.71
Wheat : 0.84

Water LER = 1.55

Root profiles of 14 year old walnut trees (November 2009)



Pure walnut grove

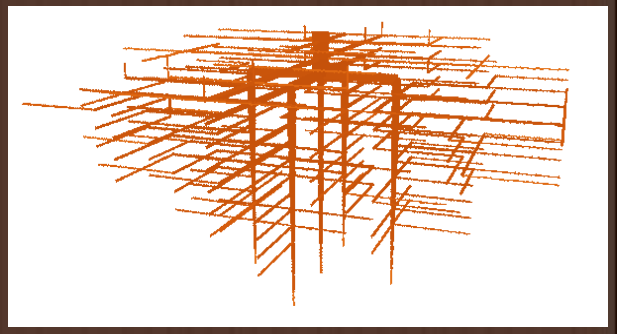


Walnut wheat Agroforestry

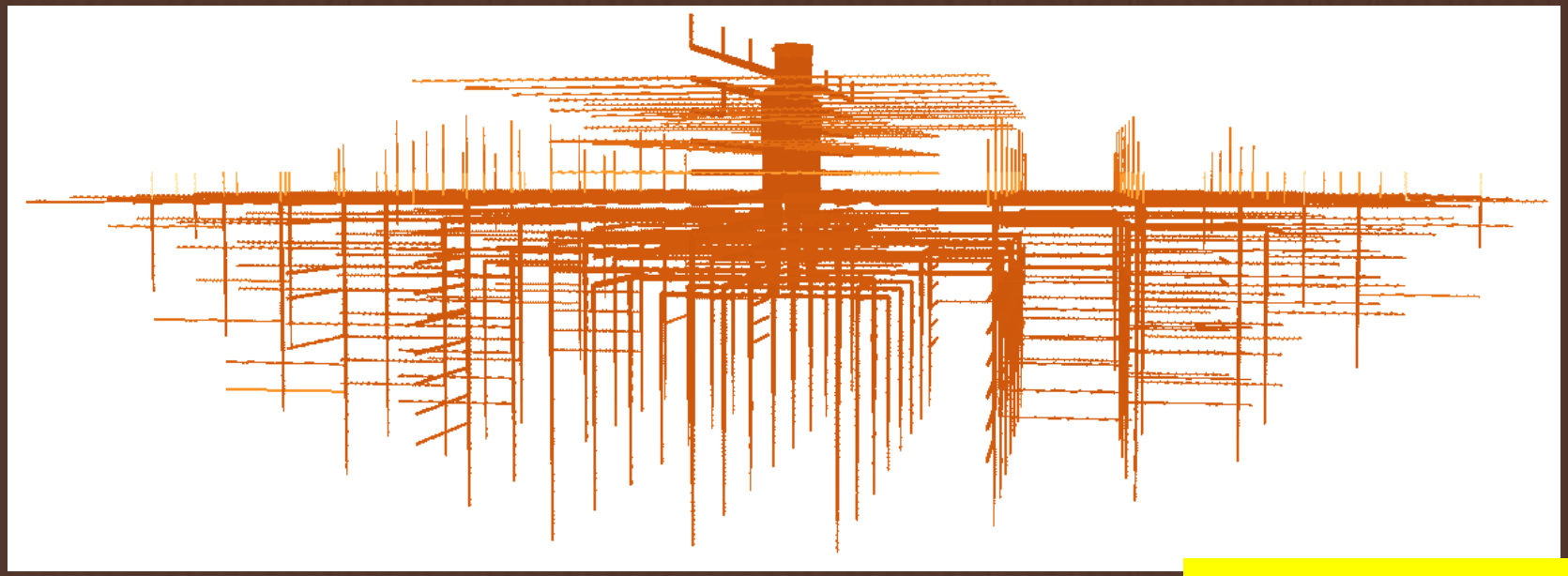
Experimental measures

Tree roots systems influenced by crop competition

Forest tree

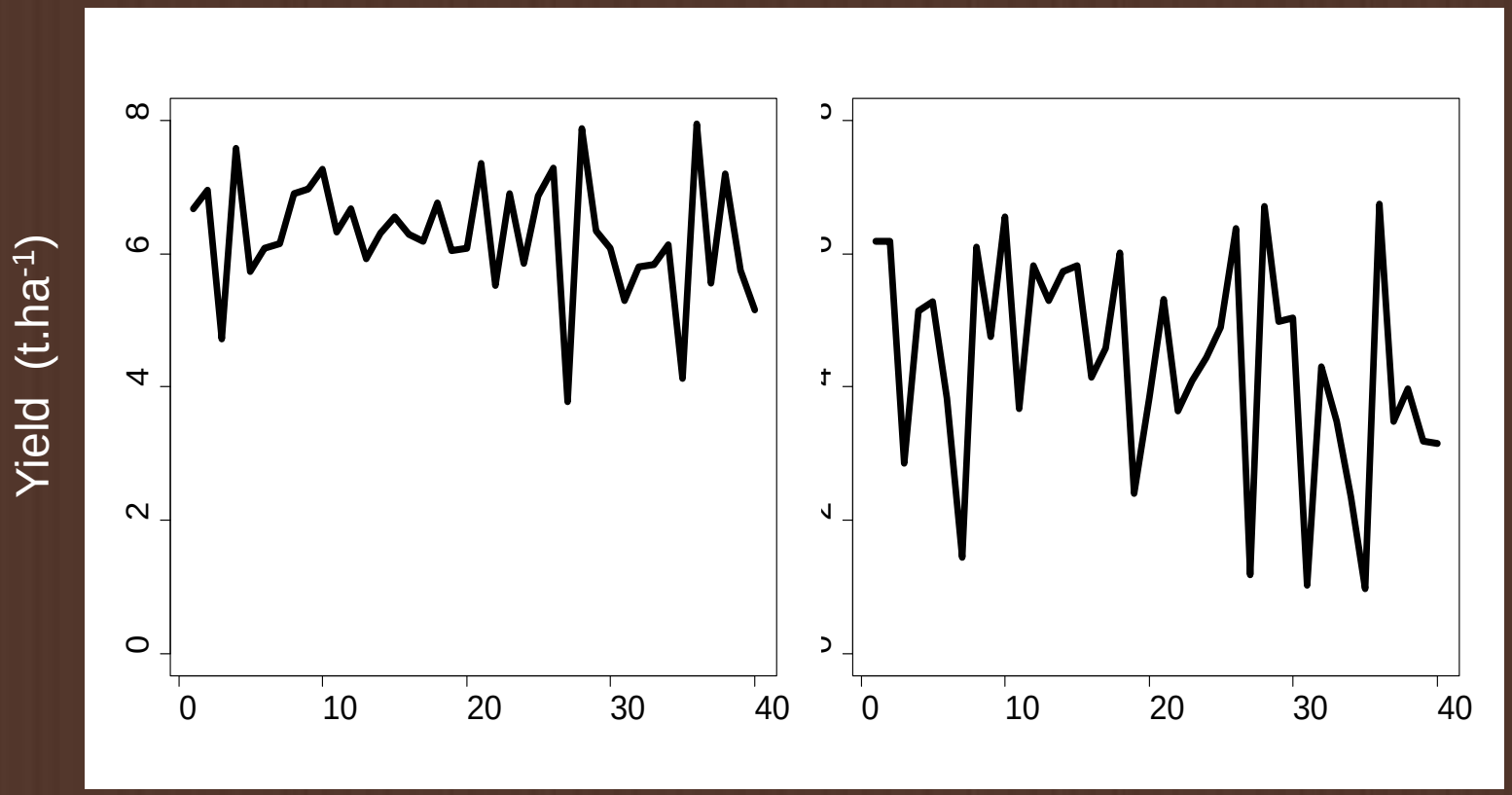


Agroforestry tree



Model predictions

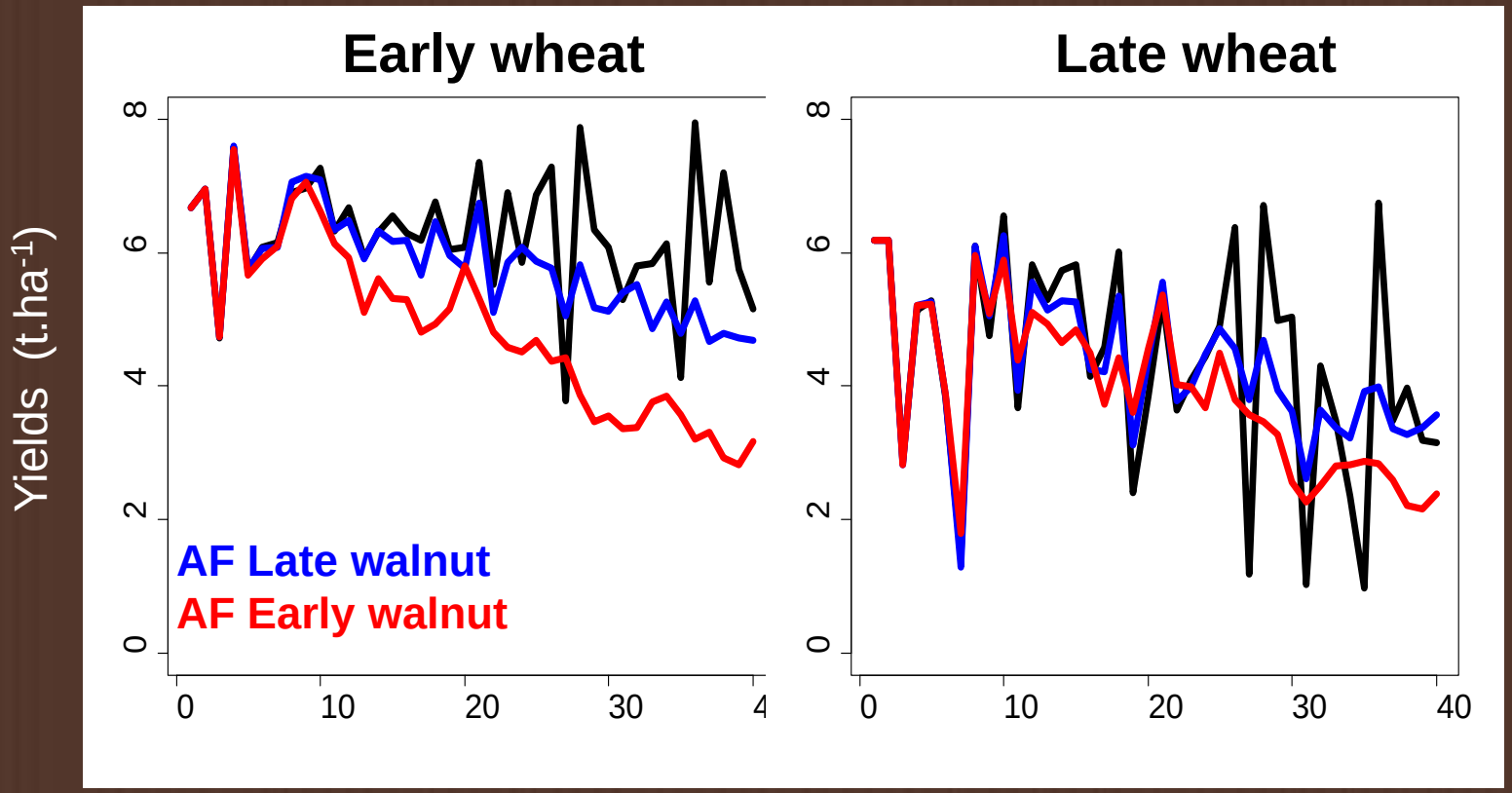
Wheat yields predicted



- Pure wheat : high variability in yields

Model predictions

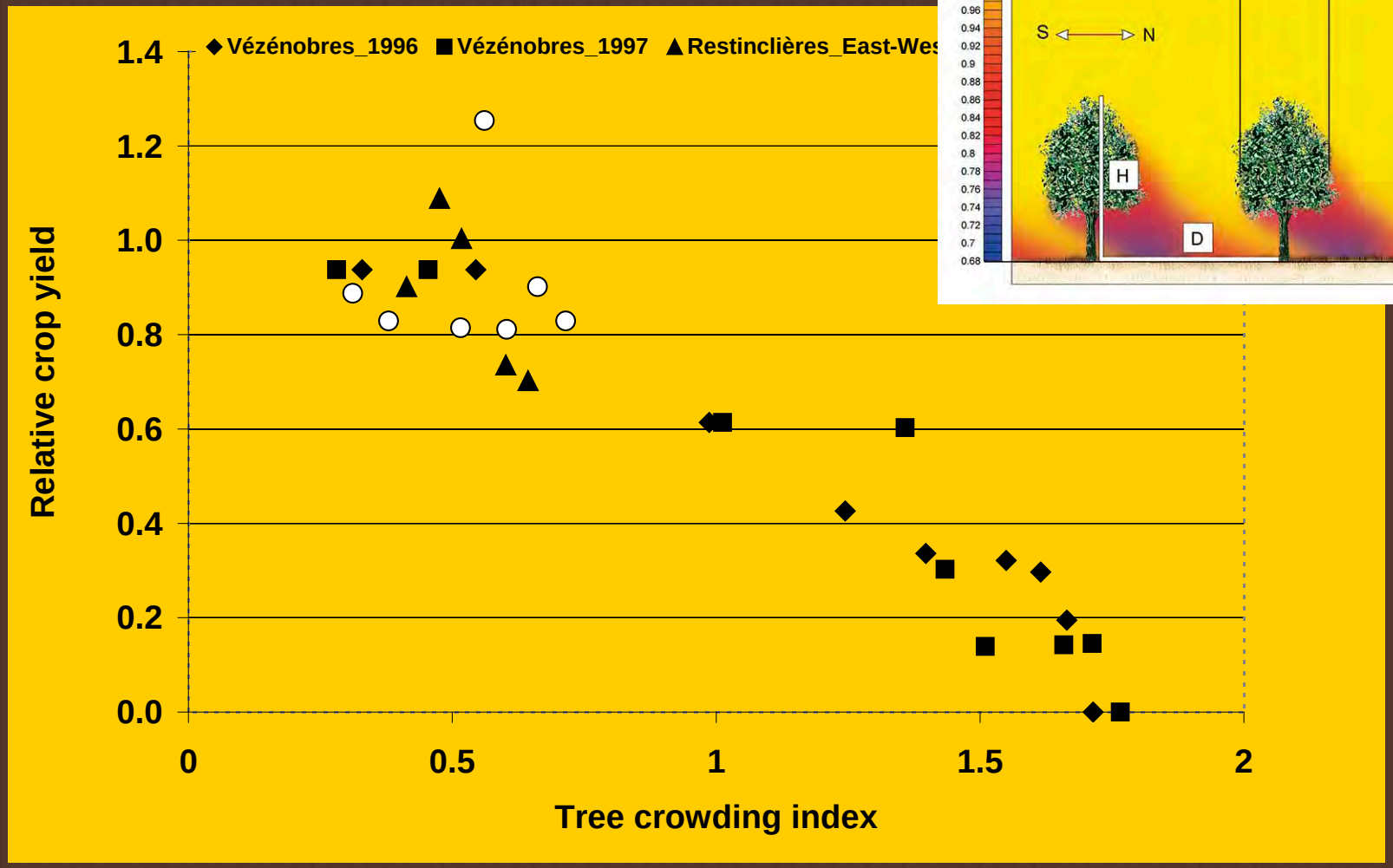
Wheat yields in agroforestry

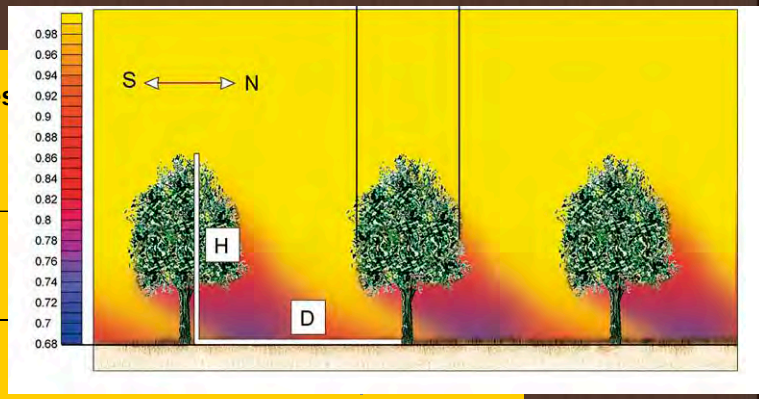


- AF : ↘ yield and variability (more impact of early walnut)

Model predictions

Looking for the best tree density





Research for action : guidelines for improved AF systems

Experimental measures

LER interpretation

- LERs can be simulated with process-based models
- The simulations allow to decompose the LER in various interacting effects
- This is a way to hierarchy factors of success in agroforestry and agrivoltaism

Talbot, 2011, Ph. D. thesis (Env. Model. Soft. In press)

LER interpretation for a walnut-wheat AF system

Land Equivalent Ratio :

Walnuts : 0.76
Wheat : 0.52

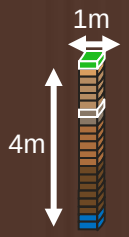
→ **LER = 1.28**

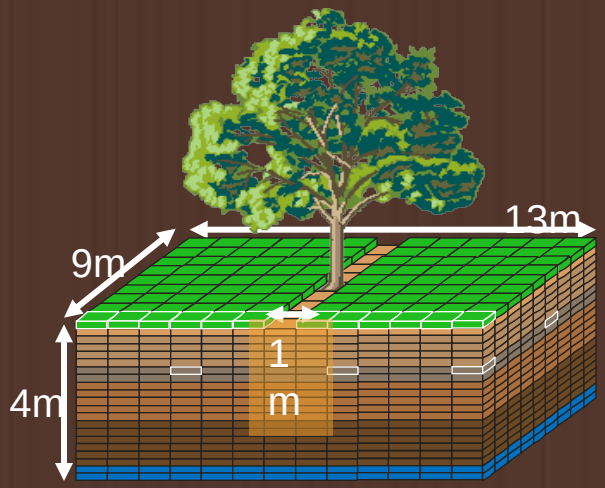
Modelling the 3 options concurrently

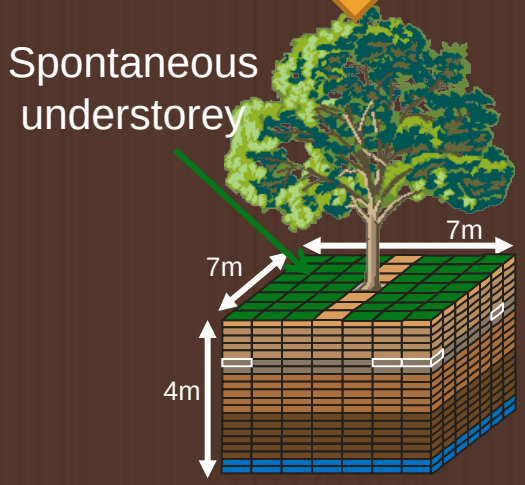
Pure crop

Same soil
Same climate
Same management
40 years

Pure tree







Decomposing the LER

- LER= $Ry_{tree} + Ry_{crop}$
- RY = π[relative indexes]
- Exemple of decomposition :
- RY =

  Relative density
  x Size Memory
  x Light competition
  x Water competition
  x Harvest Index

Decomposing the relative yield of trees

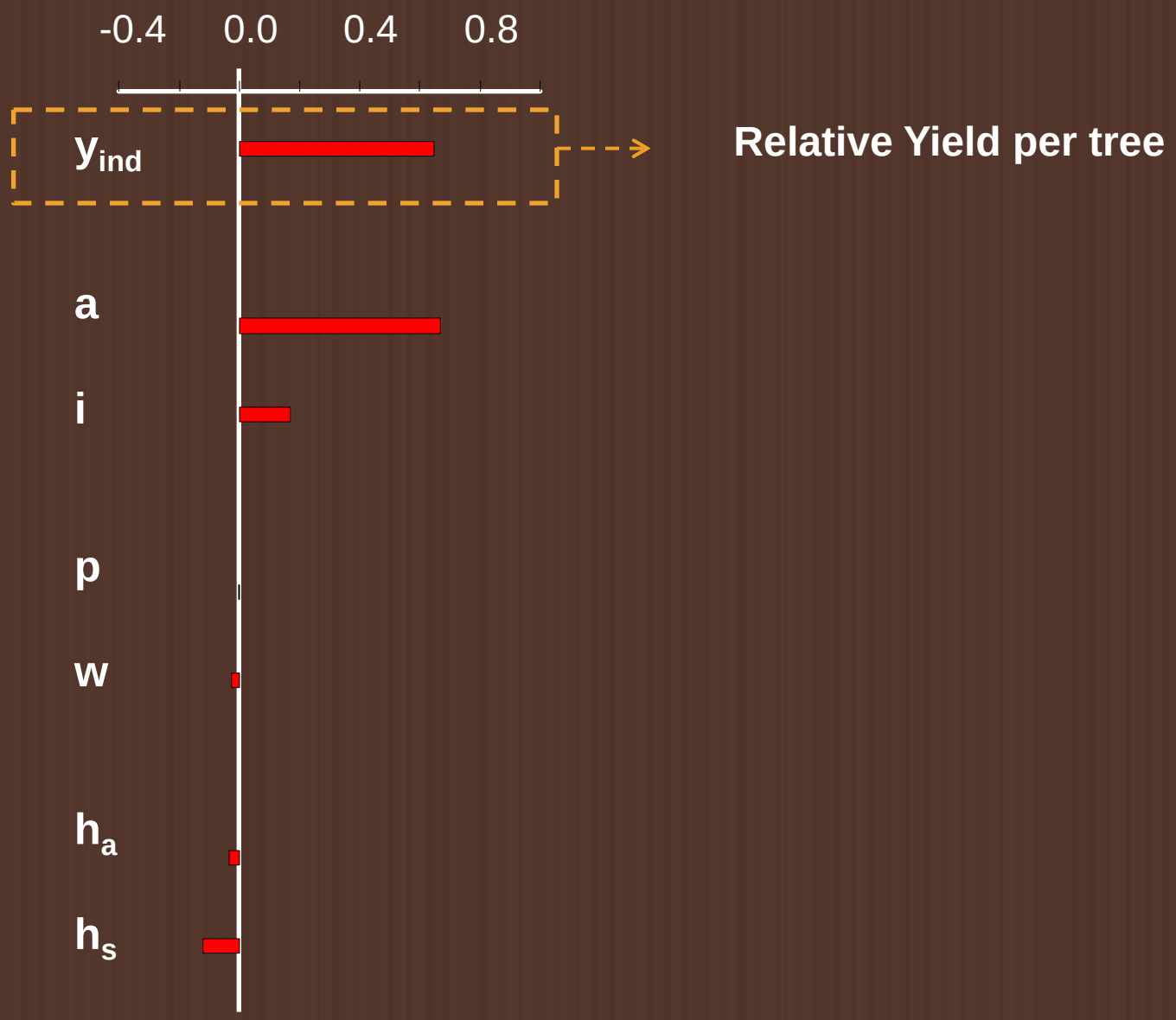
$$y_{ind} = [a\ i] * [p\ w] * [h_a h_s]$$

Interception light:
- a : interception capacity
- i : competition

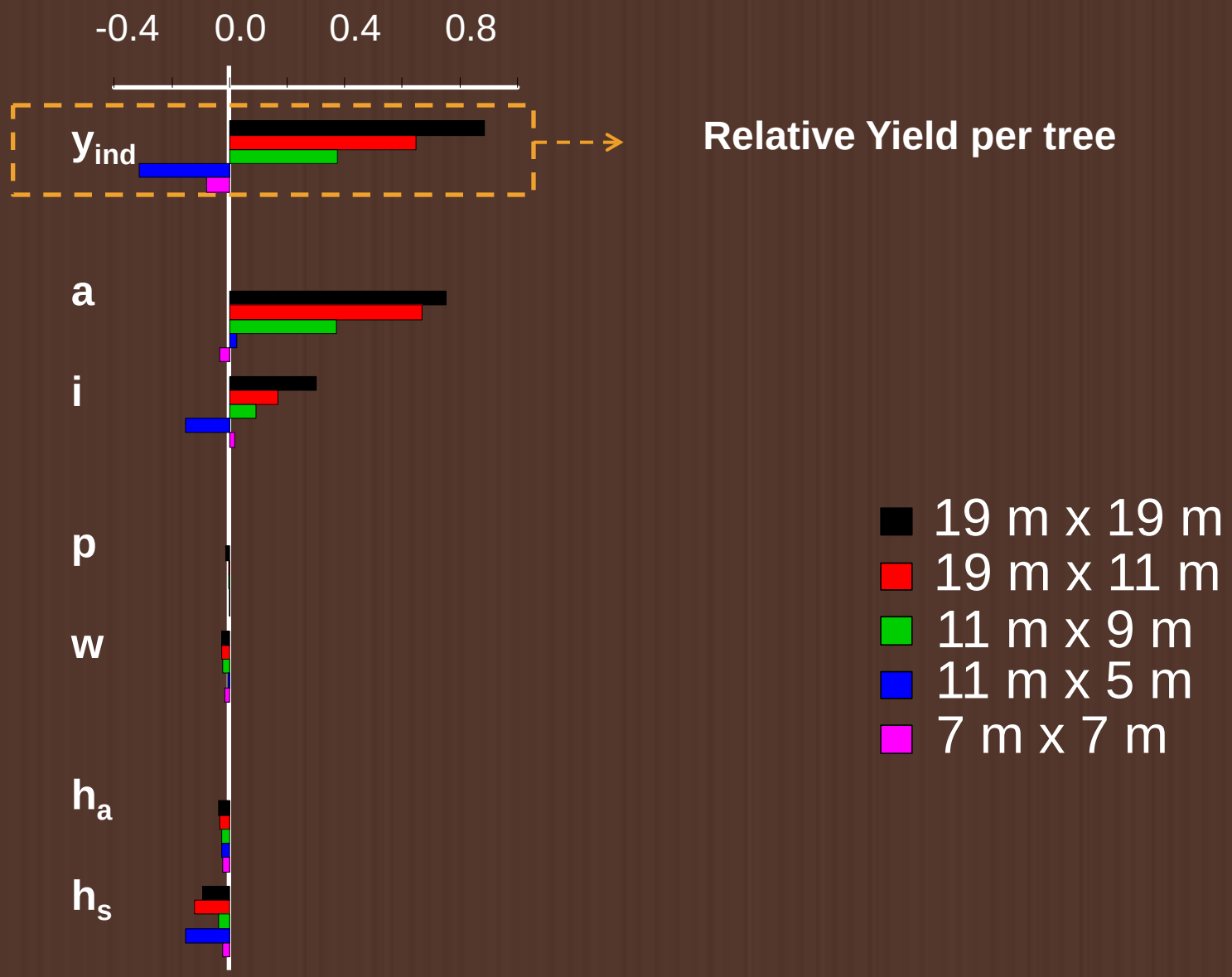
Conversion into biomass:
- p : leaf aging
- w : water stress

Harvest ratio
- h_a : ABG/BG allocation
- h_s : Trunk allocation

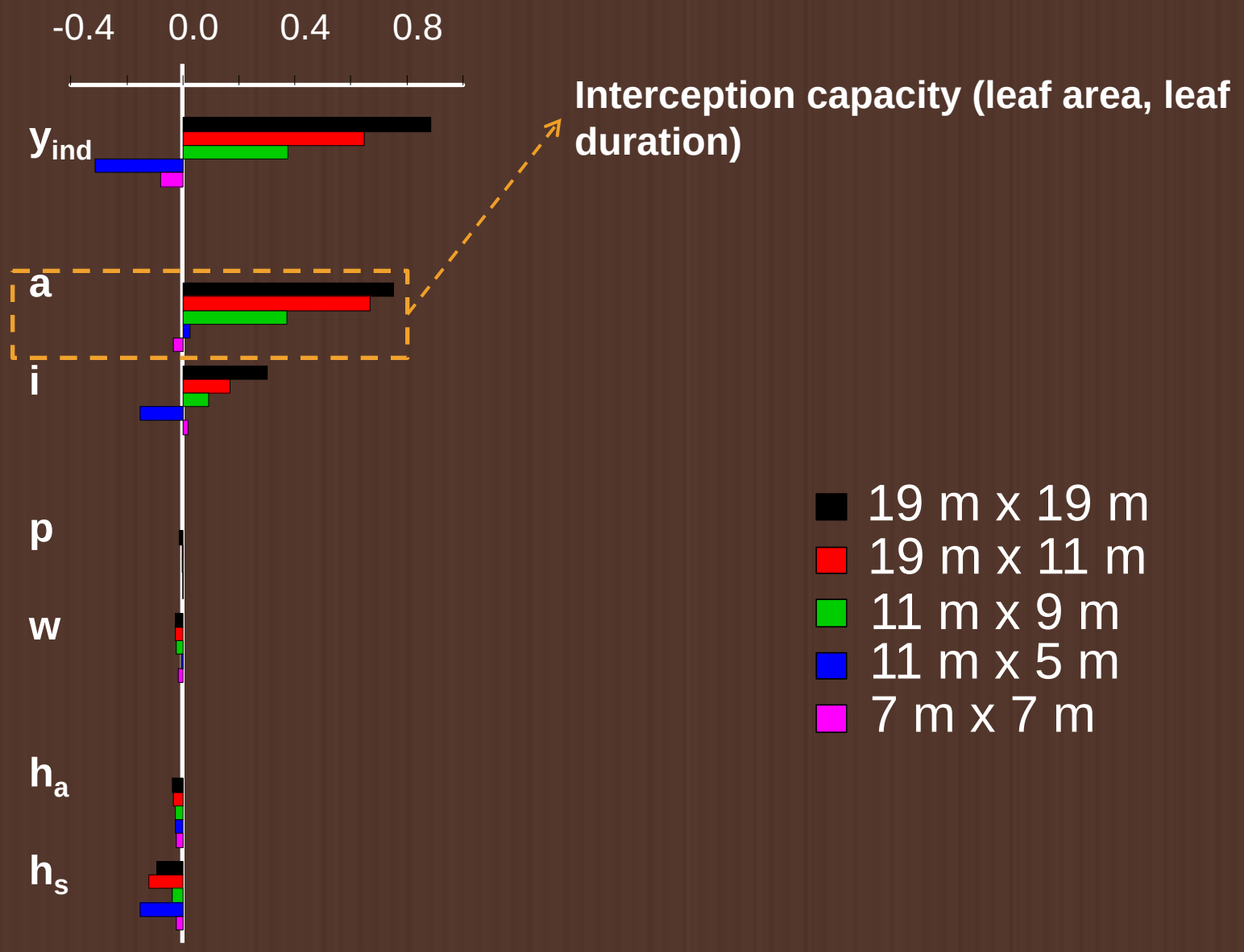
Decomposing the relative yield of trees



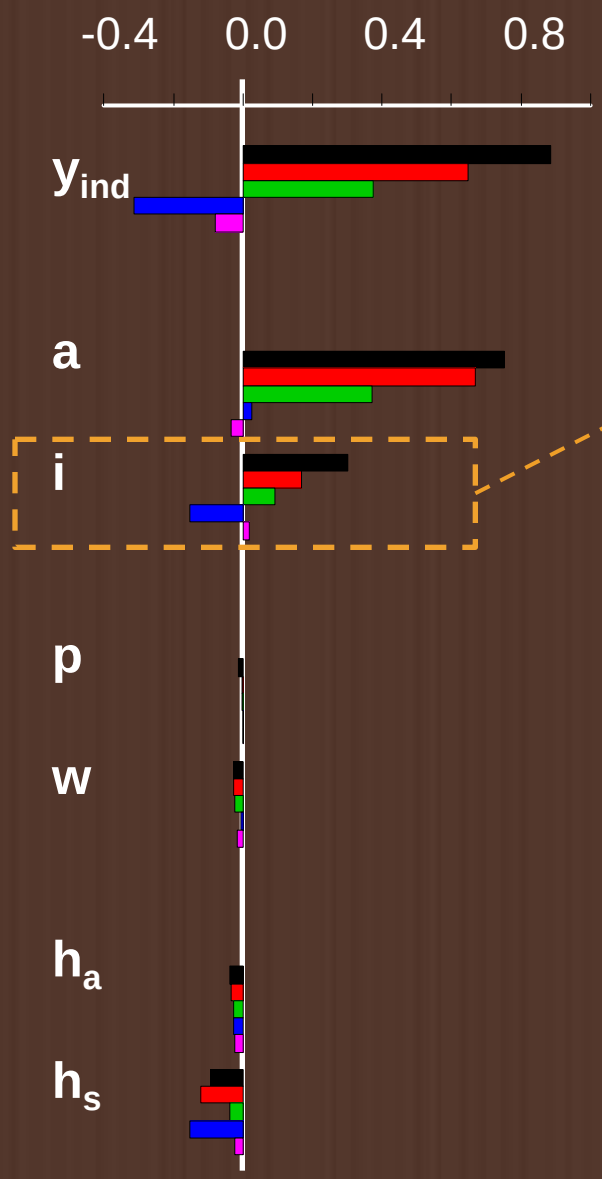
Decomposing the relative yield of trees



Decomposing the relative yield of trees



Decomposing the relative yield of trees

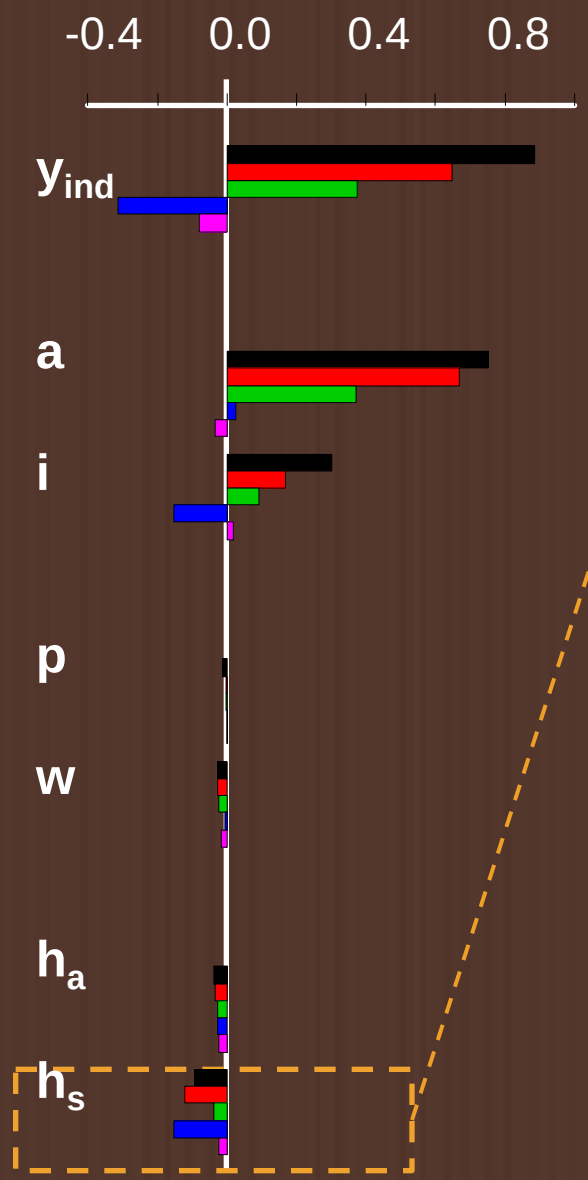


Light competition

- On the tree line space essential

- 19 m x 19 m
- 19 m x 11 m
- 11 m x 9 m
- 11 m x 5 m
- 7 m x 7 m

Decomposing the relative yield of trees



C Allocation to trunk:

- Negative
- Large canopies -> C allocated to branches

- 19 m x 19 m
- 19 m x 11 m
- 11 m x 9 m
- 11 m x 5 m
- 7 m x 7 m

Decomposing the crop yield

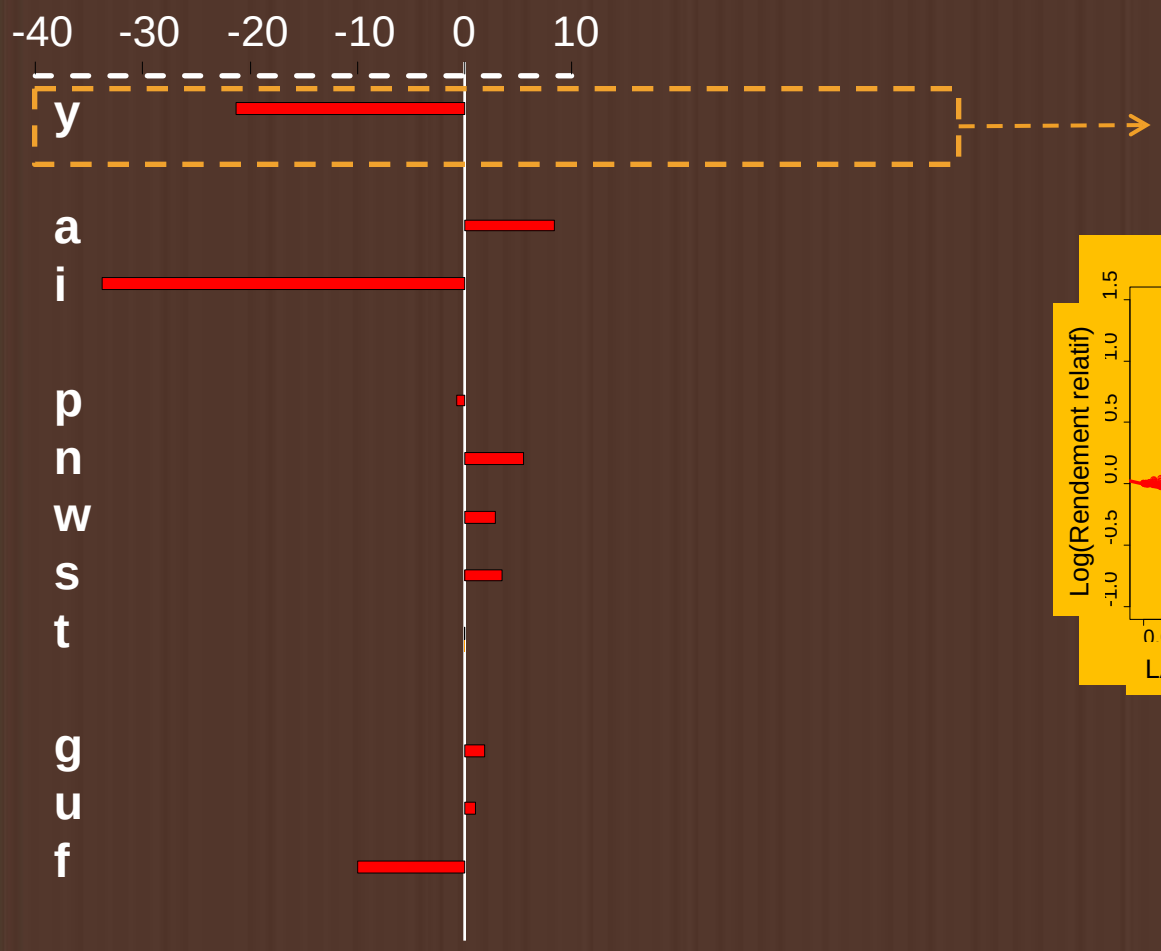
$$y = [a\ i] * [p\ n\ s\ t\ w] * [g\ u\ f]$$

Light Interception :
- a : interception capacity
- i : competition by trees

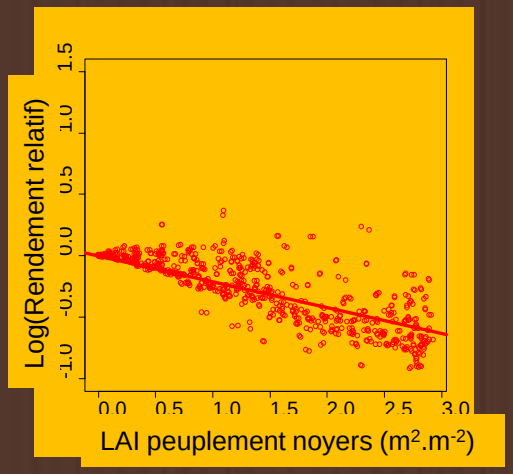
Conversion to biomass :
- p : phenology
- n : nitrogen stress
- s : light saturation
- t : temperature stress
- w : water stress

Harvest index
- g : grain filling duration
- u : thermal stress
- f : grain number

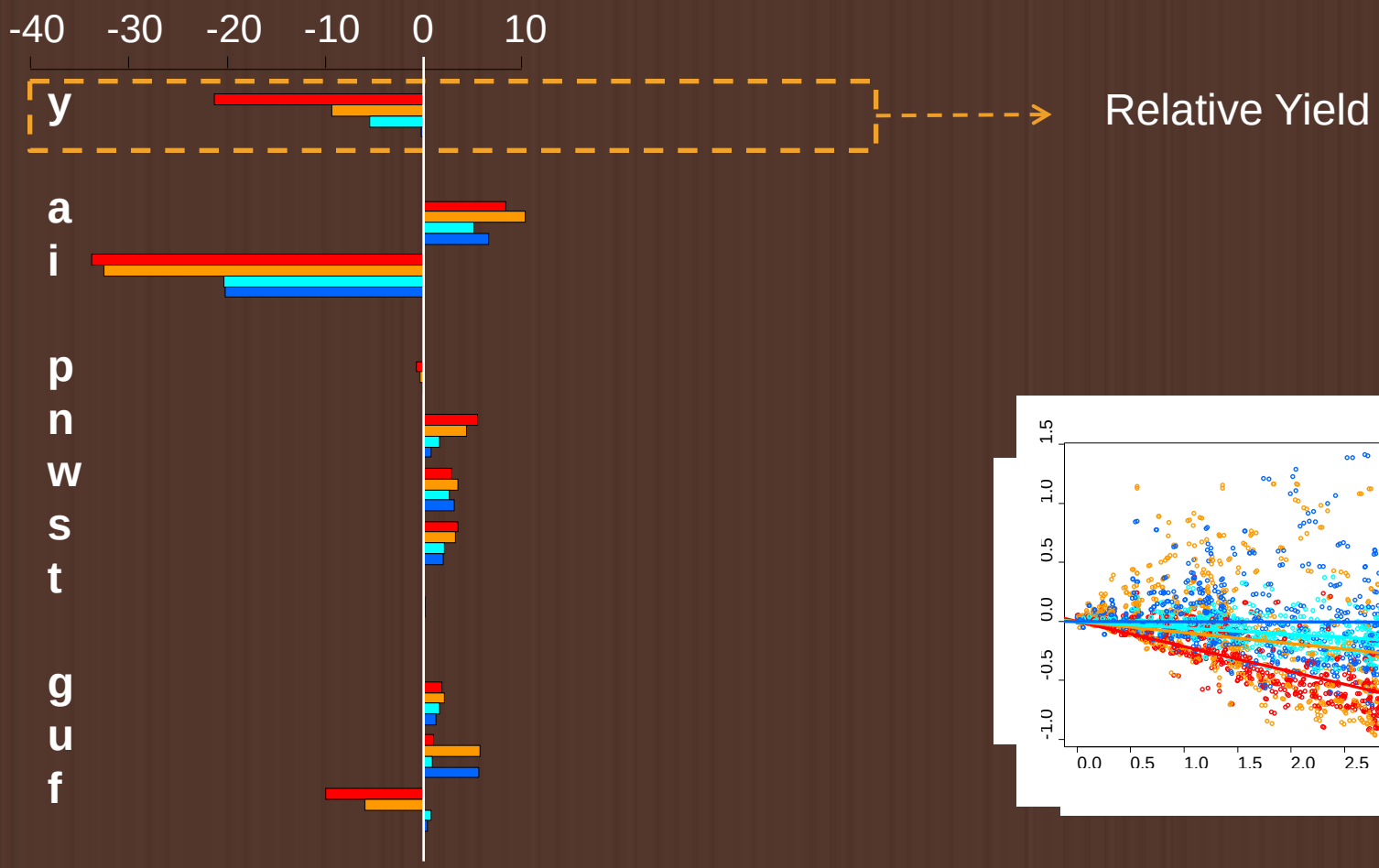
Decomposing the crop yield

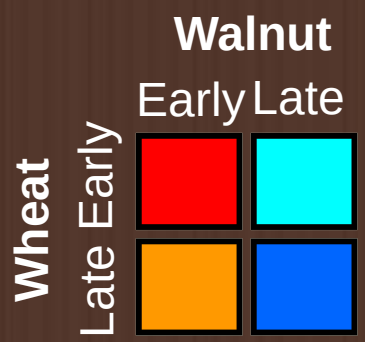


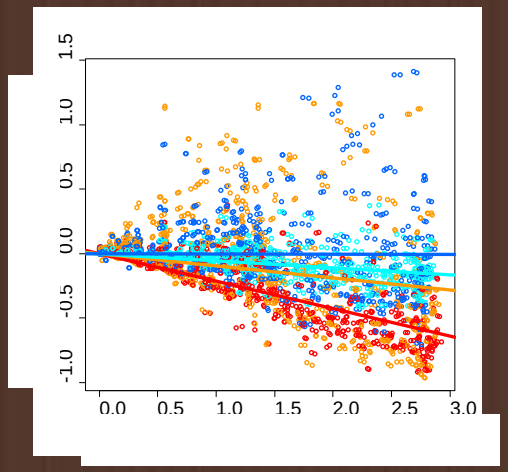
Relative yield



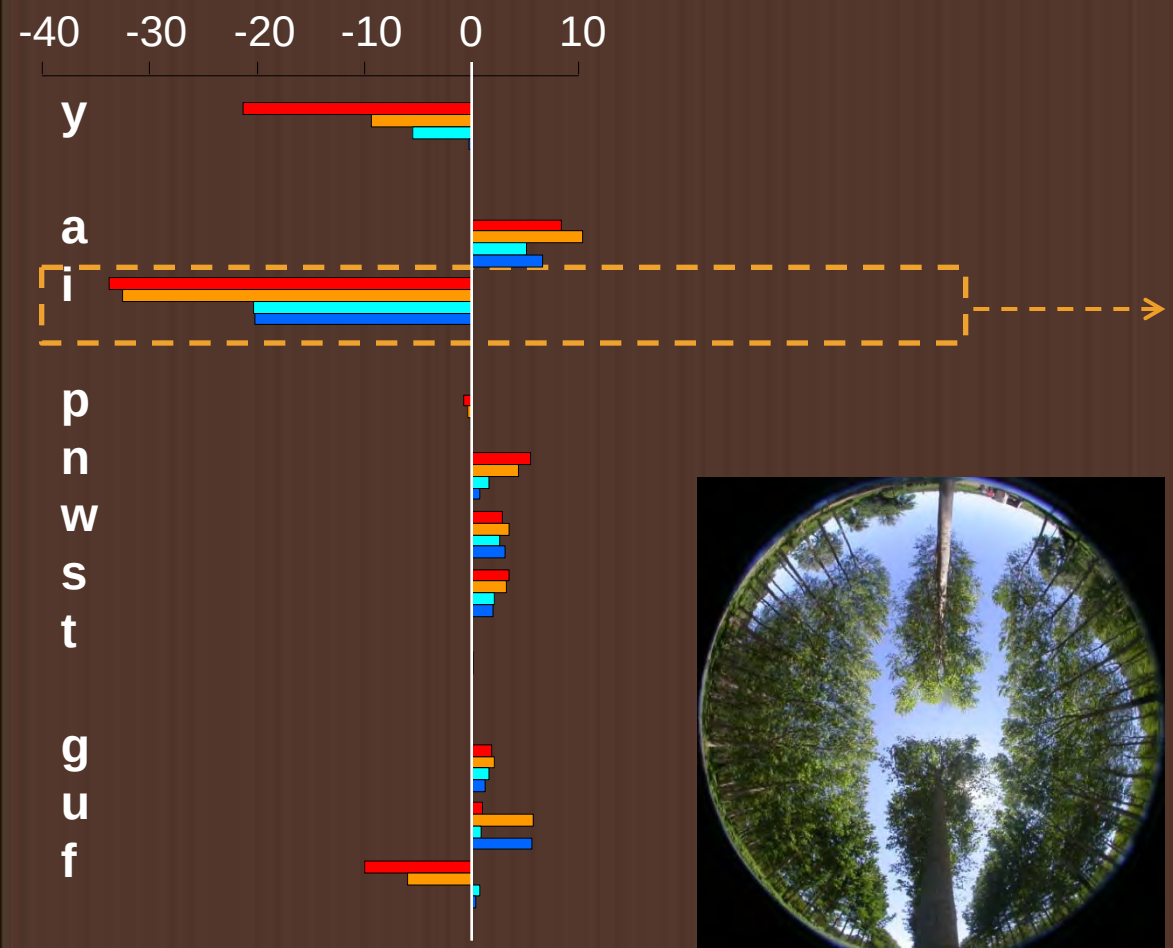
Decomposing the crop yield

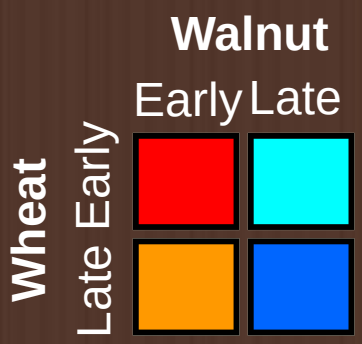






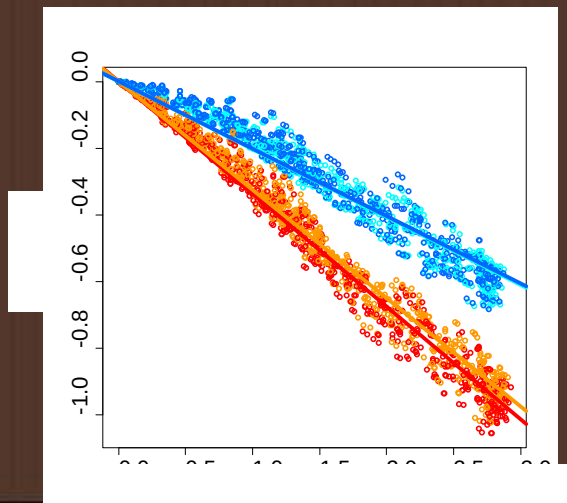
Decomposing the crop yield



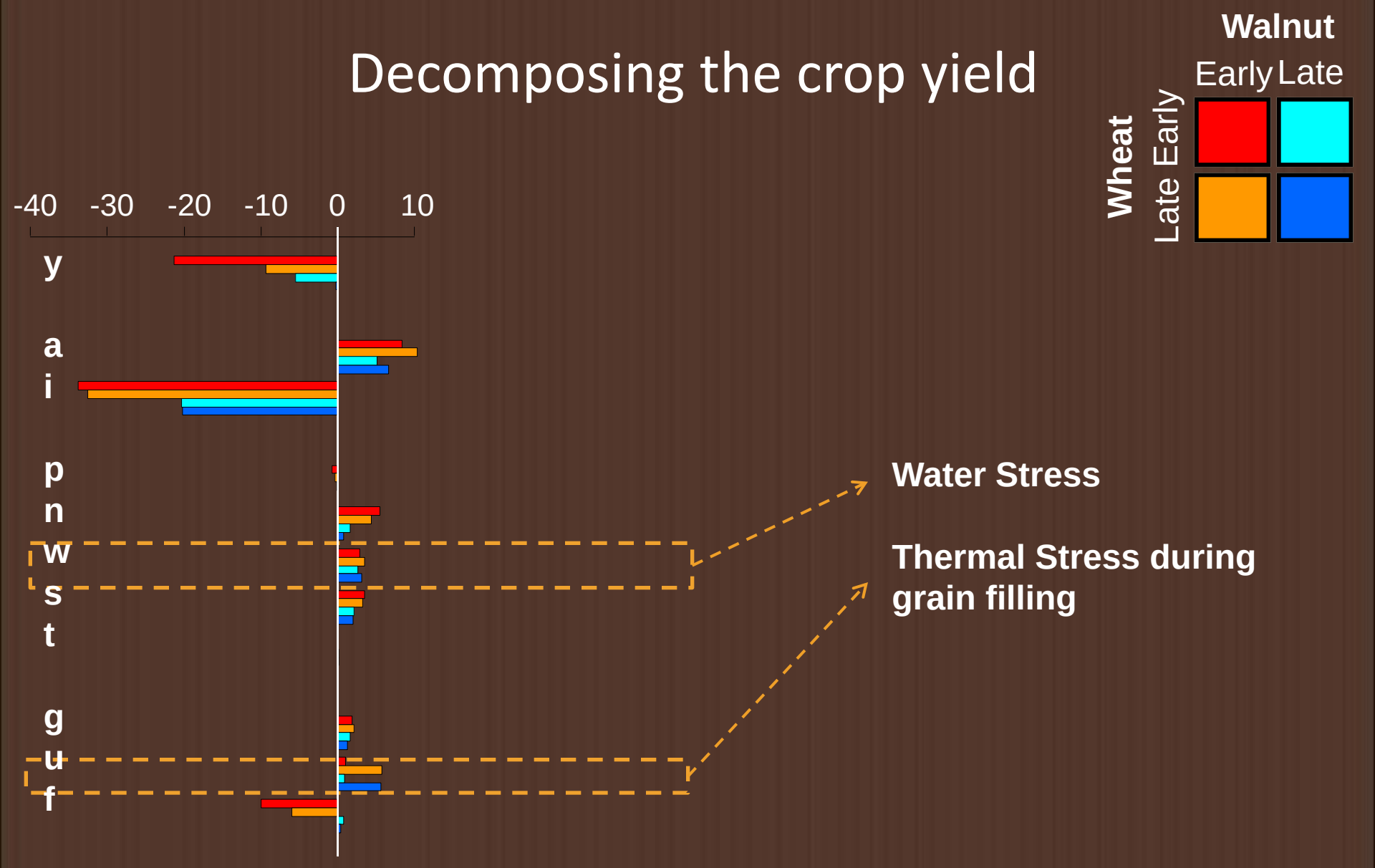


Light Competition :

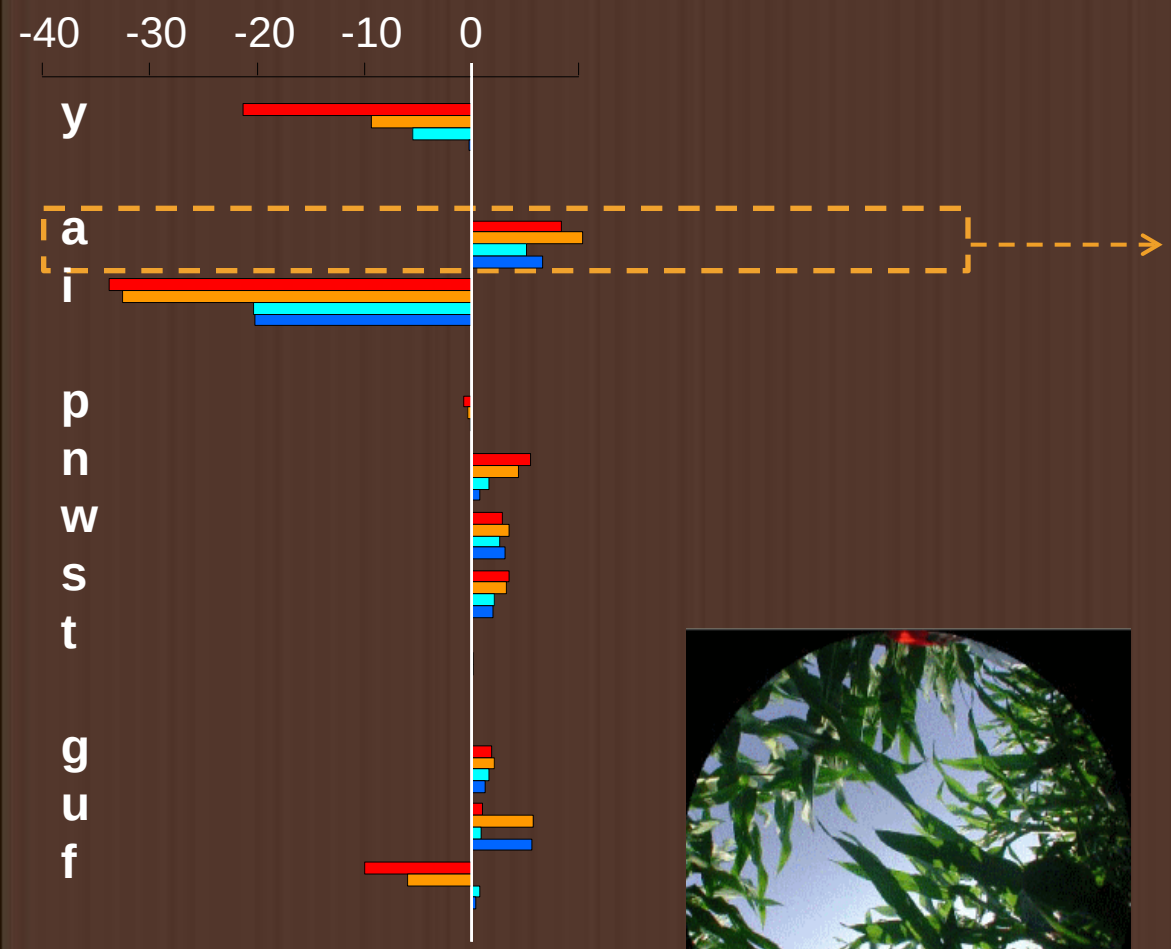
- Major and negative effect
- Strong under early walnut

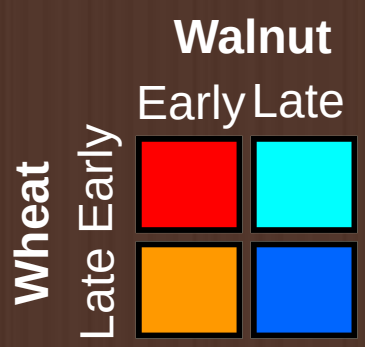


Decomposing the crop yield



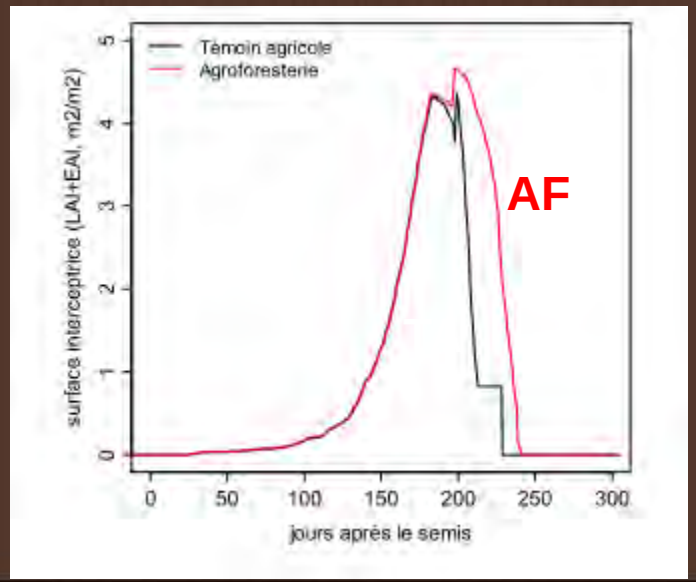
Decomposing the crop yield



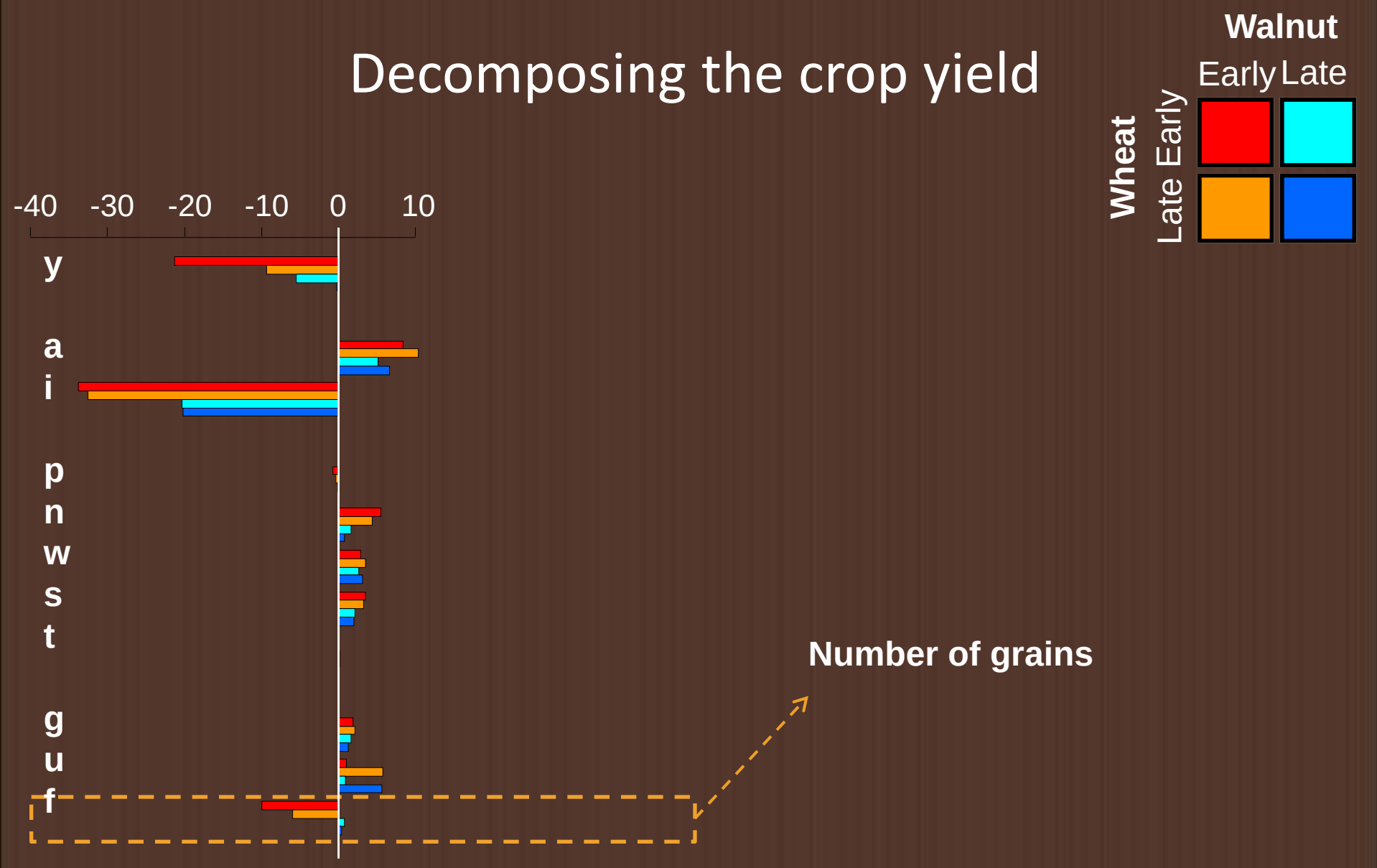


Interception capacity

- Delayed senescence



Decomposing the crop yield

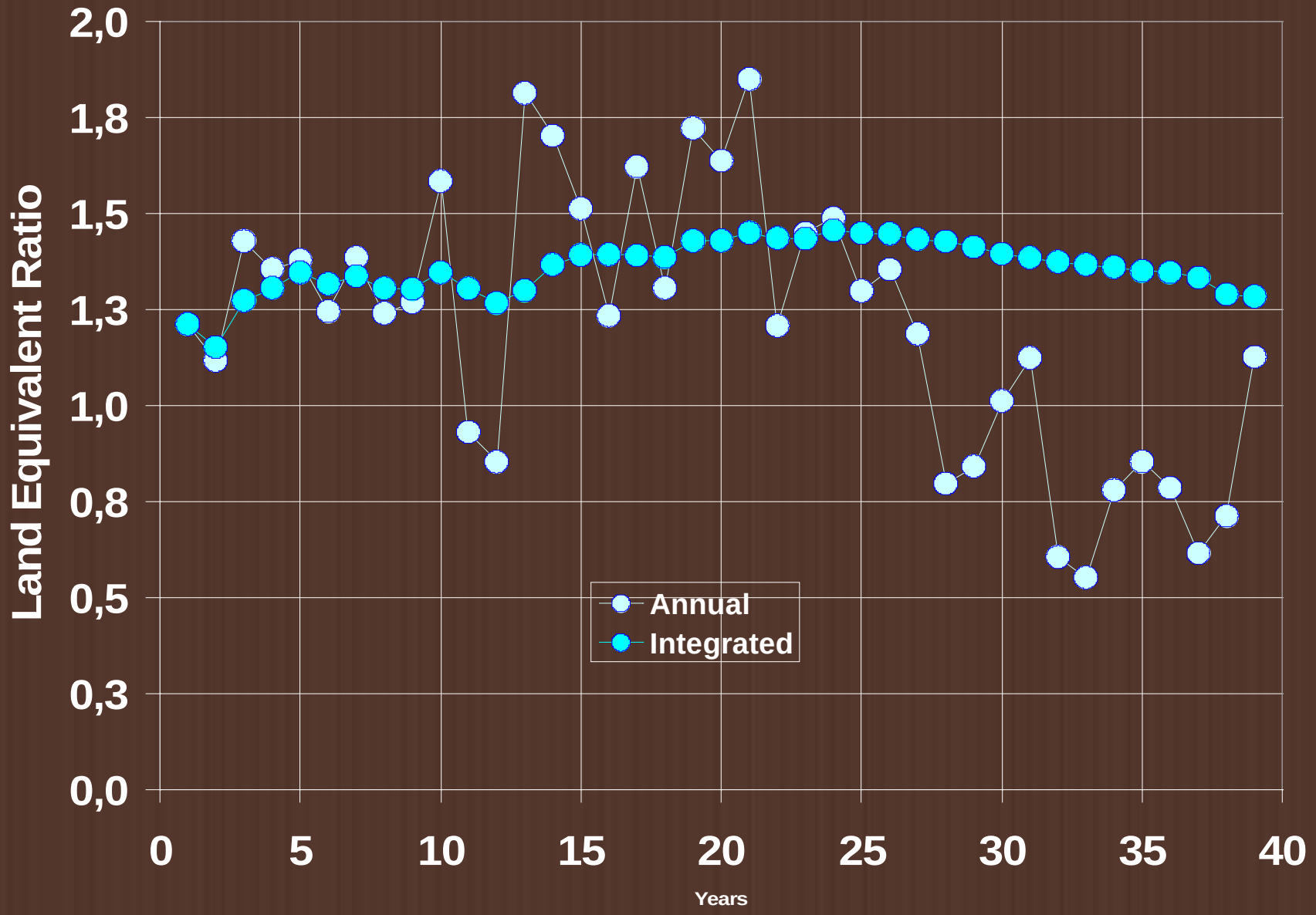


If the model is right…

	Advantages in AF	Drawbacks in AF	Neutral
Trees	**Larger canopies** Less light competition	Few trees Invest C in roots	Water stress
Winter Crops	Reduced water stress Longer life of leaves Reduced N stress Reduced heat stress	Reduced cropped area **Less light**	Harvest index (?)

Integrated over 40 years

But what dynamics during the 40 years?


Land Equivalent Ratio
2,0
1,8
1,5
1,3
1,0
0,8
0,5
0,3
0,0
0
5
10
15
20
25
30
35
40
Years
Annual
Integrated

A synthesis of probable LERs of temperate AFs

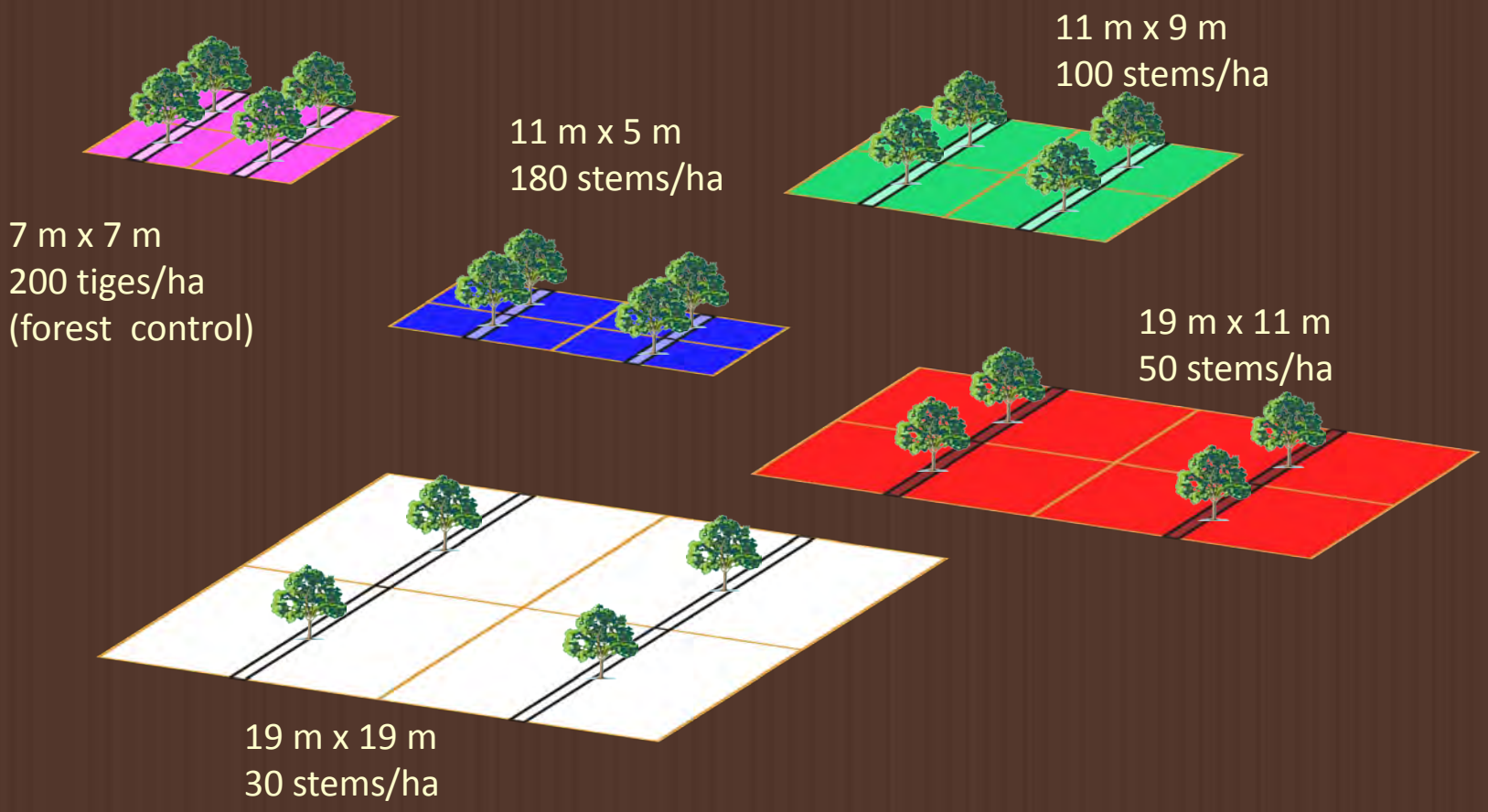
Association type	Plant Cycles	Soil depth	Root segre-gation	Water body in summer	Probable LER
Walnut-cereal on plains with a water table	Almost complementary	Deep	High	Yes	1.5
Sorbus-wheat	Lagged	Medium	Intermediate	No	1.4
Prunus-Medicago	Close	Deep	Intermediate	No	1.3
Prunus-sunflower	Synchronous	Shallow	Poor	No	1.2
Populus-maize	Synchronous	Poor	No	Yes	1.1
Evergreen tree and summer crop	Superposed	Any	Variable	No	1.0
Never demonstrated so far					<1.0

Conclusions

- LERs of AFs may be extremely high (part of a second green revolution?)
- Process-based models can help in interpreting productivity results of AF systems at various time steps.
- Winter crops better in AF (temperate latitudes-specific)

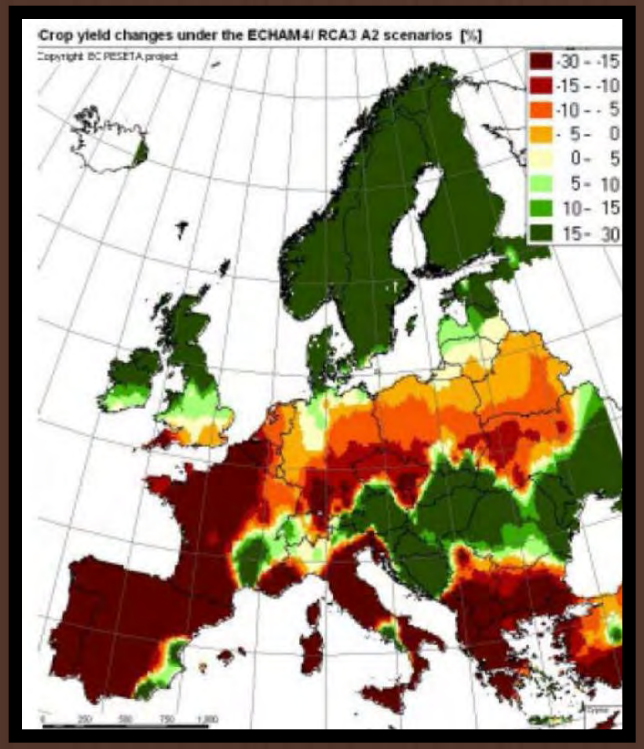
Pending : more virtual experiments

Tree density and plantation design

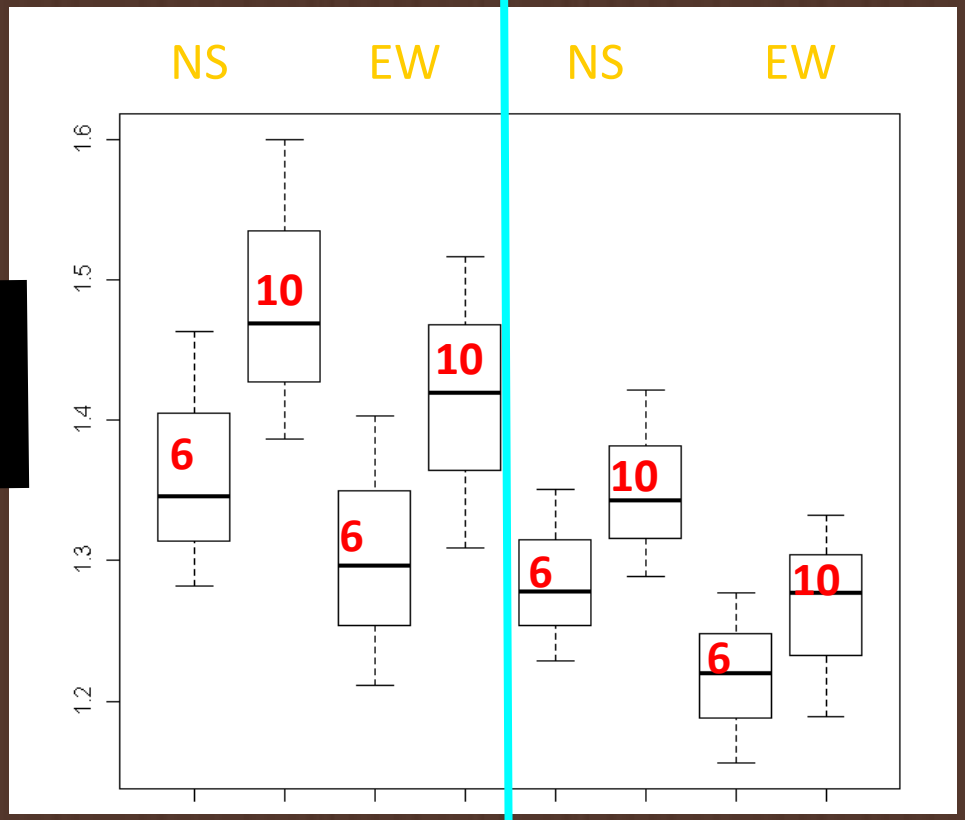


Pending : more virtual experiments

AF and Climate change :
are crops in AF protected against climate change hazards ?



Pending : System management optimisation assisted by modelling



133 trees.ha^{-1}

64 trees.ha^{-1}

Tree density

Tree line orientation
North-South / East-West

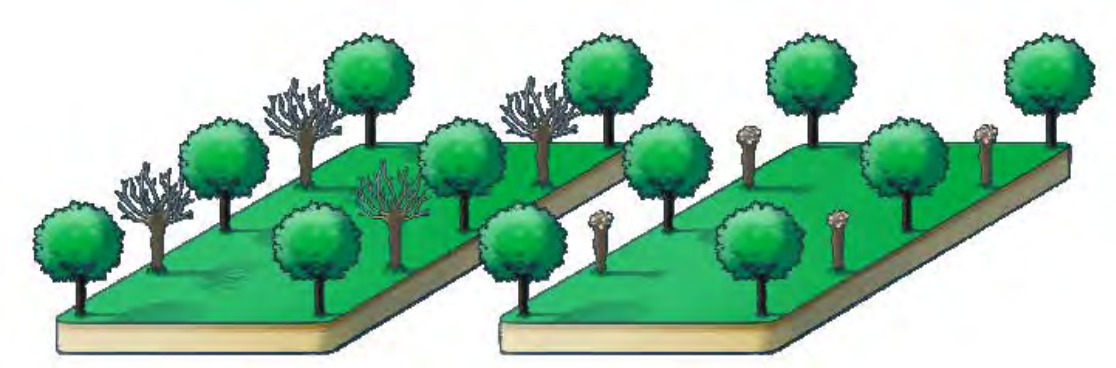
Pruning height :
10 m versus 6 m

Pending : Designing enhanced and innovative agroforestry systems

Biomass production in agroforestry

Various tree managements (pollarding, root trenching, precision fertilisation…)

Mixtures of tree species




Merci