STICS-intercrop

New formalisms for intercropping modelling (Vézy et al., 2023)

Agronomy for Sustainable Development (2023) 43:61
https://doi.org/10.1007/s13593-023-00917-5

RESEARCH ARTICLE

Check for updates

Modeling soil-plant functioning of intercrops using comprehensive and generic formalisms implemented in the STICS model

Rémi Vezy[1,2] · Sebastian Munz[3] · Noémie Gaudio[4] · Marie Launay[5] · Patrice Lecharpentier[5] · Dominique Ripoche[5] · Eric Justes[6]

Accepted: 2 August 2023

First version of STICS-Intercrop in 2004 (Brisson *et al.*)

Intercropping systems: interests and modelling

The simplest example of a “complex” system.

Intercropping : high potential to increase the durability of current cropping systems:

- Need less chemical inputs
- Increase resilience to climate variability
- Increase ecosystem services
- Fix more carbon

… **potentially**

Huge opportunity for modelling to:

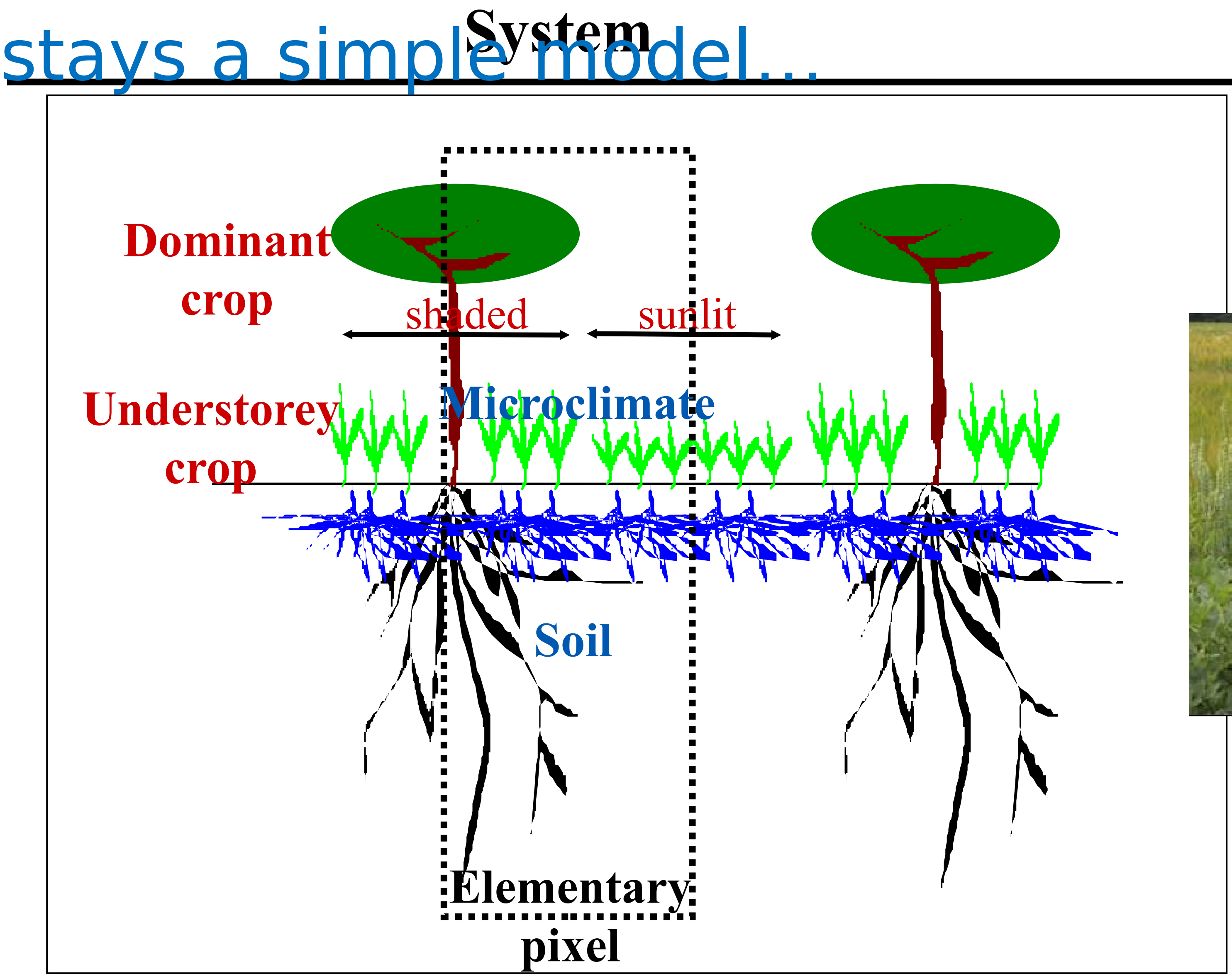
- help us designing the species combinations that have good properties and sort out the ones that does not.
- Assess agronomic performances
- pre-screen varieties with the best traits for intercropping...

Intercropping systems in STICS: approach & limits

- **Bi-specific intercropping only: 2 crops in row and strip/alley (only 2!)**
- **Spatial design with variable inter-row distance**
- **Sowing and Harvest could be independent for each crop (relay intercropping)**
- **Competition for light, water and N uptake**
  = f(rate of root in depth & density/soil layer, LAI expansion, growth rate)
- **Niche complementary for water and N**
  f=(depth and density of roots, N2 fixation=f(soil nitrate concentration))
- The performance of intercrop is an emerging properties of the model
- **BUT:** NO true **facilitation** simulated, neither biotic interactions with soil micro- & macro- biology…

Intercropping systems: STICS-Intercrop is 2D

but stays a simple model…



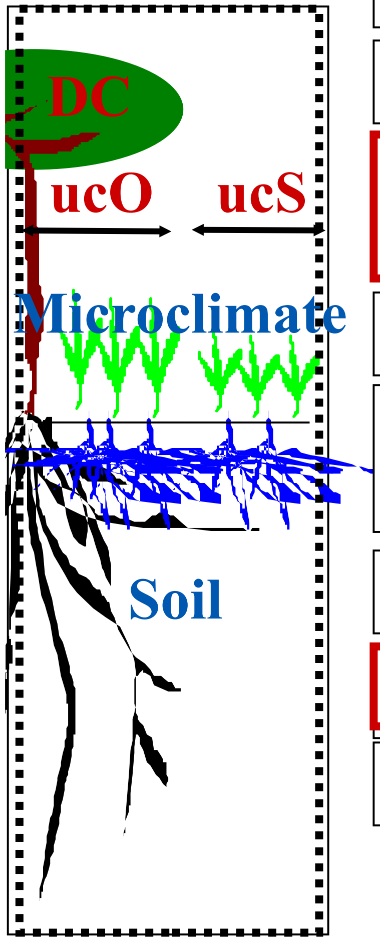
rcropping systems: a virtual compartmentalizati

DC: Dominant crop

ucO: Shaded understorey crop

ucS: Sunlit understorey crop

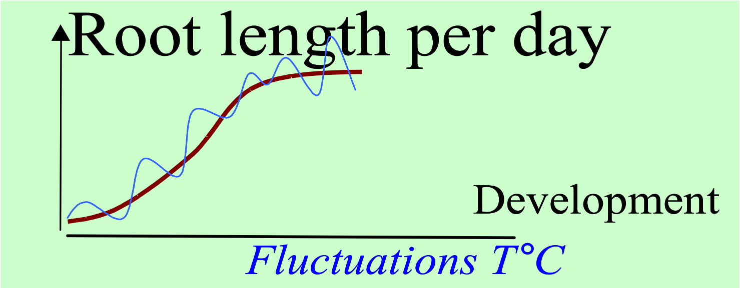
System

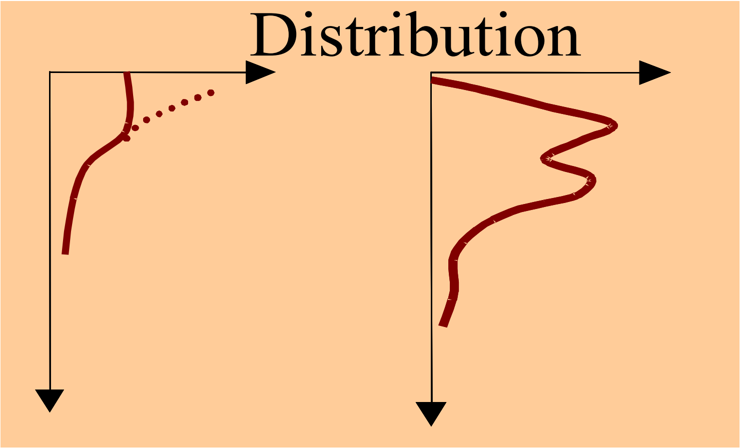


Process	Sub-system		
Phenology	DC	uc	
Foliar surface growth	DC	ucO	ucS
Radiation interception	DC	ucO	ucS
Shoot growth	DC	ucO	ucS
Yield elaboration	DC	ucO	ucS
Root growth	DC	uc	
H_2O / N transfers	DC	ucO	ucS
Crop management	DC	uc	

Growth : root growth and radiation interception

True density





Effect of **Water logging** **Soil dryness**

RADIATIVE TRANSFERS

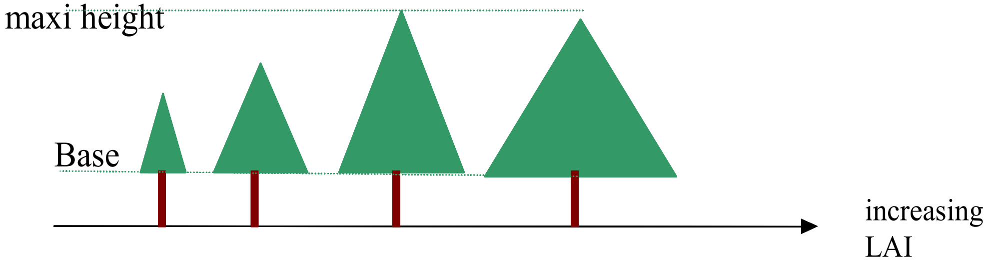
Choose a shape

leaf density profil types

Constant leaf density

Width/thickness ratio constant until max height

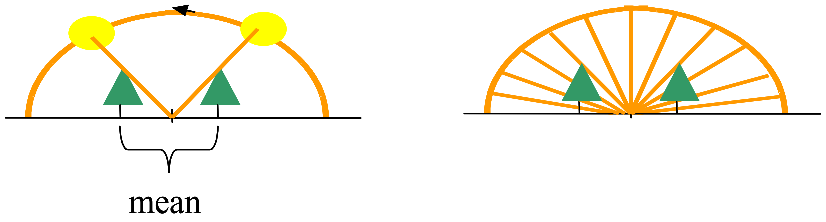
Grow he shape



Daily radiation transfer

direct radiation

scattered radiation (47 directions)



infinite crop

between-row sampling and mean

Spatial design in 2D: 2 rows represented

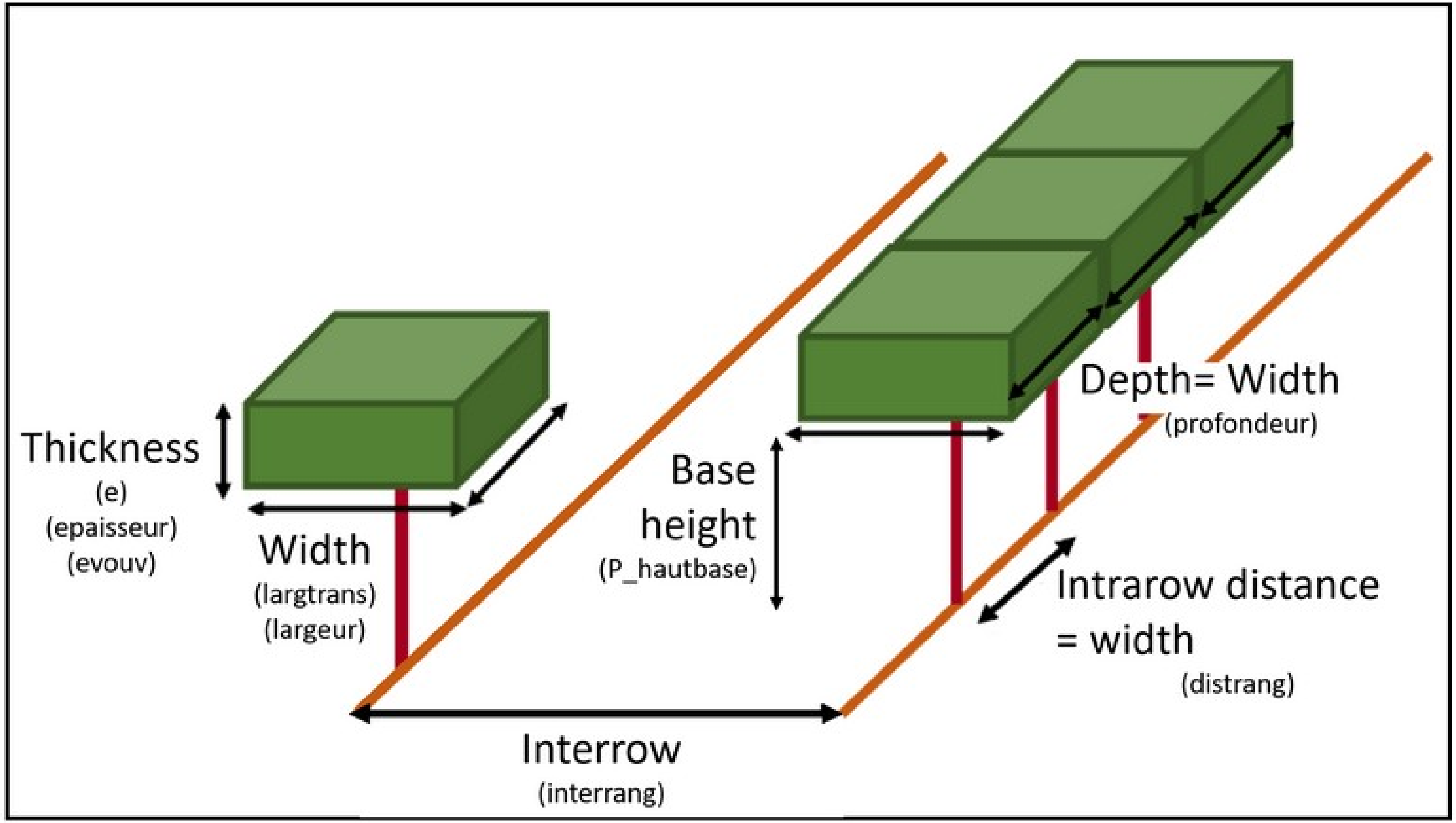


Figure 2.1: **Diagram representing the different parameters used to compute plant width. The different names used in the model are shown between parenthesis**

Light competition between the 2 rows

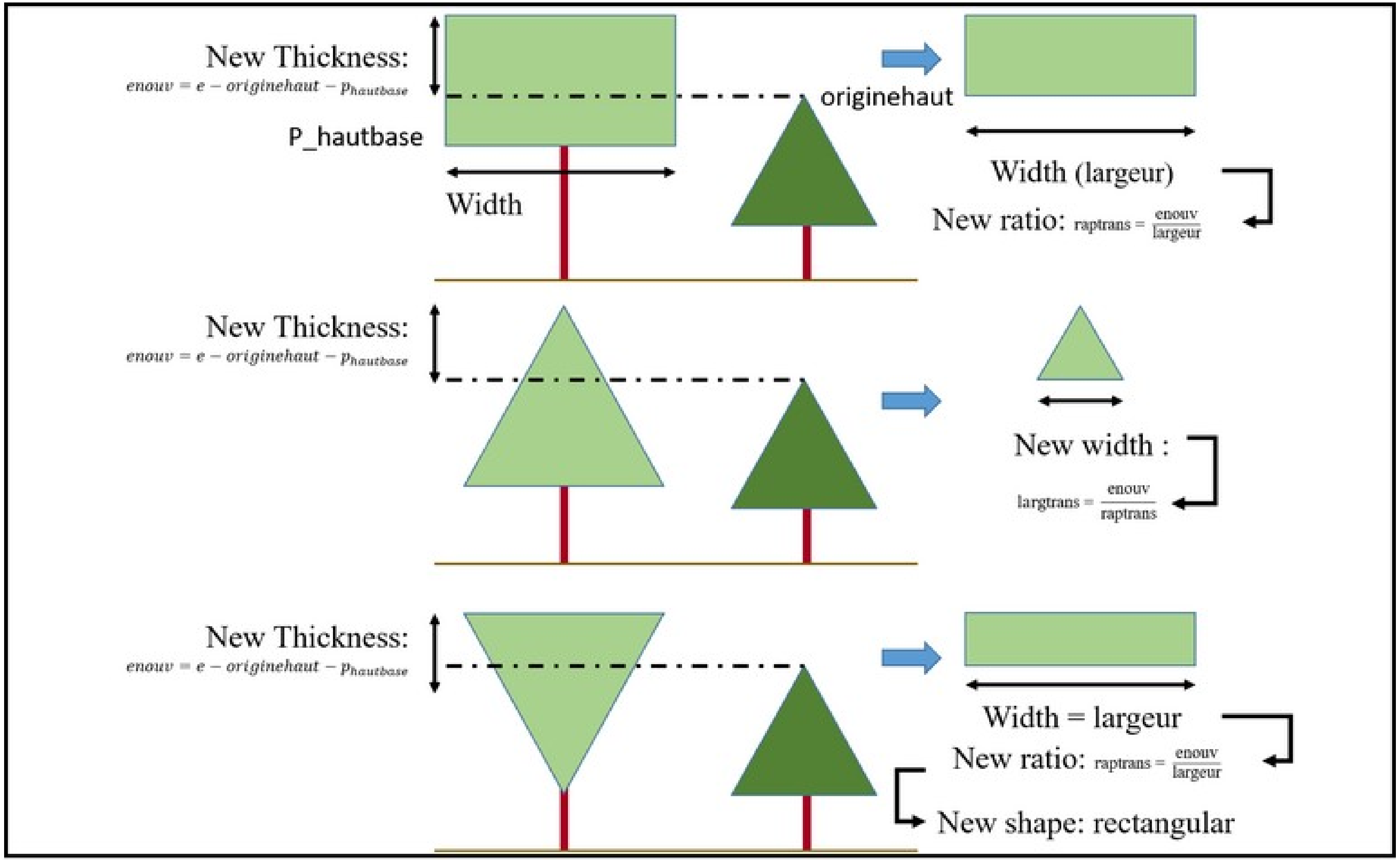


Figure 2.2: **Competition for radiation interception of the dominant plant induced by a high dominated plant**

nt competition: dominance simulated in dynamic

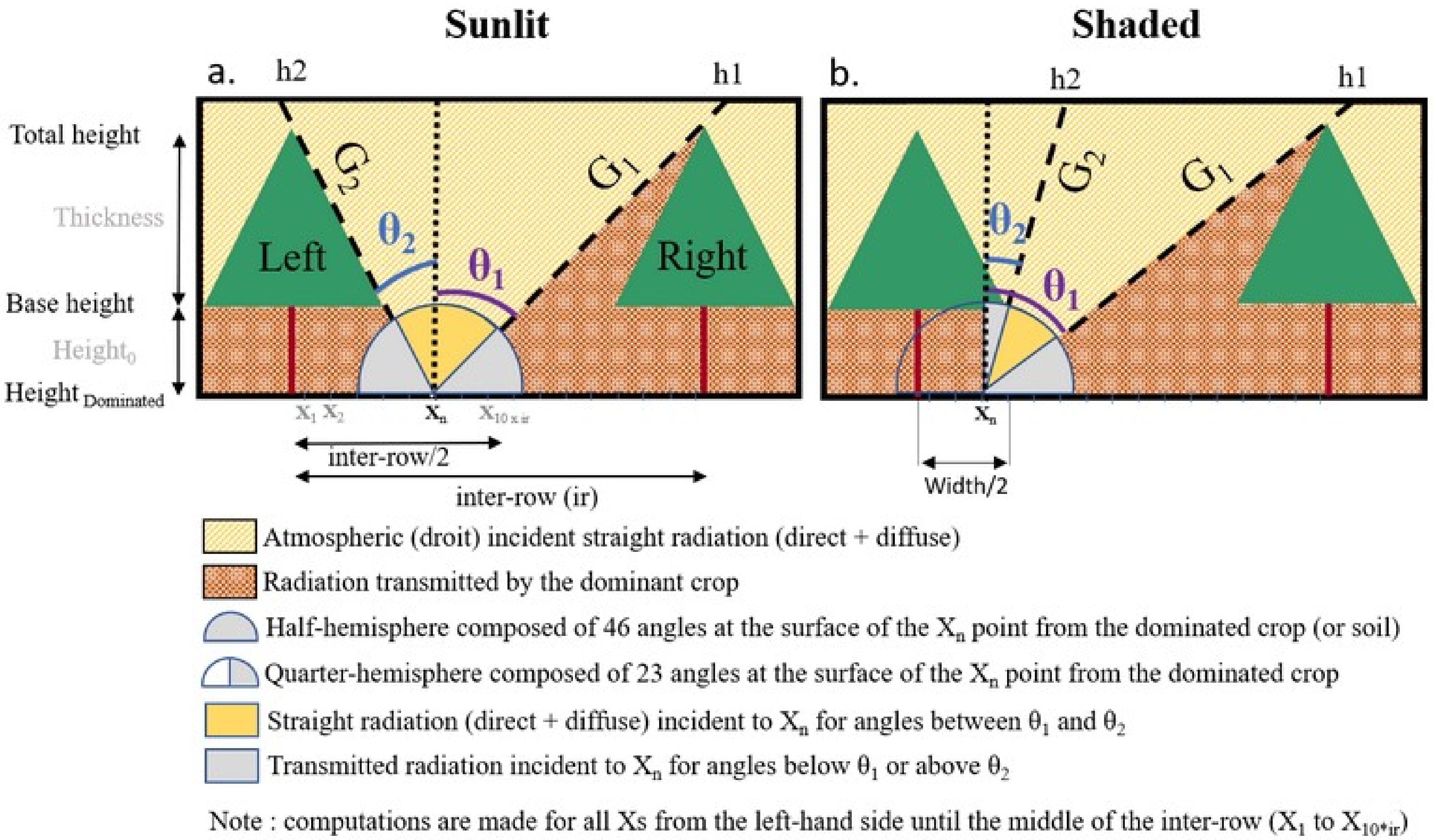


Figure 2.3: **Diagram of the computation workflow of STICS for radiation interception for two X points placed above the dominated plant species. a. The X point is considered sunlit; b. The X**

main of validity of STICS intercropping

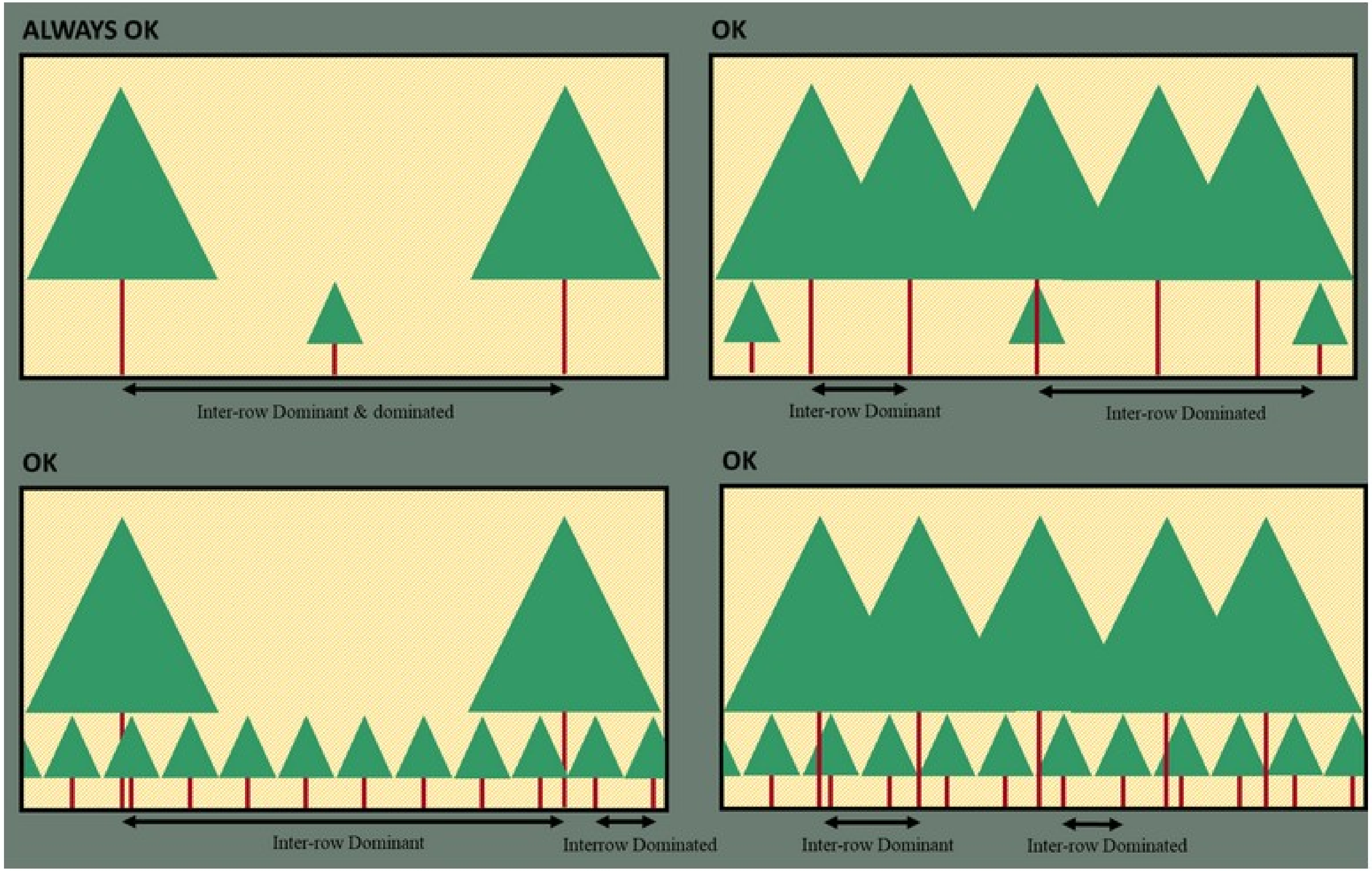


Figure 7.1: Depiction of the potentially adapted intercrop designs for simulation using the STICS model.

OUT of the domain of validity: strip intercropping

Several independent simulations and aggregation of outputs ????

→ Need to be tested to verify the relevance of this assumption

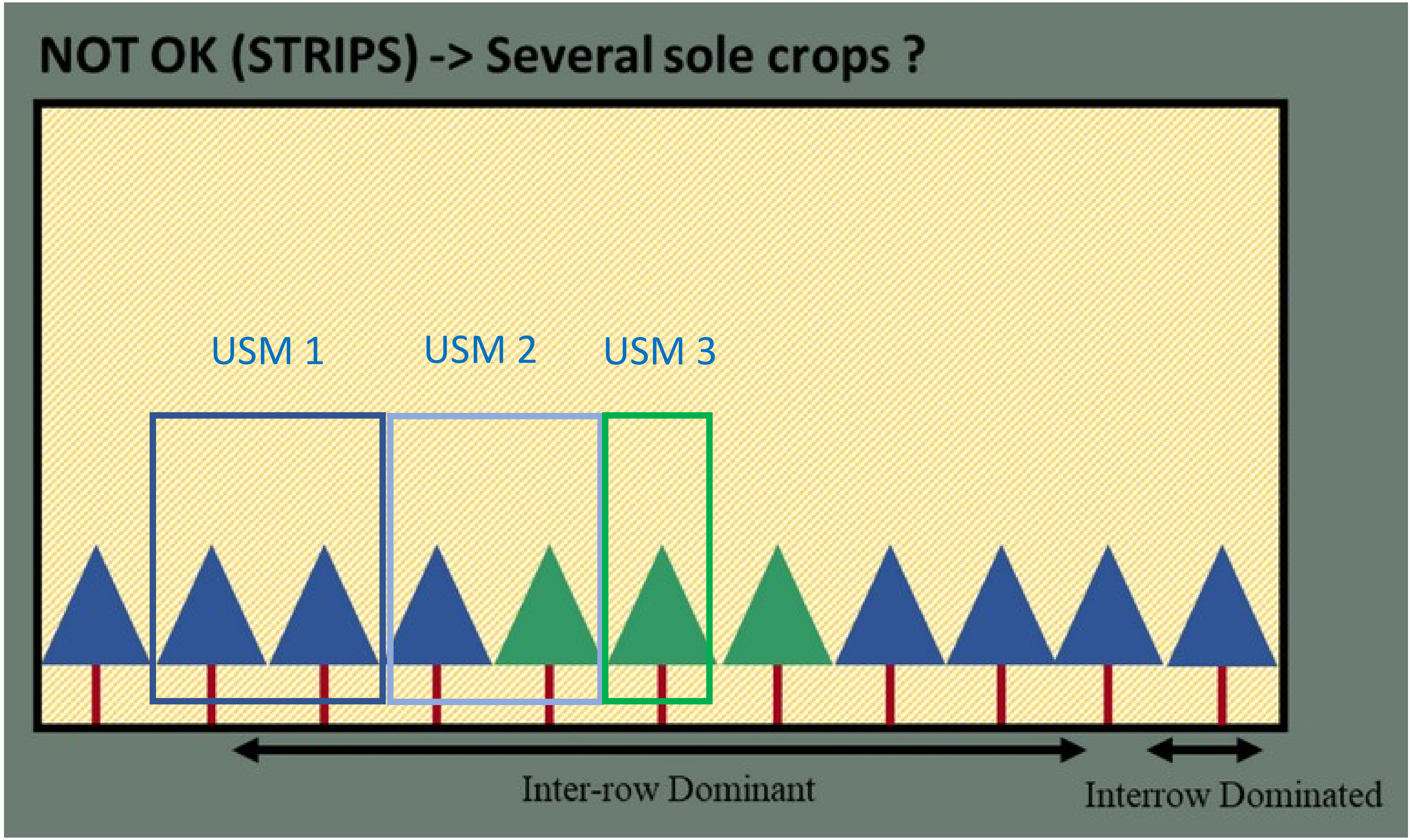
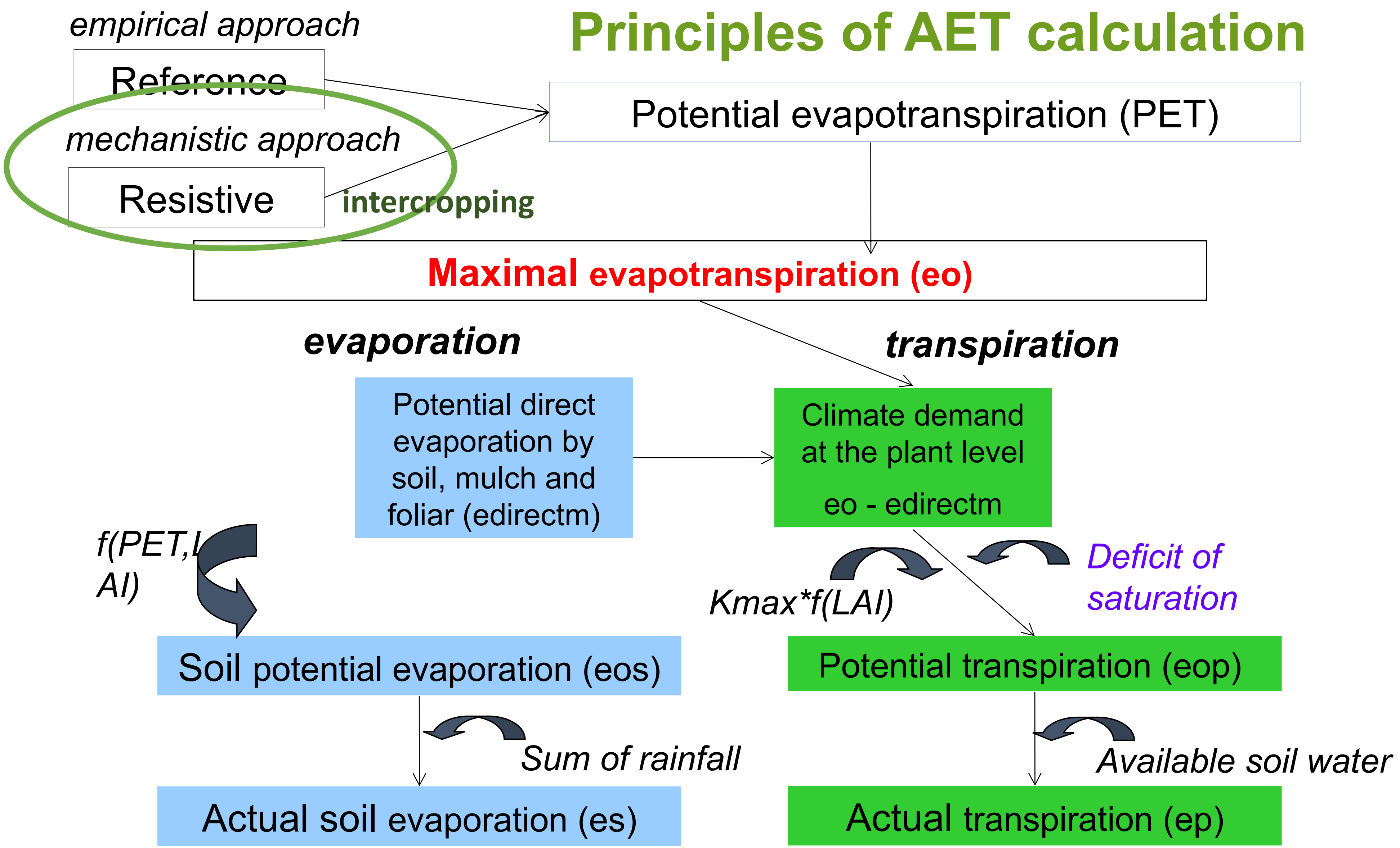


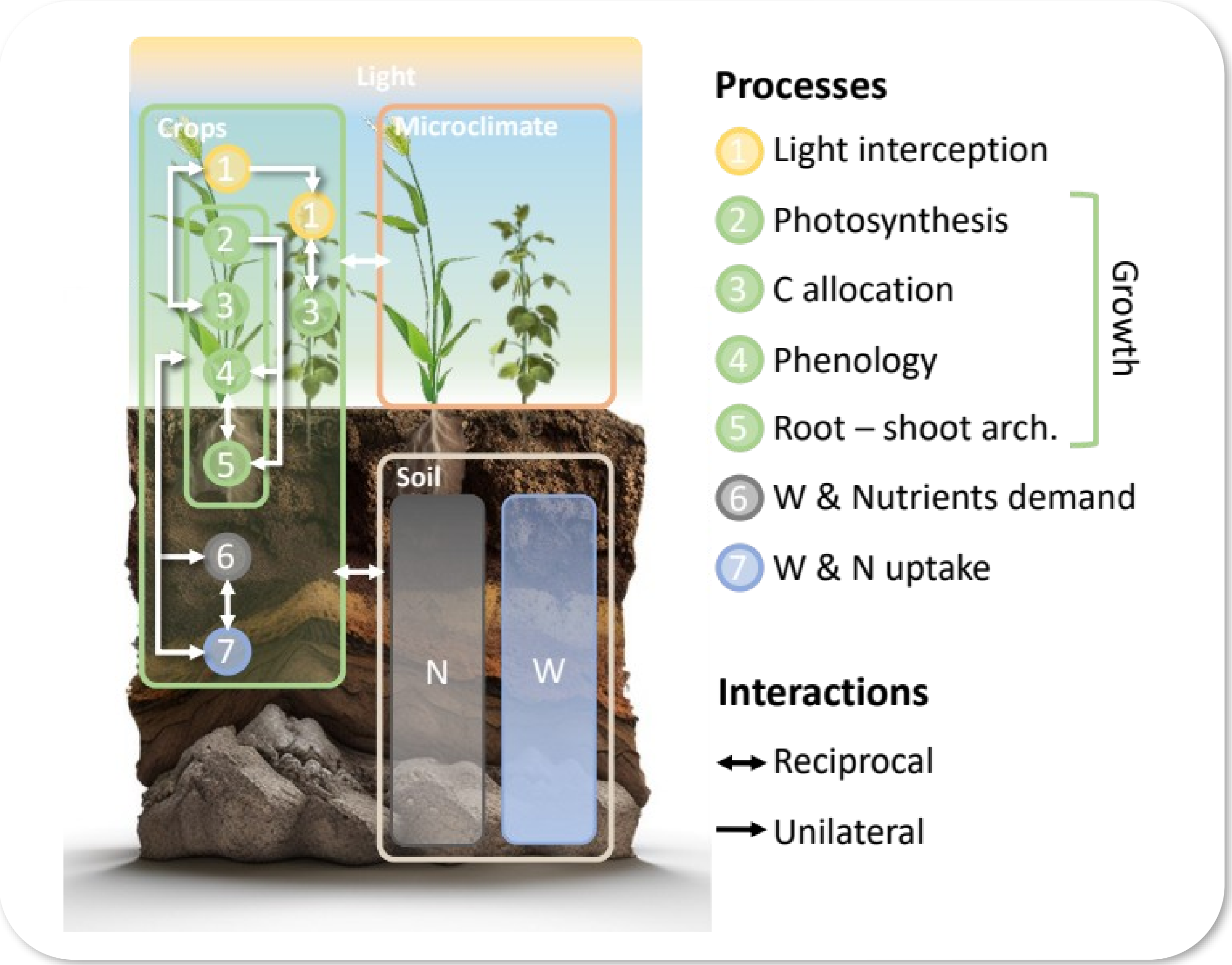
Figure 7.2: Depiction of the intercrop designs not adapted for simulation using the STICS model as is.

ter balance simulated with the resistive approac

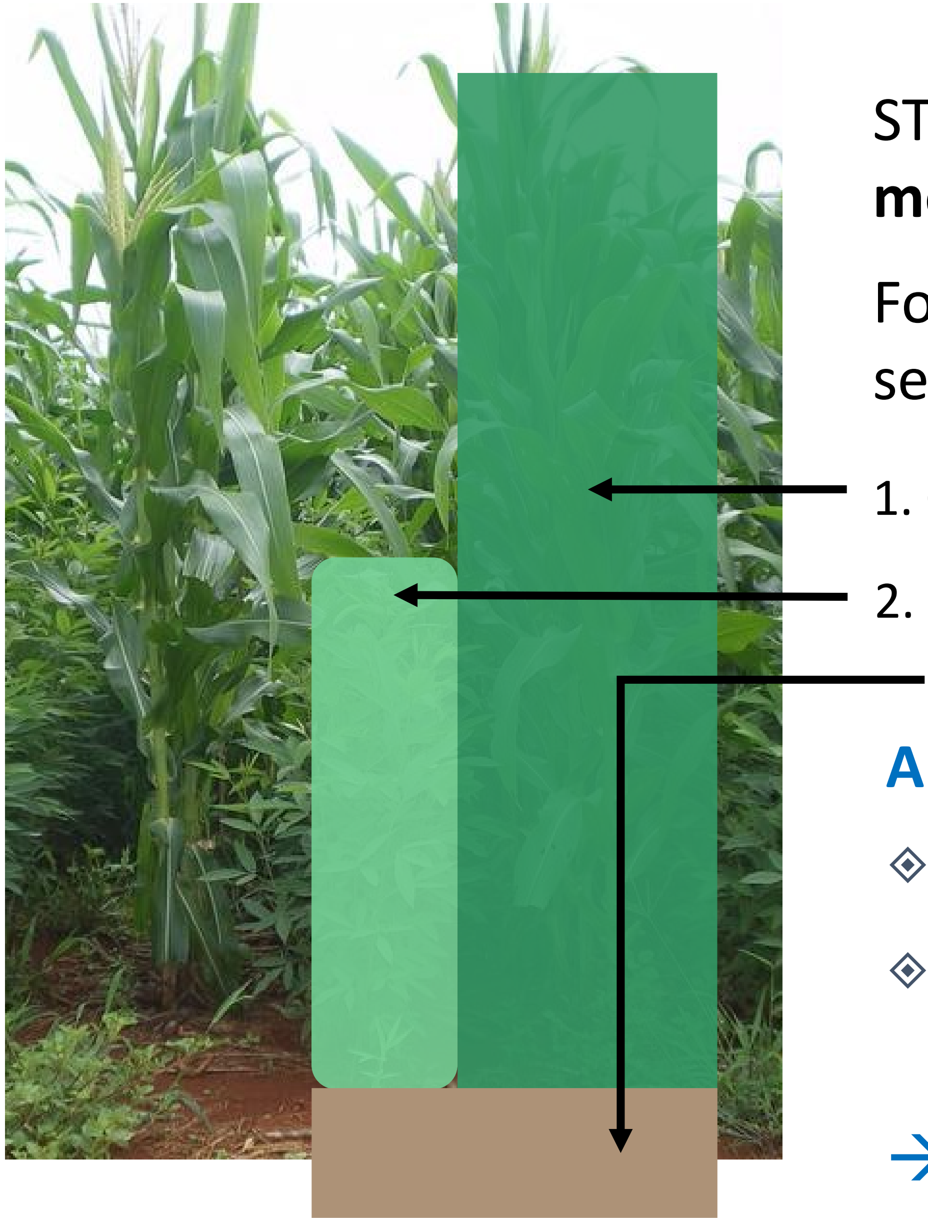


Modelling work done in the new version

Defining a set of new formalisms for simulating the main interactions in bi-specific intercropping systems



Intercrop formalisms in STICS



STICS is originally a **sole crop model**, implying that **each module simulates one plant only** (*e.g.*, light interception, lai)

For bi-specific intercrops, the modules are **called twice,** sequentially in the algoritm:

1. Once for the dominant plant
2. Once for the dominated plant
3. With a shared soil

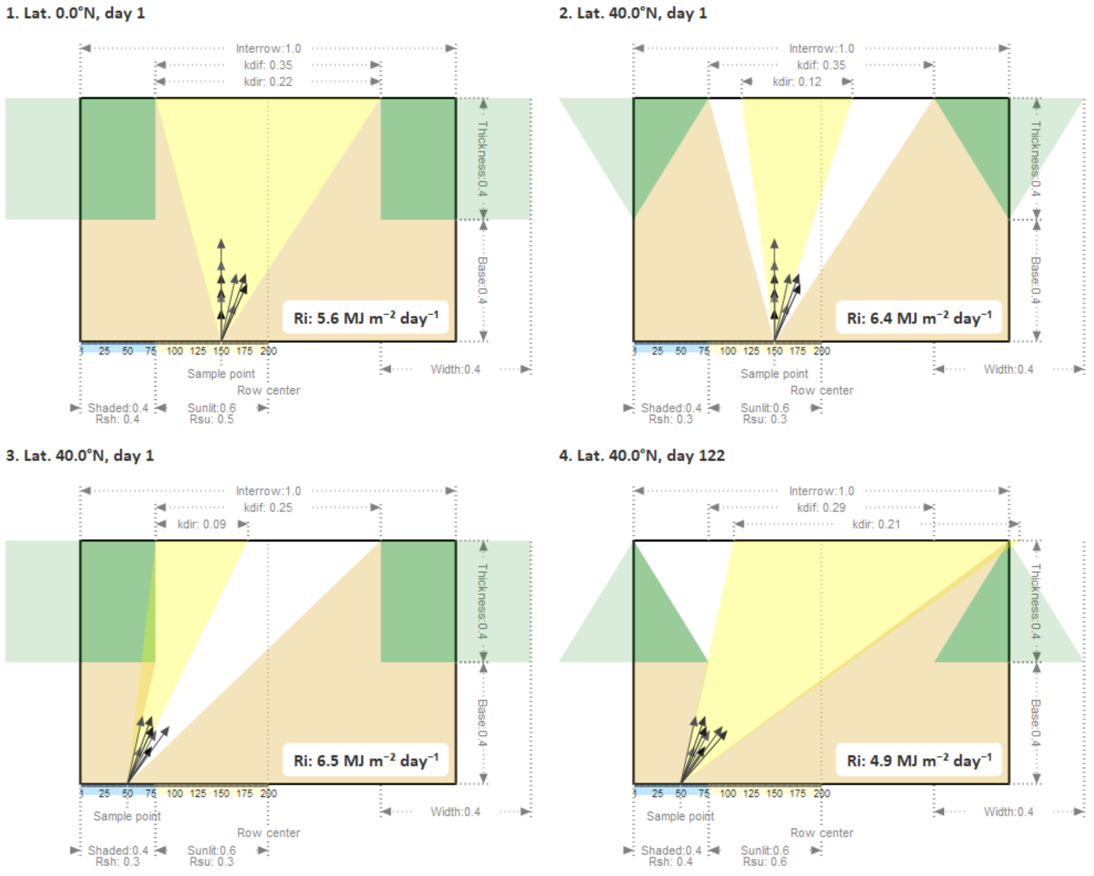
Approach for calibration :

- Paramètres determined for sole crop model
- 1 parameter only for intercrop option: effect of shading on stem elongation

→ Simulation of intercrop is « a almost a validation step »

Improvement of formalisms: Light

Light interception (2.5D shape extrusion)



- Fixed several bugs in the algorithm (see appendix)
- Fallback to Beer when canopy height is close:

$$FaPAR_1 = \frac{LAI_1 \cdot k_1}{\left(LAI_1 \cdot k_1 + LAI_2 \cdot k_2\right) \cdot \left(1 - e^{-LAI_1 \cdot k_1 - LAI_2 \cdot k_2}\right)}$$

- Closed the energy balance
- New plant height computation

Improvement of formalisms: new equations

Needed a **new plant height** computation because **crop height is de-coupled from LAI dynamics** in intercrops

Two changes:

1. Adding an option for computing height using phenological development instead:

$$Hp_i = H_0 + \frac{a}{1 + e^{-c \cdot (dev_i - b)}}$$

dev: sum of development units cumulated from sowing (thermal-time corrected by vernalisation and photoperiod)
a and b: parameters
: crop base height

2. Computing height incrementally each day:

$$H_i = H_{i-1} + \Delta H_i$$

And:

$$\Delta H_i = (Hp¿¿i - Hp_{i-1}) \cdot S \cdot E¿$$

Improvement of formalisms: Nitrogen in plant

Louarn et al. (2021):

$$demand_{i,p} = \frac{\Delta Nmax_{i,p}}{\Delta max\left(W ¿¿ i, tot, biometa\right) \cdot G_{i,p} ¿}$$

with:

And: with

Same equations than sole crops, with same parameter values, but using **total biomass** of the IC system.

Details:

- is the N demand of the crop (kg N ha^{-1} day^{-1})
- the maximum N concentration of the crop (gN kg^{-1})
- the daily crop growth rate (t ha^{-1} day^{-1})
- the total aerial biomass of both intercropped crops (t ha^{-1})
- the threshold of above which N dilution becomes significant (t ha^{-1})
- denotes the current day, the change in the variable value between two days, and the current computed crop

Improvement of formalisms: Interspecific competition

Introducing an effect of **equivalent plant density** () for computation of root length growth rate () for self-governing root length expansion (default):

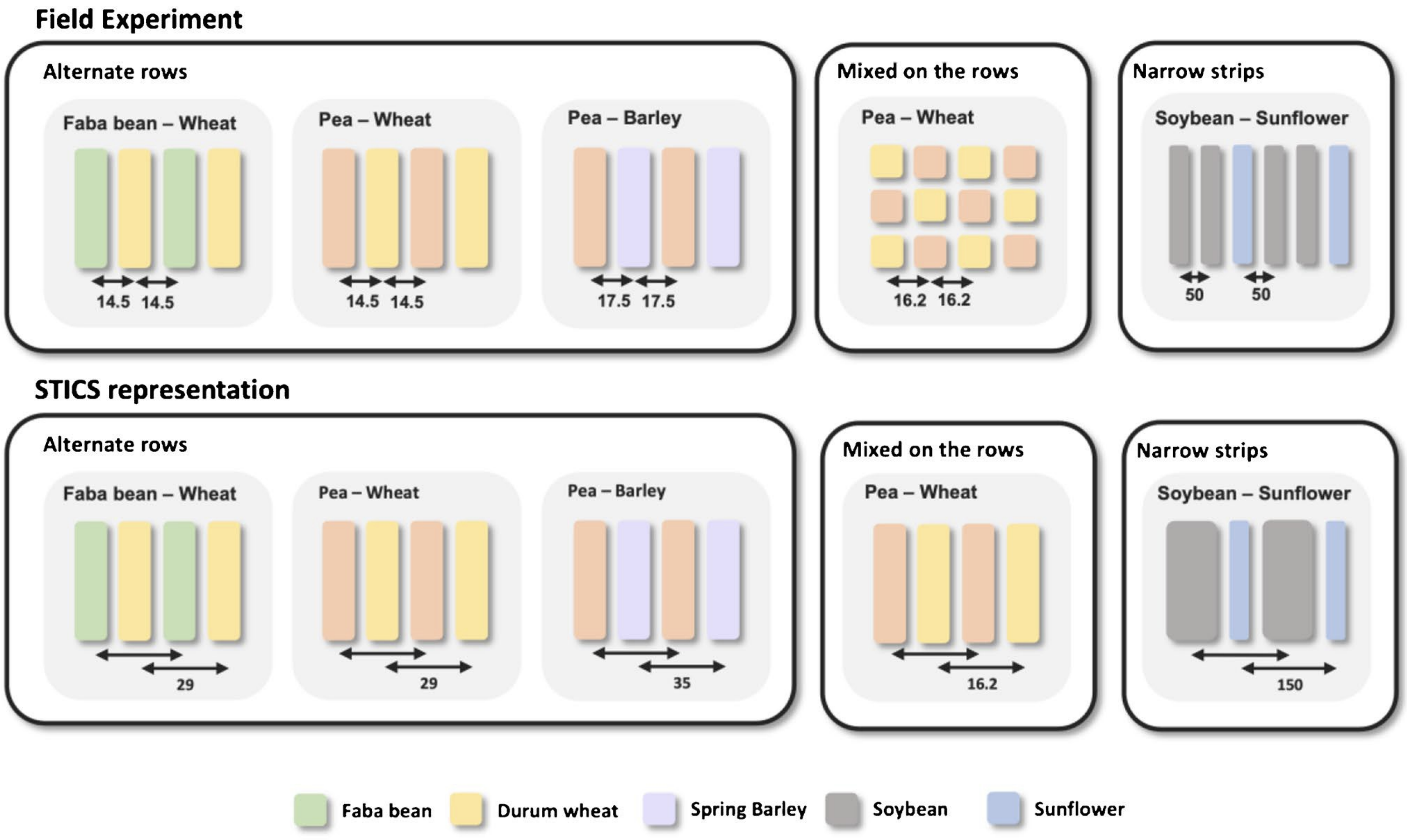
$$LG_f = RDfront \cdot \frac{D}{D_e} \cdot deltaz \cdot 10^4$$

$$RLG = \frac{RLGdd_{max}}{1 + e^{5.5 \cdot sLAI_{max} - Uroot}} \cdot S_D \cdot D \cdot dtj \cdot S_A + RLG_f$$

And equivalent plant density is simplified to twice the IC density, *i.e.* equivalent density for each species is now considered as the ratio of sole crop plant density divided by intercrop plant density.

The intraspecific competition is now guaranteed to be the same for the equivalent sole crop, as the *adens* and *bdens* parameters are determined for sole crops.

Spatial design in field and in STICS
Data set used for evaluation



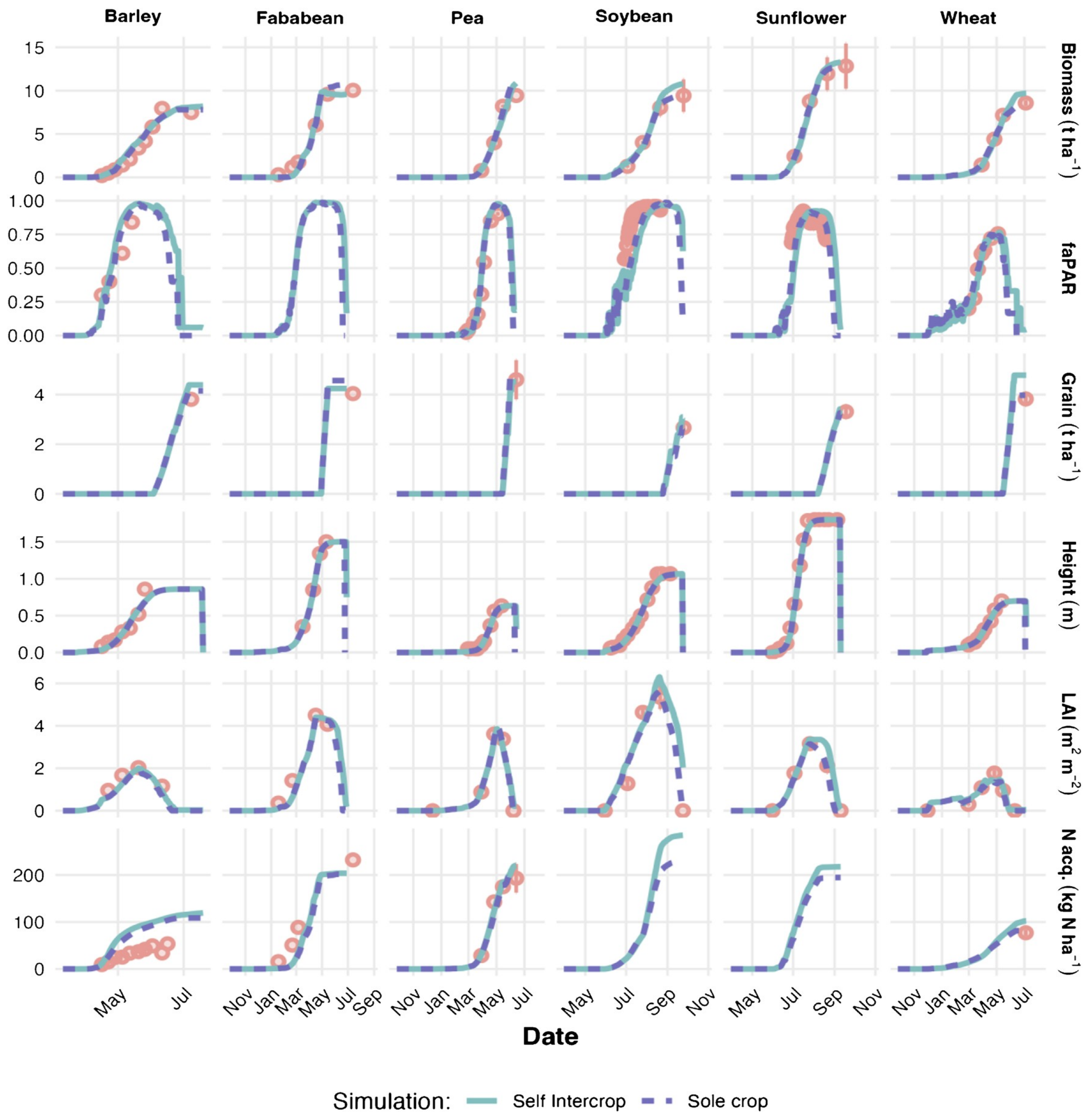
Simulation of dynamical variables

Sole crop simulated as:

- Regular sole crop
- Self-intercrop (half-density intercropped with itself)

STICS had a consistent behavior in the simulation of both

Crucial for analyzing system performances based on sole crops vs intercrop



Interspecifc interactions

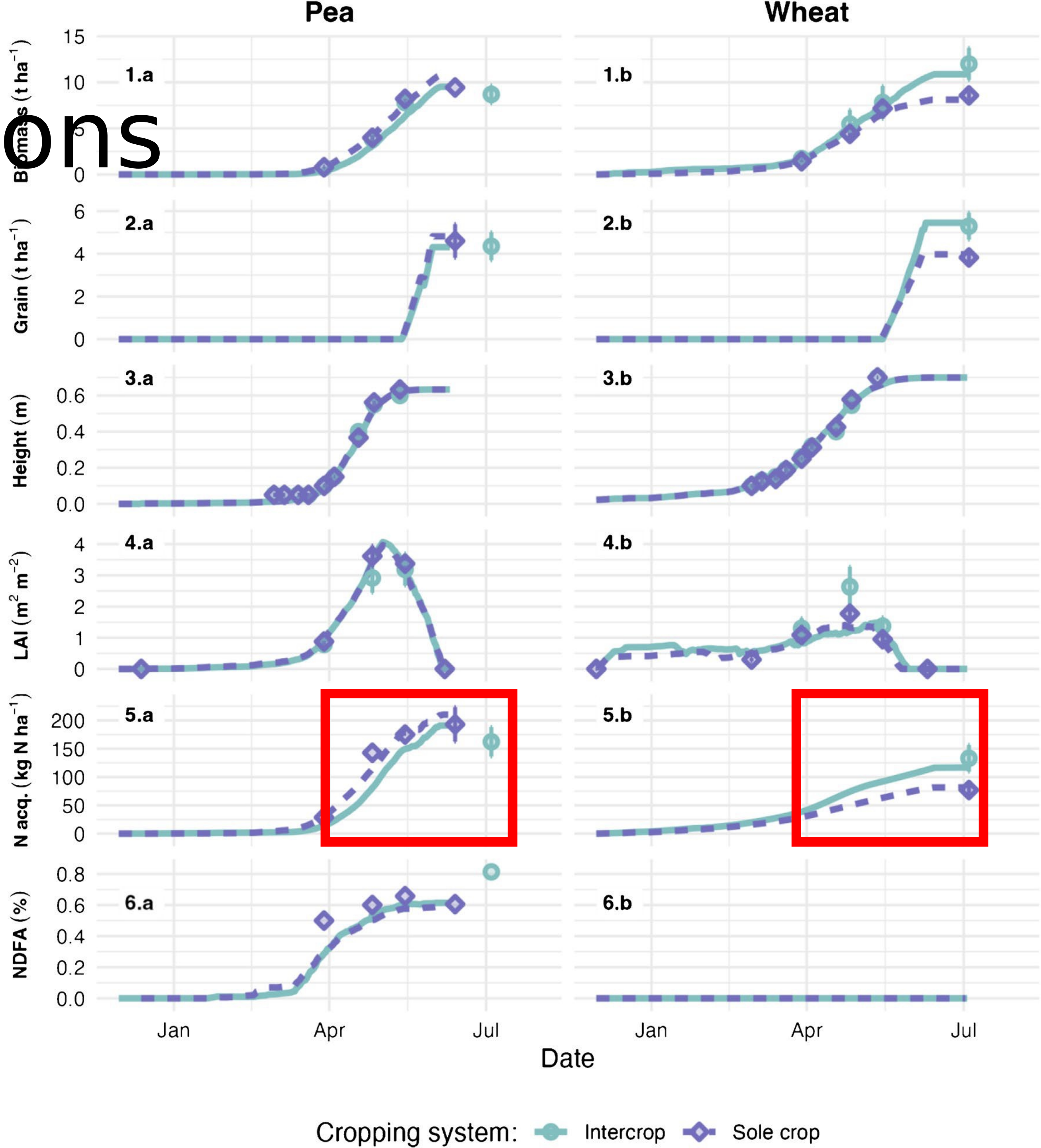
STICS is calibrated on the sole crop and applied on the IC

The hypothesis is that the model should simulate all interactions by itself, without the need of a re-calibration

STICS simulations are close to observations

STICS can simulate niche complementarity for N!

→ Increased N acquisition (wheat) thanks to higher competitiveness that force pea to increase NDFA

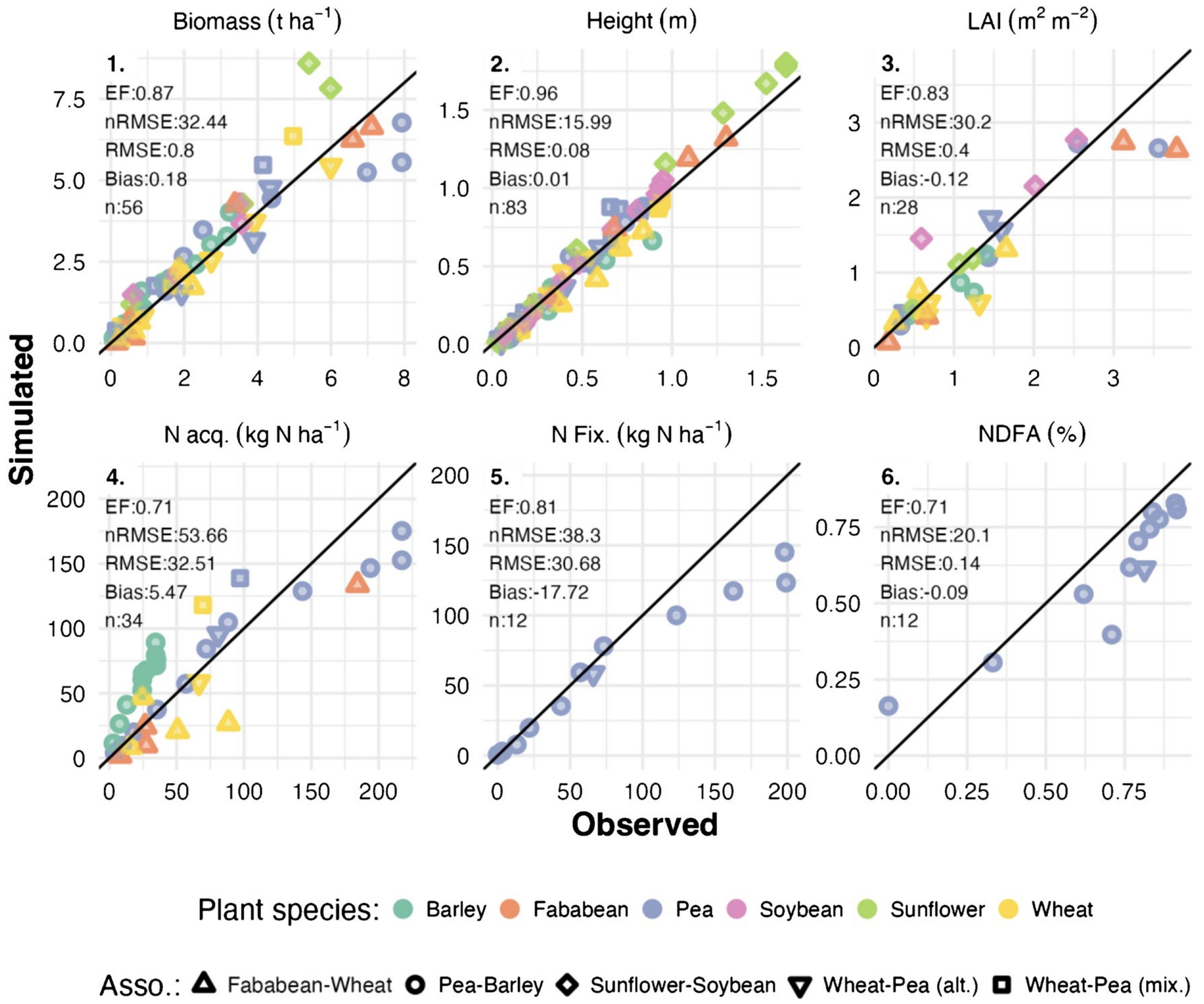


Genericity

EF >= 0.71 for all variables throughout the growing season;

Correct performances per se and in comparison to classical sole crops publications

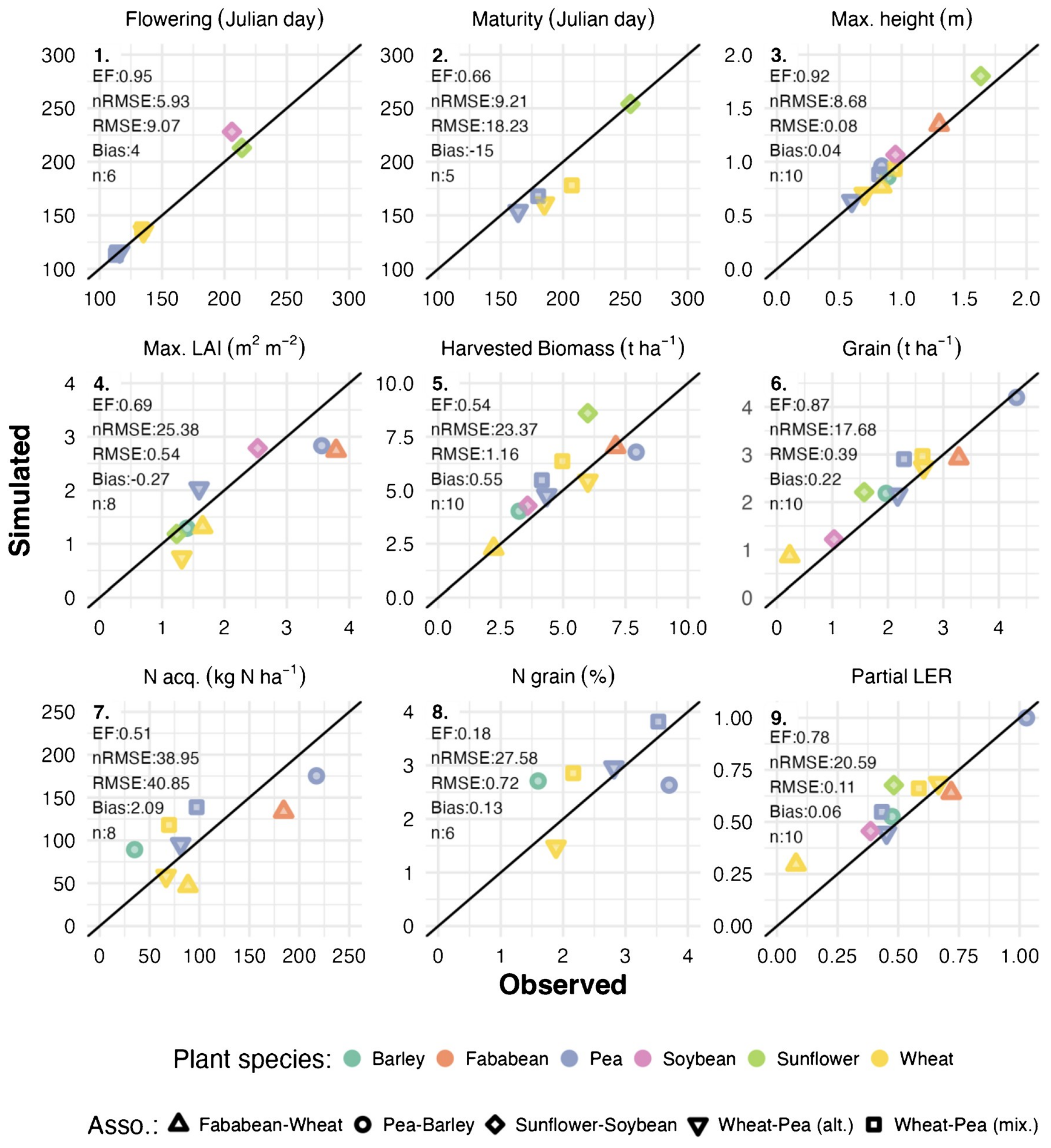
Simulations are “very good”, except for NDFA that is “good” (Coucheney et al. 2015)



The model is found consistant in its functionning

Simulations also satisfactory at **critical crop growth stages**

The model is accurate for a wide range of bi-specific intercropping systems.



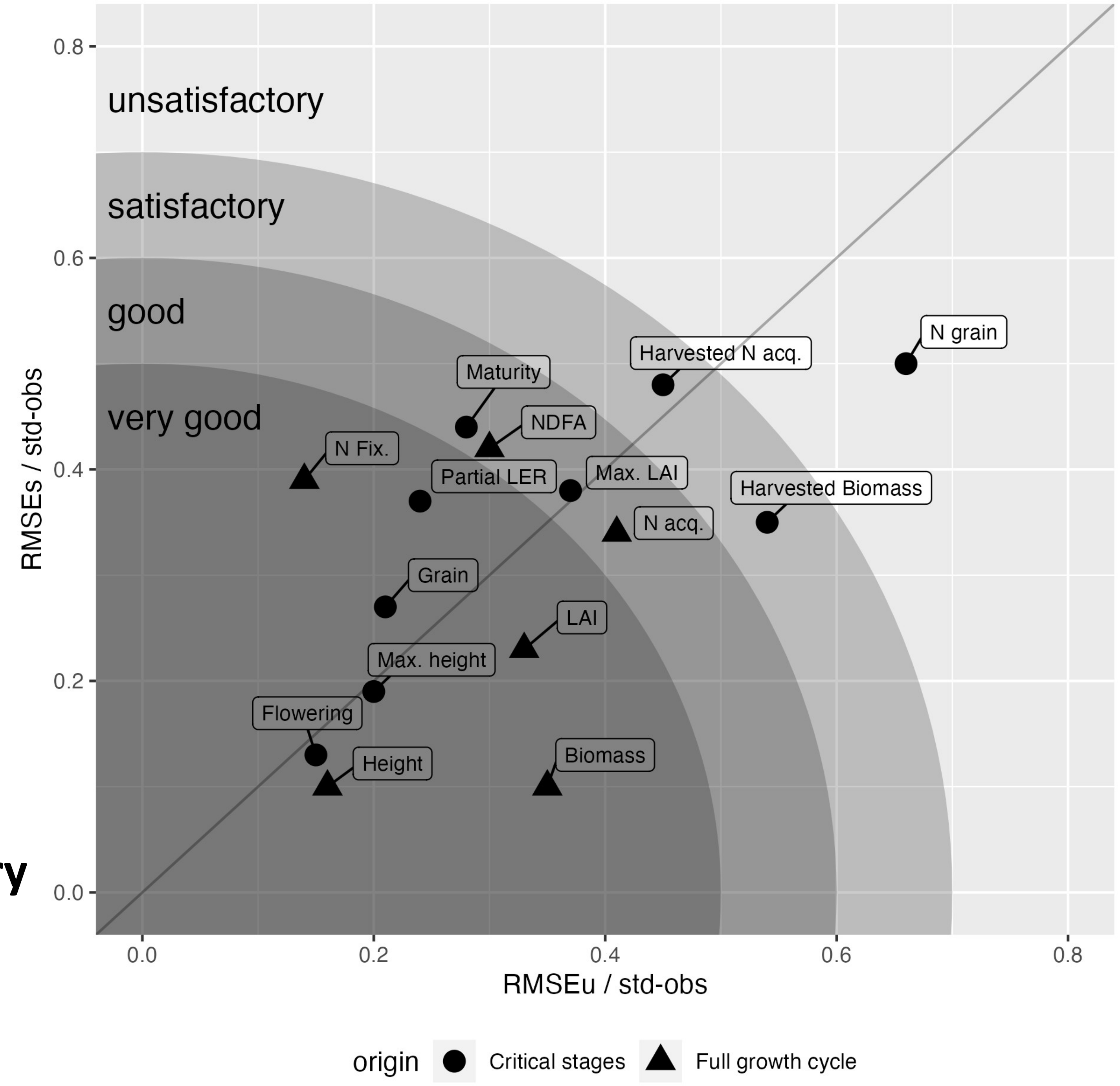
Model performance

Very good for dynamic variables (except NDFA, good)

Harvested N acquired and biomass satisfactory
N Grain unsatisfactory (nRMSE: 28%) → **need more work**

pLER and **yield** are **<u>very good</u>**

This was also our target: very satisfactory result



Practical aspects

New parameters in plant files (sole crops)
New parameter for intercrop → need a new plan file architecture

Prospects

Intercrop Branch almost integrated in the trunk (few bugs to be fixed by Patrice)
Beta Version of STICS 11 will be available in early 2024

Thanks for your attention

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