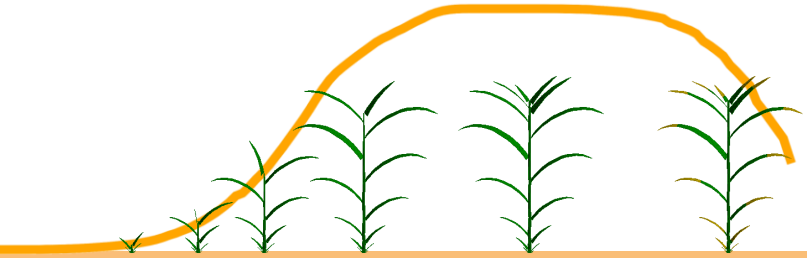
XIVth STICS seminar, 17-19 March 2026, organized by ULiege-GxABT & INRAE

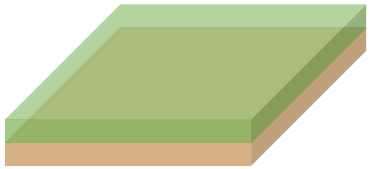


ArchiCrop: Adding the 3D dimension to STICS

Oriane Braud[1,2,3,4], Thomas Arsouze[3,4], Rémi Vezy[3,4], Myriam Adam[1,2], Marc Jaeger[3,4], Christophe Pradal[1,2]

[1]*CIRAD, UMR AGAP Institut, F-34398 Montpellier, France*
[2]*AGAP Institut, CIRAD, INRAE, Institut Agro, Univ Montpellier, Montpellier, France*
[3]*CIRAD, UMR AMAP, F-34398 Montpellier, France*
[4]*AMAP, Univ Montpellier, CIRAD, CNRS, INRAE, IRD, Montpellier, France*
oriane.braud@cirad.fr

Crop vs. Plant Growth Models



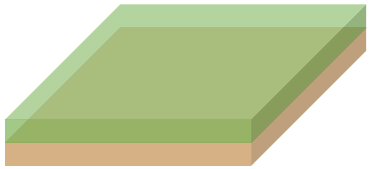
Crop models

- 1D crop at crop scale
- Assumptions of spatial homogeneity
- Computationally efficient (<1s)
- Many processes

(de Wit et al., 1970)

Heterogeneous crops :
in domain of validity ?

Crop vs. Plant Growth Models

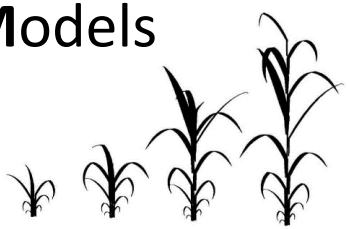


Crop models

- 1D crop at crop scale
- Assumptions of spatial homogeneity
- Computationally efficient (<1s)
- Many processes

(de Wit et al., 1970)

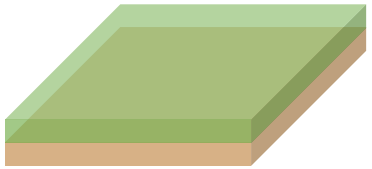
Functional–**S**tructural **P**lant **M**odels **(FSPM)**



- 3D plant architecture at organ scale
- Manage spatial heterogeneity
- Computationally intensive (hours)
- Few processes

(Perttunen et al., 1998)

Crop vs. Plant Growth Models



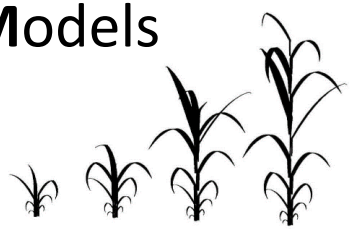
Crop models

- **Computationally efficient**
- **Many processes**

(de Wit et al., 1970)

FRAMEWORK

Functional–**S**tructural **P**lant **M**odels **(FSPM)**



- **3D plant architecture at organ scale**
- **Manage spatial heterogeneity**

(Perttunen et al., 1998)

How to design such a framework?

How to compare the representation processes at crop and organ scales?

➔ **evaluate the impact of heterogeneity on crop model processes**

Light Interception Models at Crop and Organ Scales

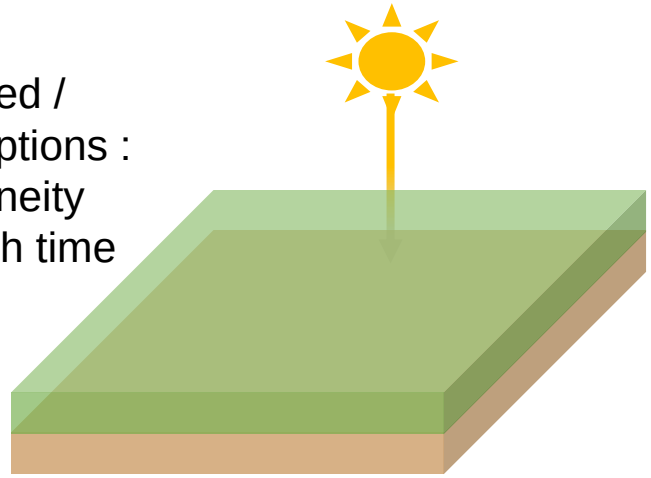
Crop models

Beer-Lambert : $\mathrm{faPAR} = 1 - \exp(-\boldsymbol{k} * LAI)$

(Sinoquet et al., 1991)

Parameter calibrated / fixed under assumptions :

- spatial homogeneity
- constant through time

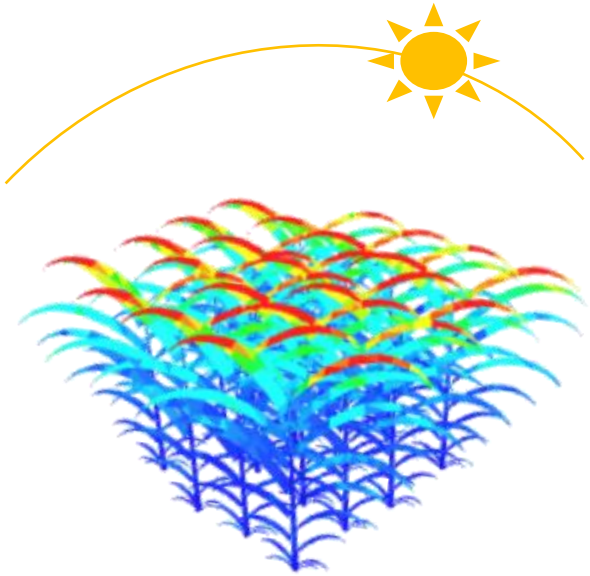


FSPM

e.g.

Radiosity : $F_{i-j} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{cos\theta_i cos\theta_j}{\pi r^2} H_{ij} dA_j \, dA_i$

(Chelle et al., 1998)



Computation on 3D scene with explicit heterogeneous organ distribution

Challenging Beer-Lambert's Law

Goal : compare light interception models (crop vs. FSP models)

- On a static architecture
  (Barillot et al., 2011; Ponce de Leon and Bailey, 2019; Ponce de Leon et al., 2025)

- Throughout crop growth cycle
  (Pao et al., 2021; Li et al., 2024)

Equivalent simulations at crop and organ scales

Upscale dynamics from FSPM to crop scale

Downscale dynamics from crop model to 3D plant model

NEW

Processes and stresses computed efficiently

Multiscale Approach to Evaluate Beer's Law in STICS

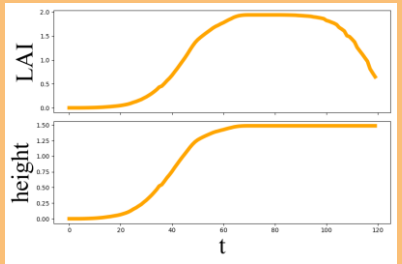
C, N, H_2O balances, etc.

Crop model

1D Beer Lambert's light extinction model *(Sinoquet et al., 1991)*

(Brisson et al., 1998)

Growth dynamics



?

How to build a 3D plant model that follows exactly the crop model dynamics?

Multiscale Approach to Evaluate Beer's Law in STICS

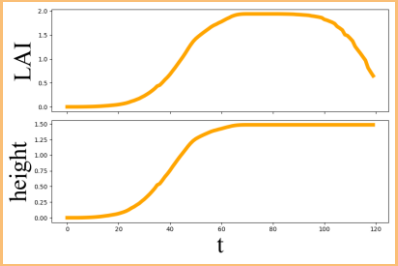
C, N, H_2O balances, etc.

1D Beer Lambert's light extinction model *(Sinoquet et al., 1991)*

Crop model

(Brisson et al., 1998)

Growth dynamics



Architectural & development parameters

Compute 3D scene through time

ArchiCrop

OpenAlea

Multiscale Approach to Evaluate Beer's Law in STICS

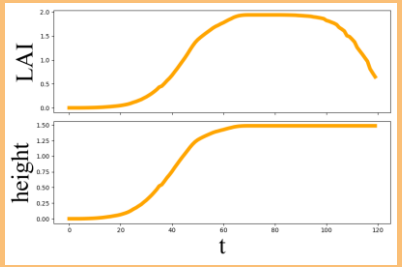
C, N, H_2O balances, etc.

Crop model

1D Beer Lambert's light extinction model *(Sinoquet et al., 1991)*

(Brisson et al., 1998)

Growth dynamics



Architectural & development parameters

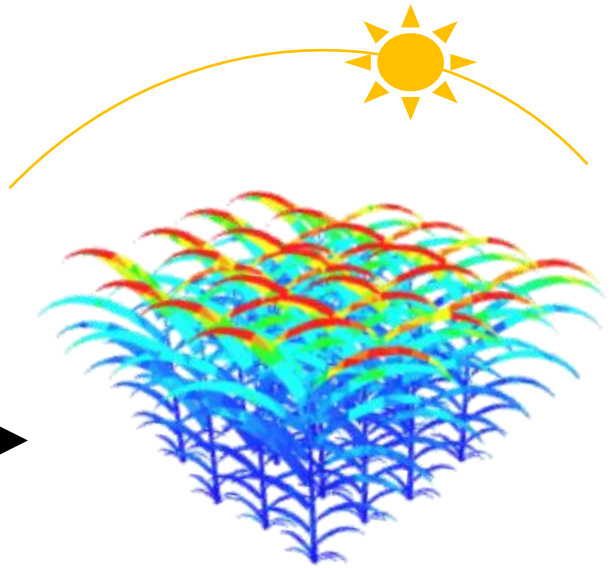
Compute 3D scene through time

ArchiCrop

OpenAlea

OpenAlea

3D radiosity model *(Chelle et al., 1998)*



Multiscale Approach to Evaluate Beer's Law in STICS

C, N, H_2O balances, etc.

Crop model

(Brisson et al., 1998)

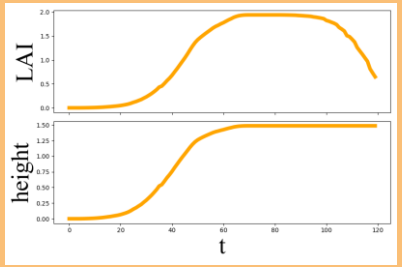
1D Beer Lambert's light extinction model
(Sinoquet et al., 1991)

Assess extinction coefficient k

OpenAlea

3D radiosity model
(Chelle et al., 1998)

Growth dynamics

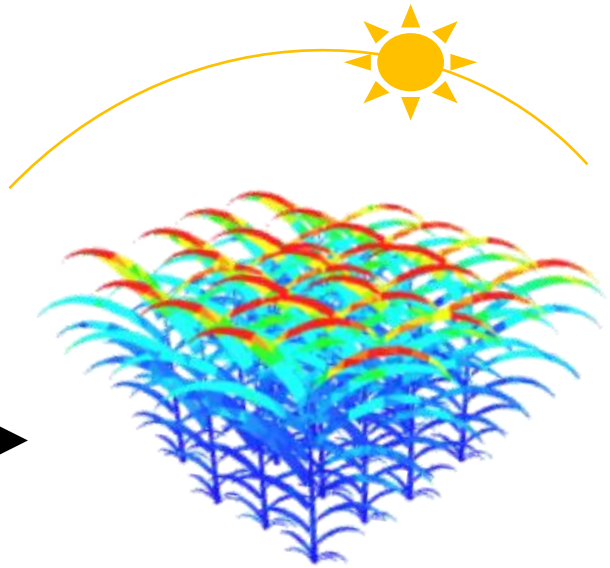


Architectural & development parameters

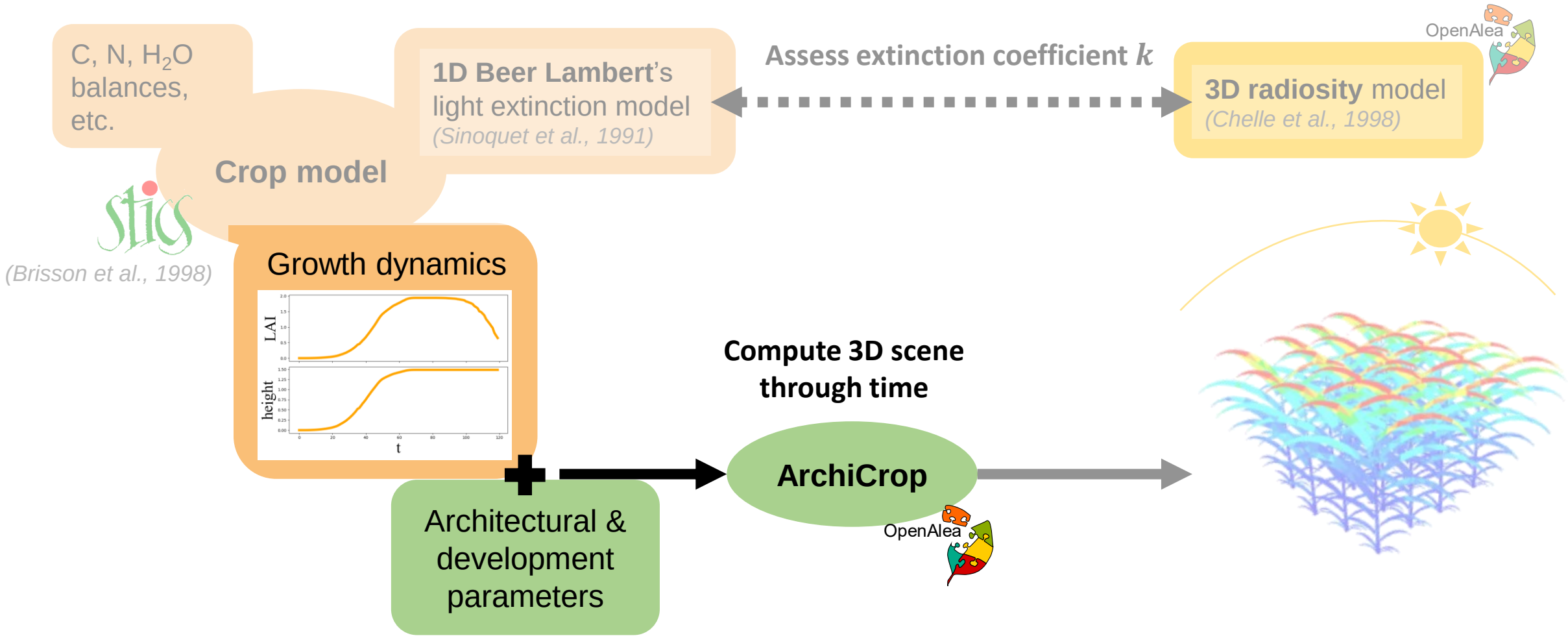
Compute 3D scene through time

ArchiCrop

OpenAlea

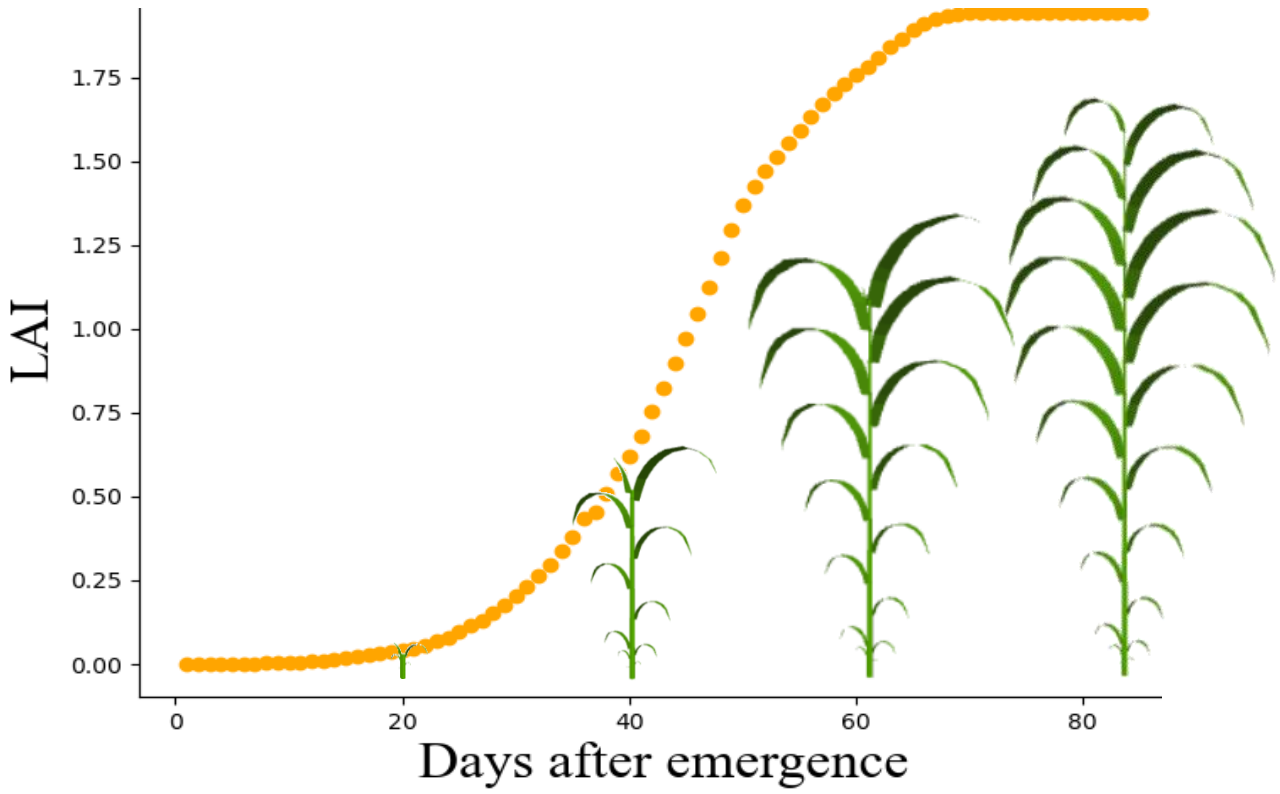


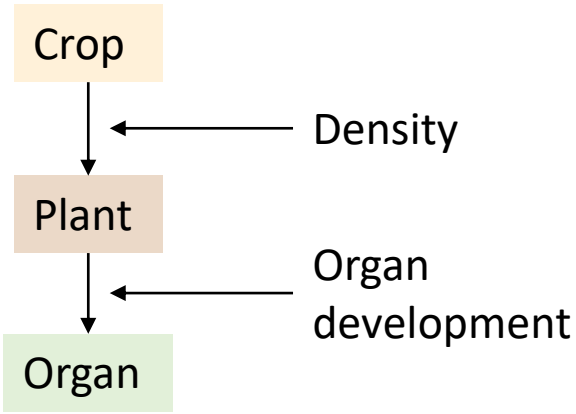
Multiscale Approach to Evaluate Beer's Law in STICS



Model - ArchiCrop

From 1D to 3D cereals

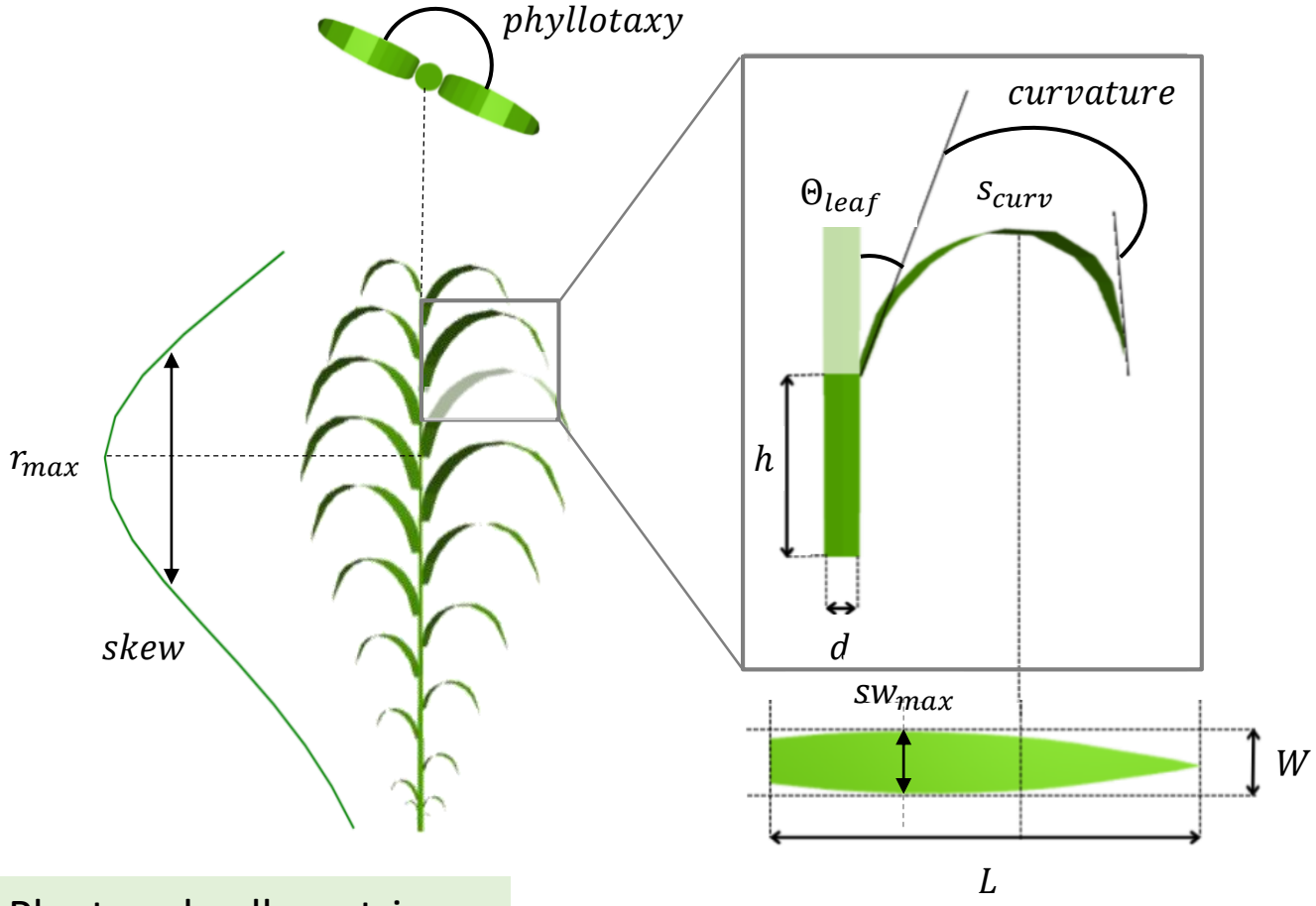




$$LAI(t) = \sum_{i \in P} \sum_{j \in A} s_{i,j}(t)$$

P: {plants in a crop}
A: {appeared leaves in a plant}

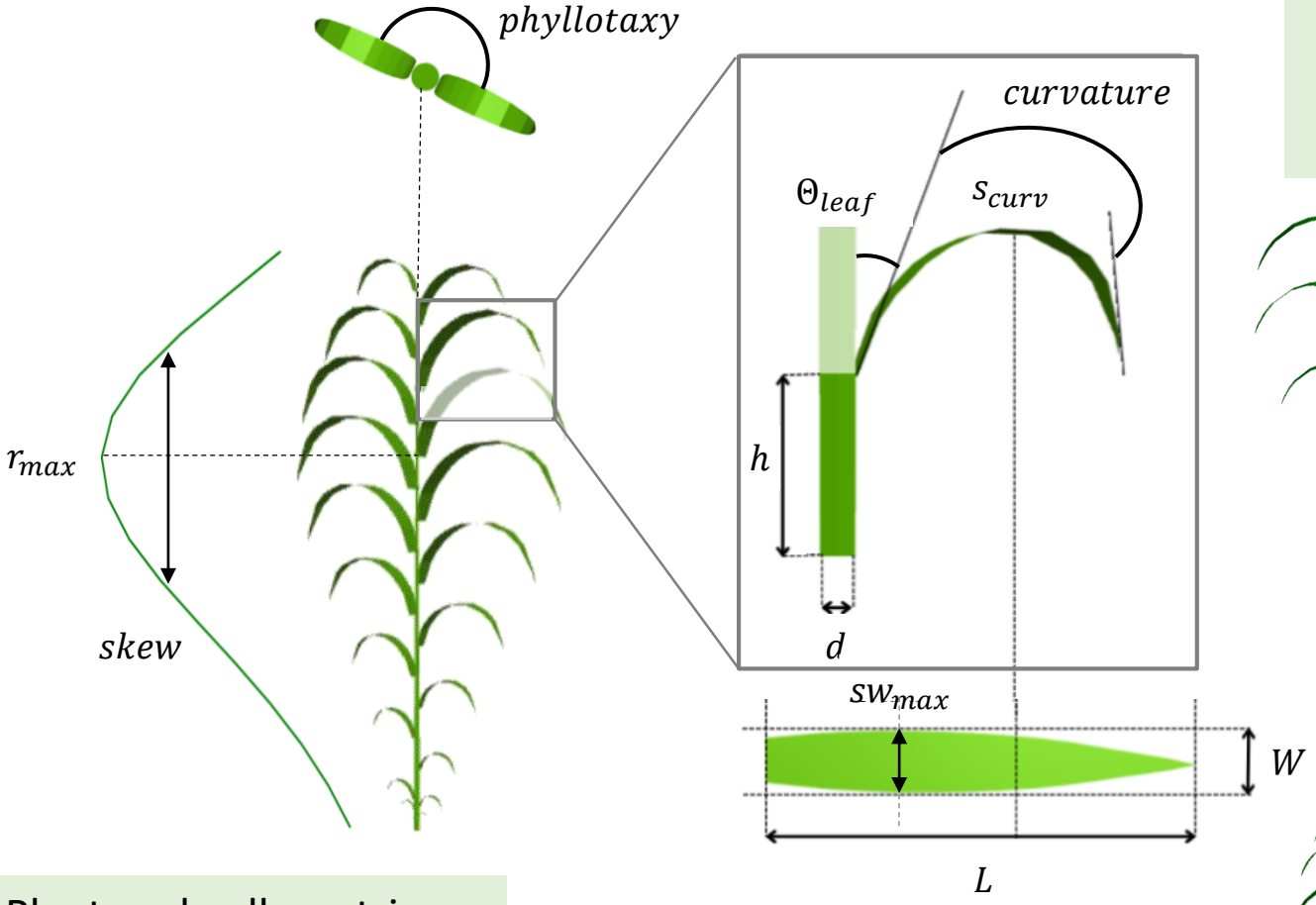
Model - Architectural parameters



Plant-scale allometries for cereals, *e.g.* leaf area distribution along stem

(Evers et al., 2005, Vidal and Andrieu, 2020)

Model - Architectural parameters

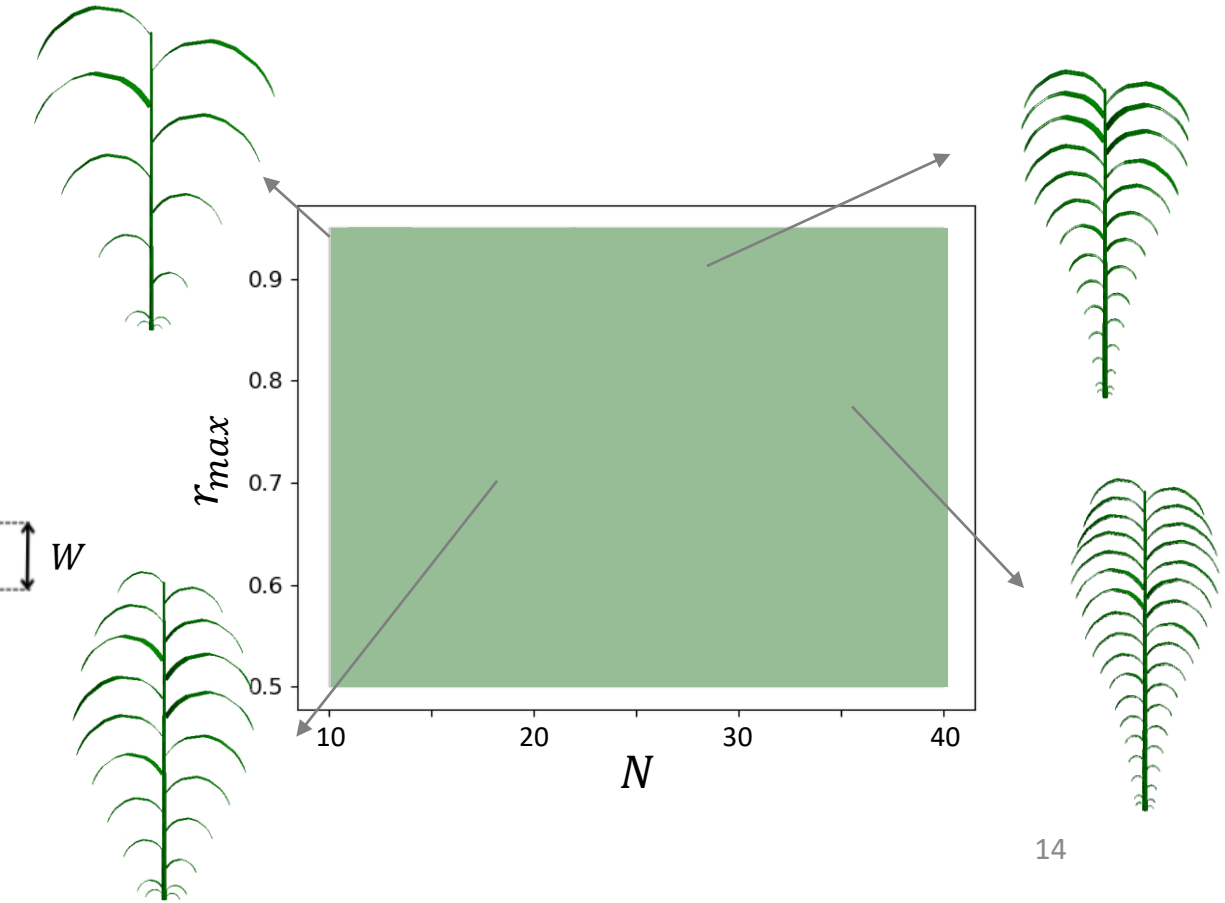


Plant-scale allometries for cereals, *e.g.* leaf area distribution along stem

(Evers et al., 2005, Vidal and Andrieu, 2020)

A species is defined by a set of 27 parameter intervals found in literature = **Morphospace**

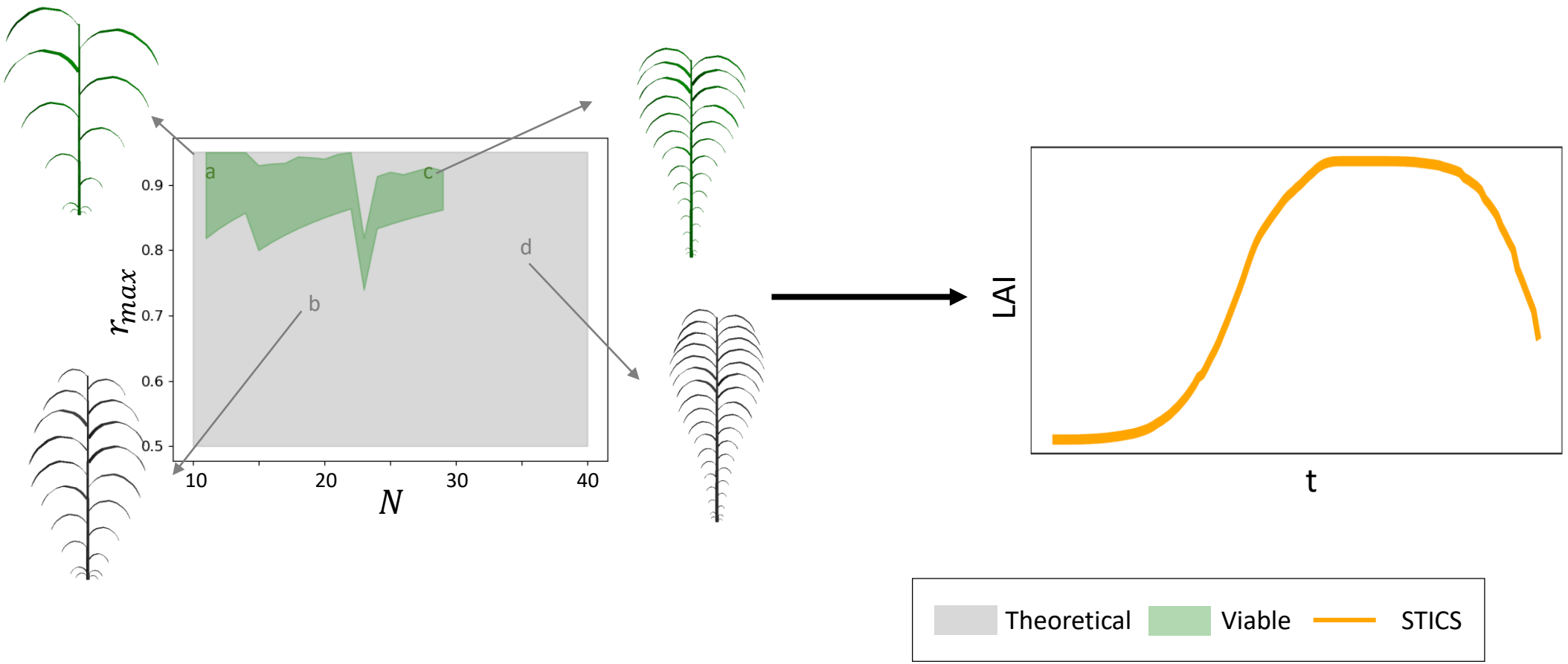
e.g. Sorghum bicolor *(Lafarge et al., 2002; Clerget, 2008)*



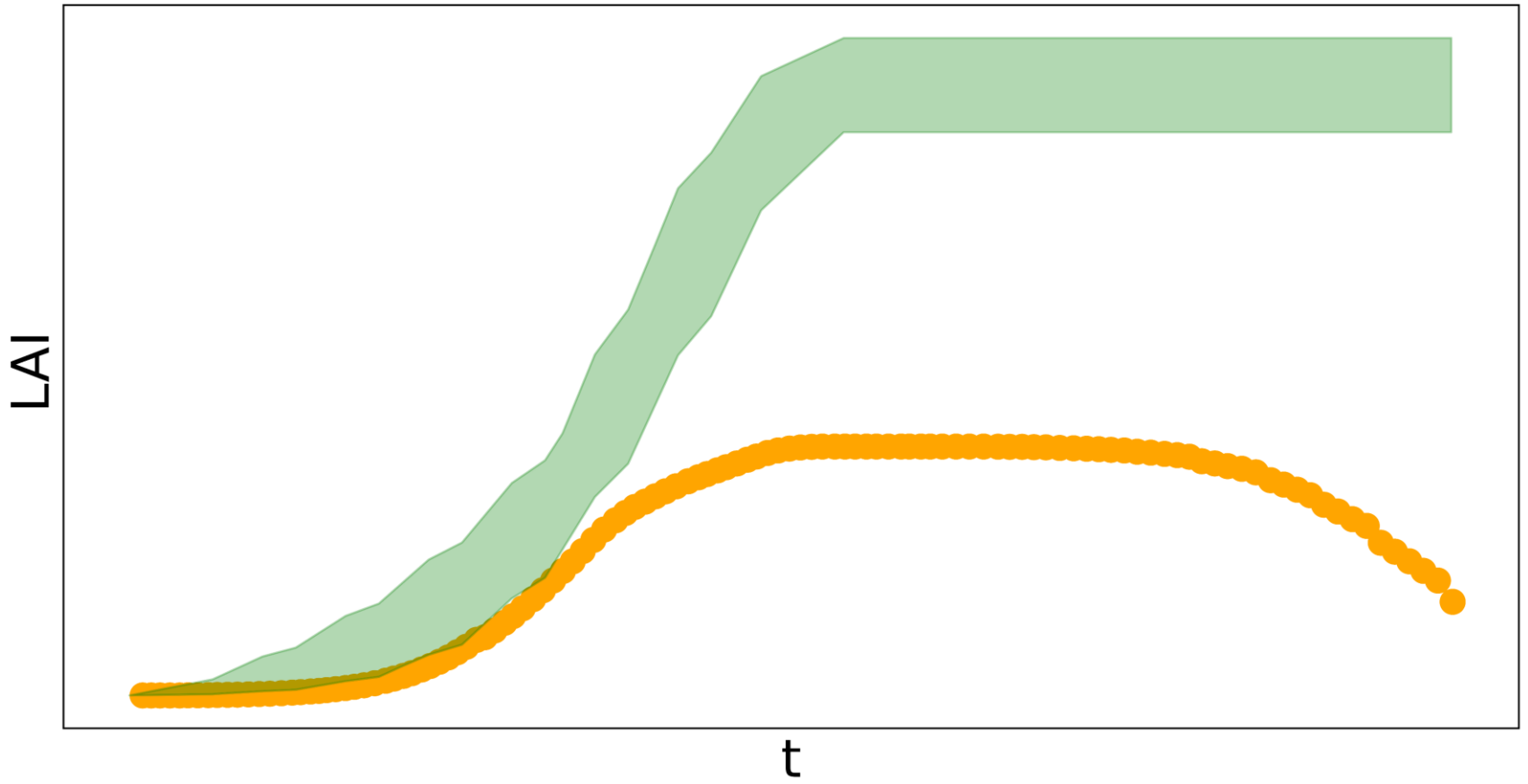
Model - Problem

Not all plant architectures of the morphospace of a species follow the crop-scale dynamics

How to find the viable sub-morphospace ?



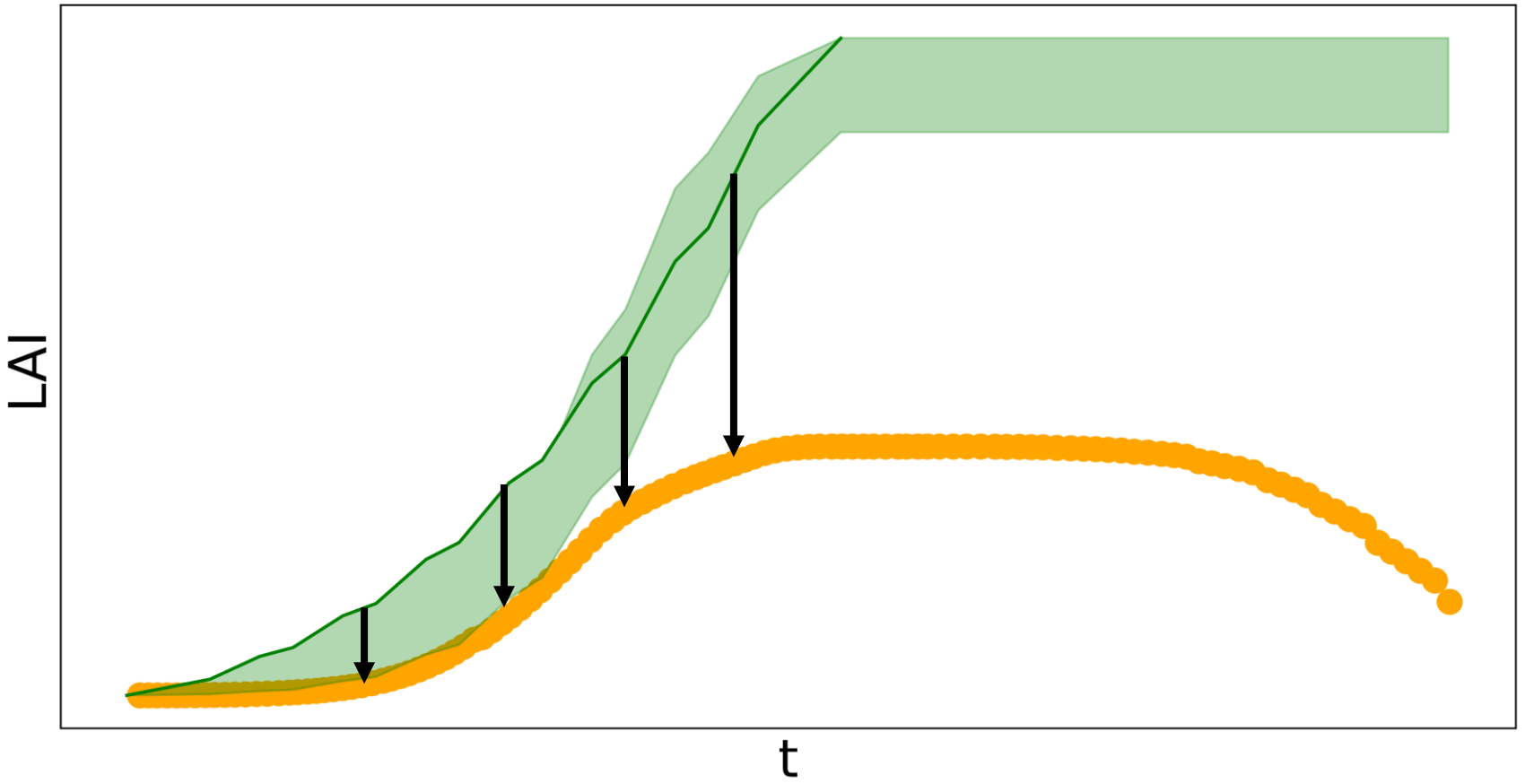
Model - Defining a viable subspace



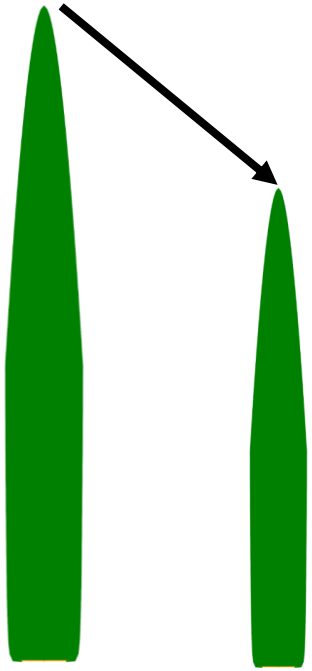
A viable subspace is a parameter space that gives all plant dynamics that are above the STICS dynamics to follow.

(Aubin et al., 1991)

Model – Solving constraints

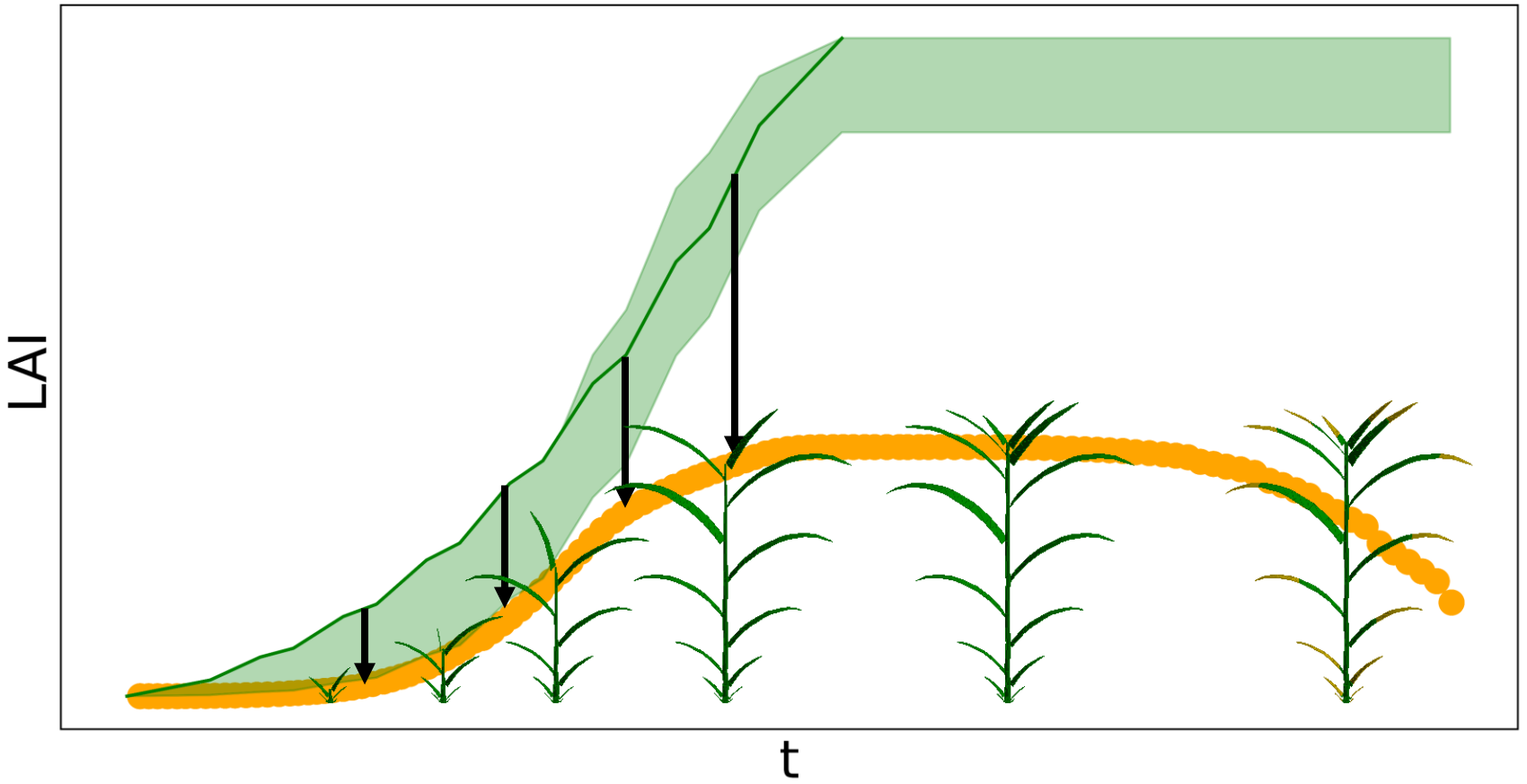


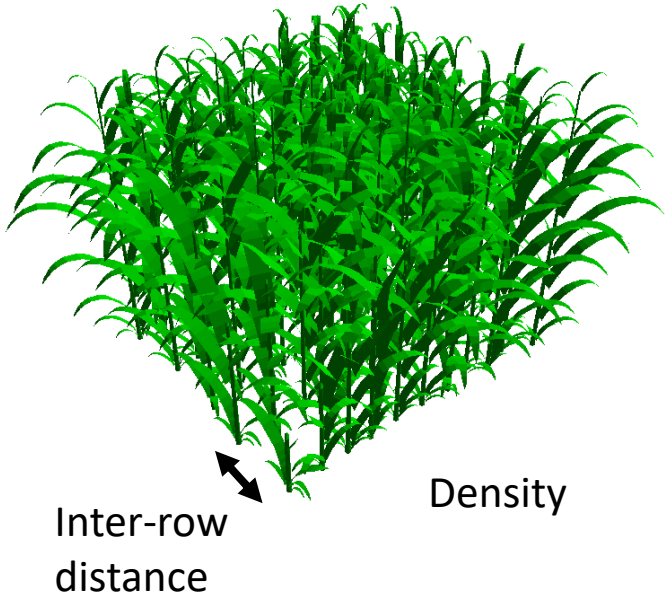
Reduce area of growing leaves to follow the dynamics



Theoretical Viable STICS

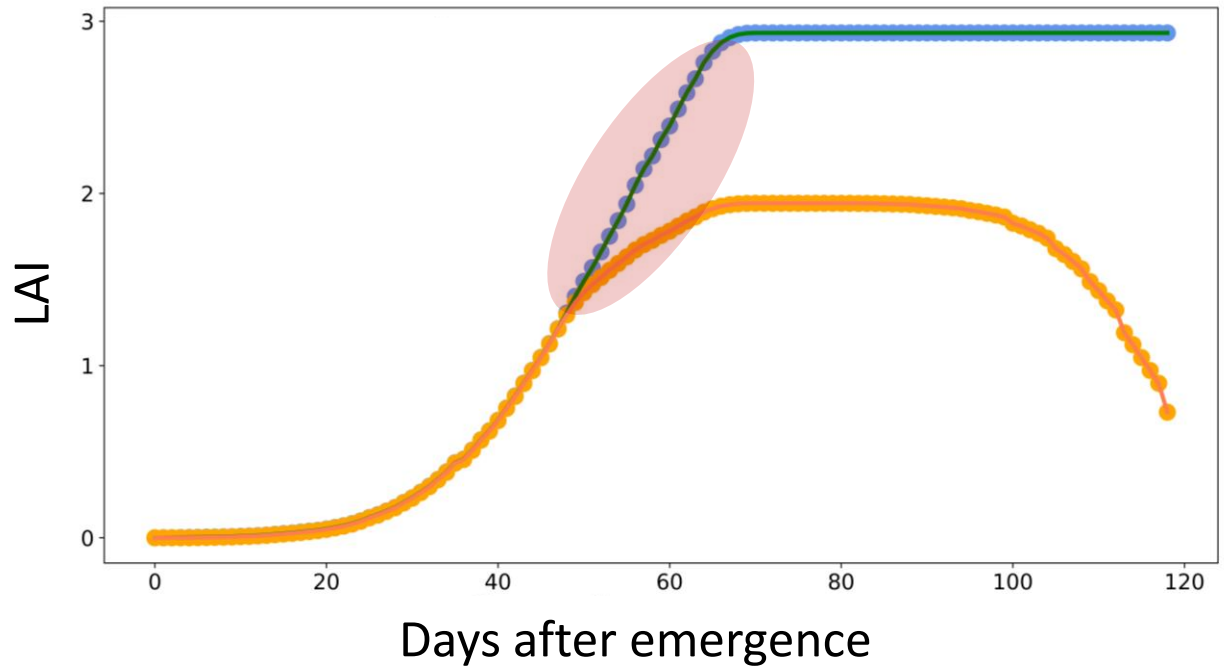
Model – Reconstructing a crop in 3D+t

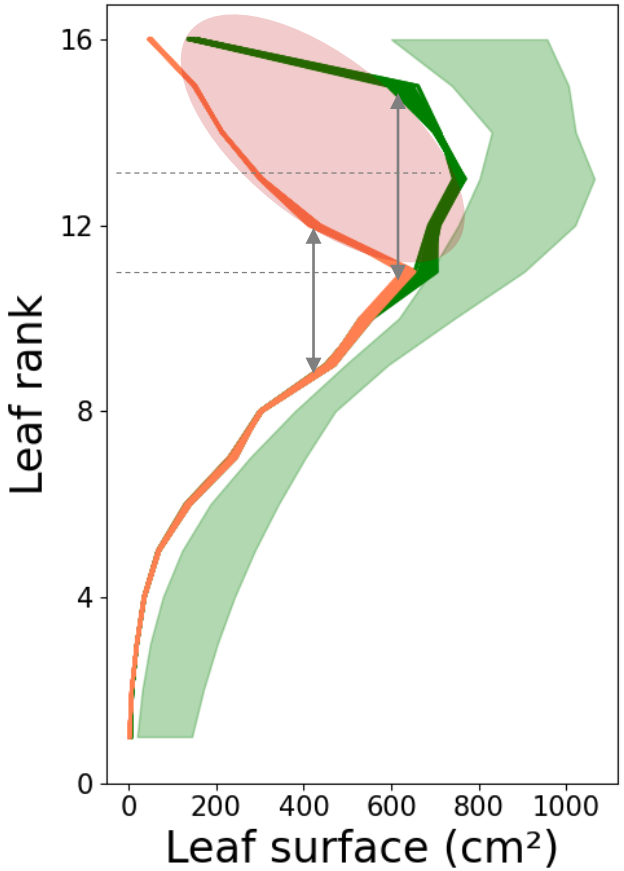




Theoretical Viable STICS

Model – Visualizing stresses in 3D





Theoretical
Viable
ArchiCrop unstressed
STICS unstressed
ArchiCrop stressed
STICS stressed
Leaf area affected by stress

Multiscale Approach to Evaluate Beer's Law in STICS

Field data

(Traore et al., 2023)

Crop model

(Brisson et al., 1998)

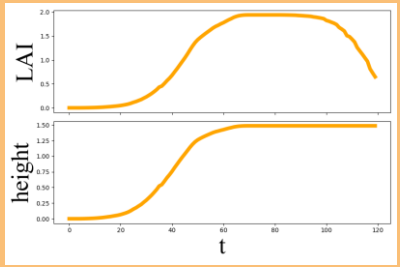
1D Beer Lambert's light extinction model
(Sinoquet et al., 1991)

Assess extinction coefficient k

OpenAlea

3D radiosity model
(Chelle et al., 1998)

Growth dynamics



Sorghum

Architectural & development parameters

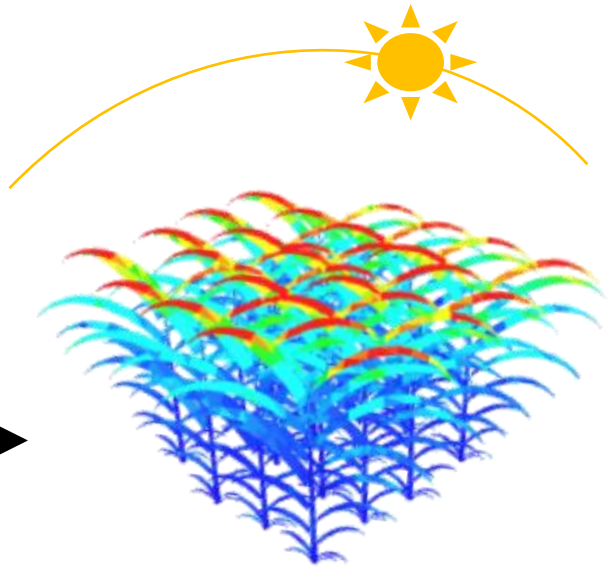
(Lafarge et al., 2002; Clerget et al., 2008; Truong et al., 2015; Ganeme et al., 2022)

Compute 3D scene through time

ArchiCrop

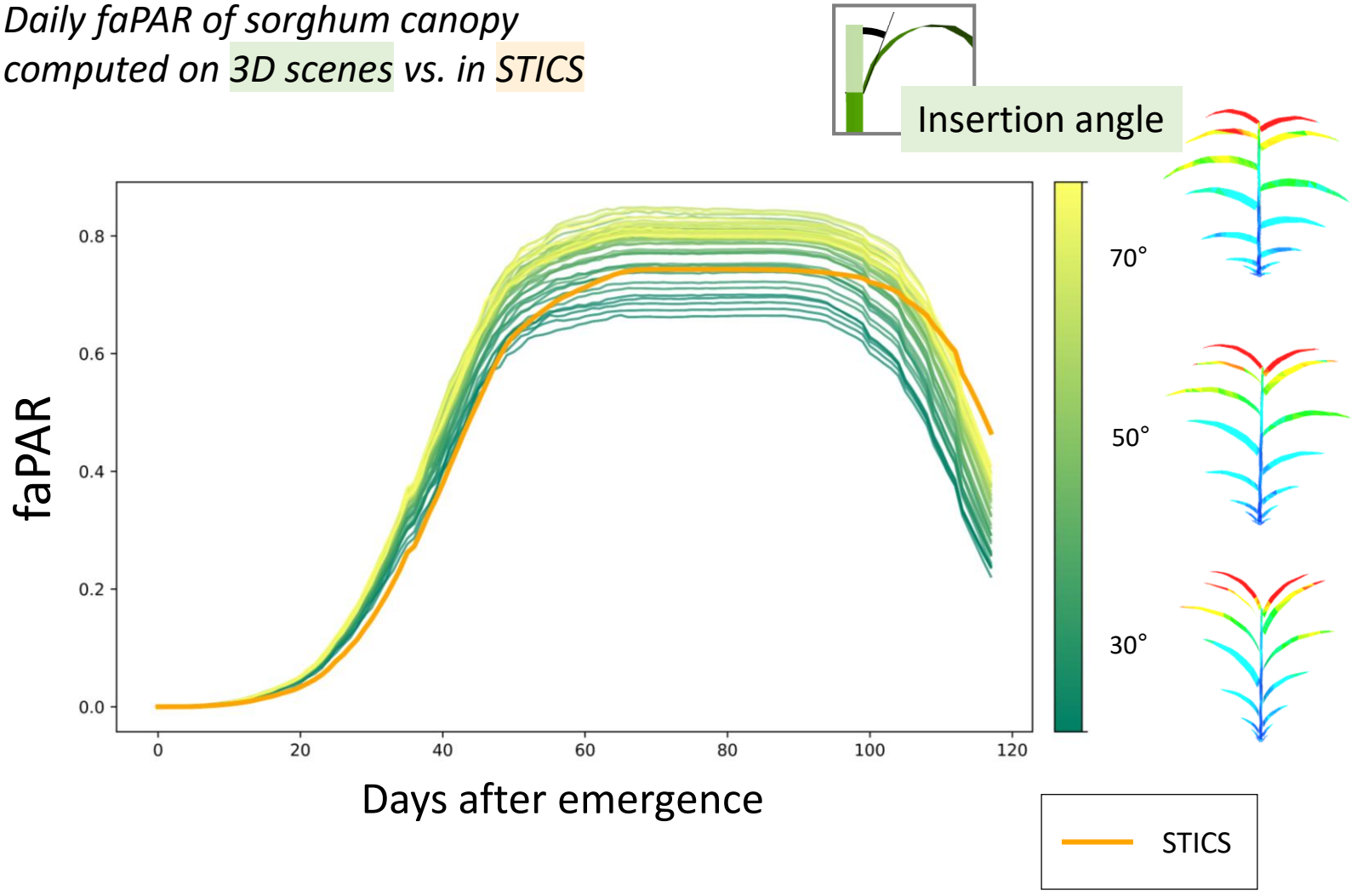
OpenAlea

Vary θ_{leaf}, N



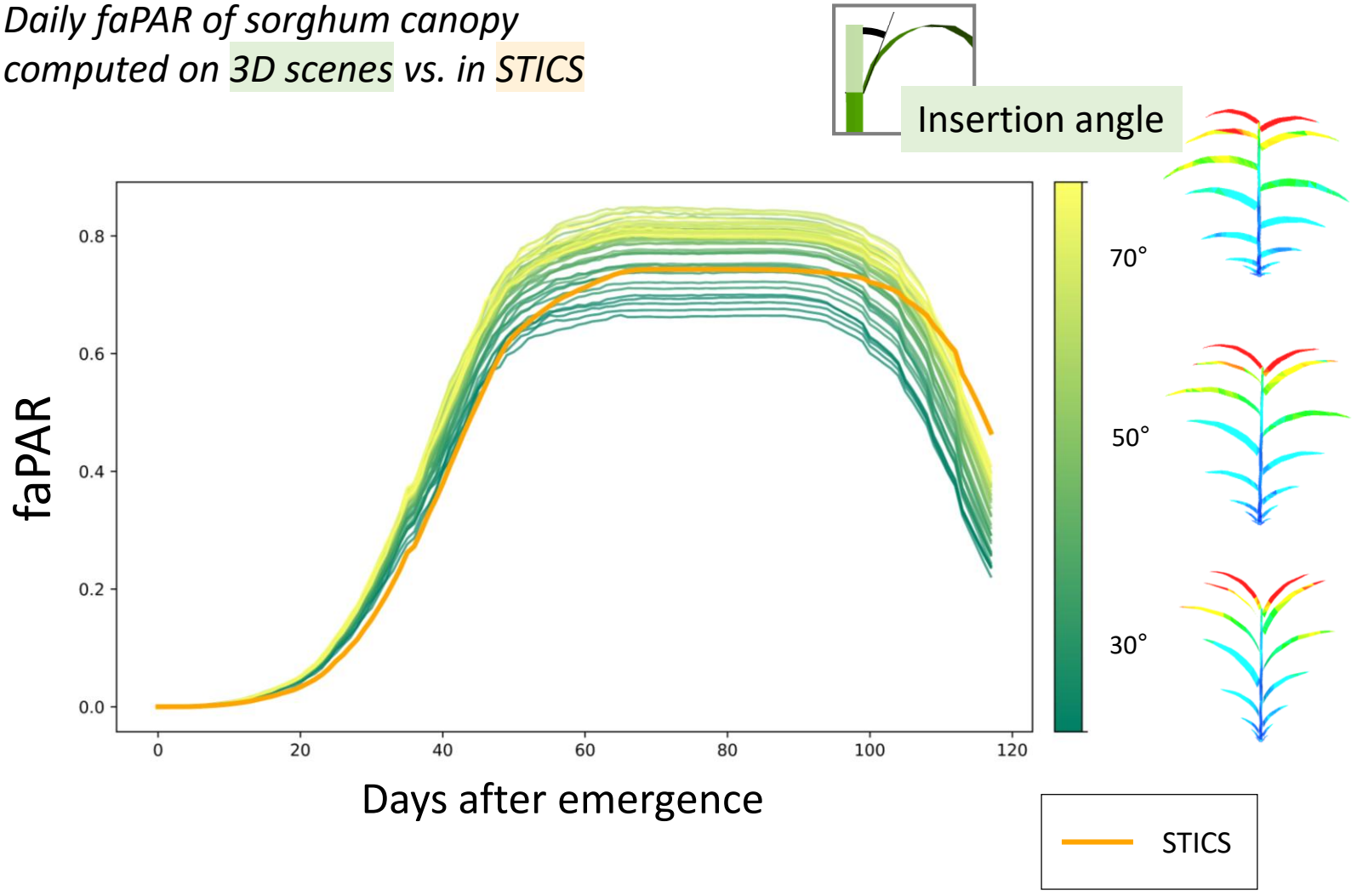
Results - Light Interception 1D vs. 3D

Daily faPAR of sorghum canopy computed on 3D scenes vs. in STICS



Results - Light Interception 1D vs. 3D

Daily faPAR of sorghum canopy computed on 3D scenes vs. in STICS



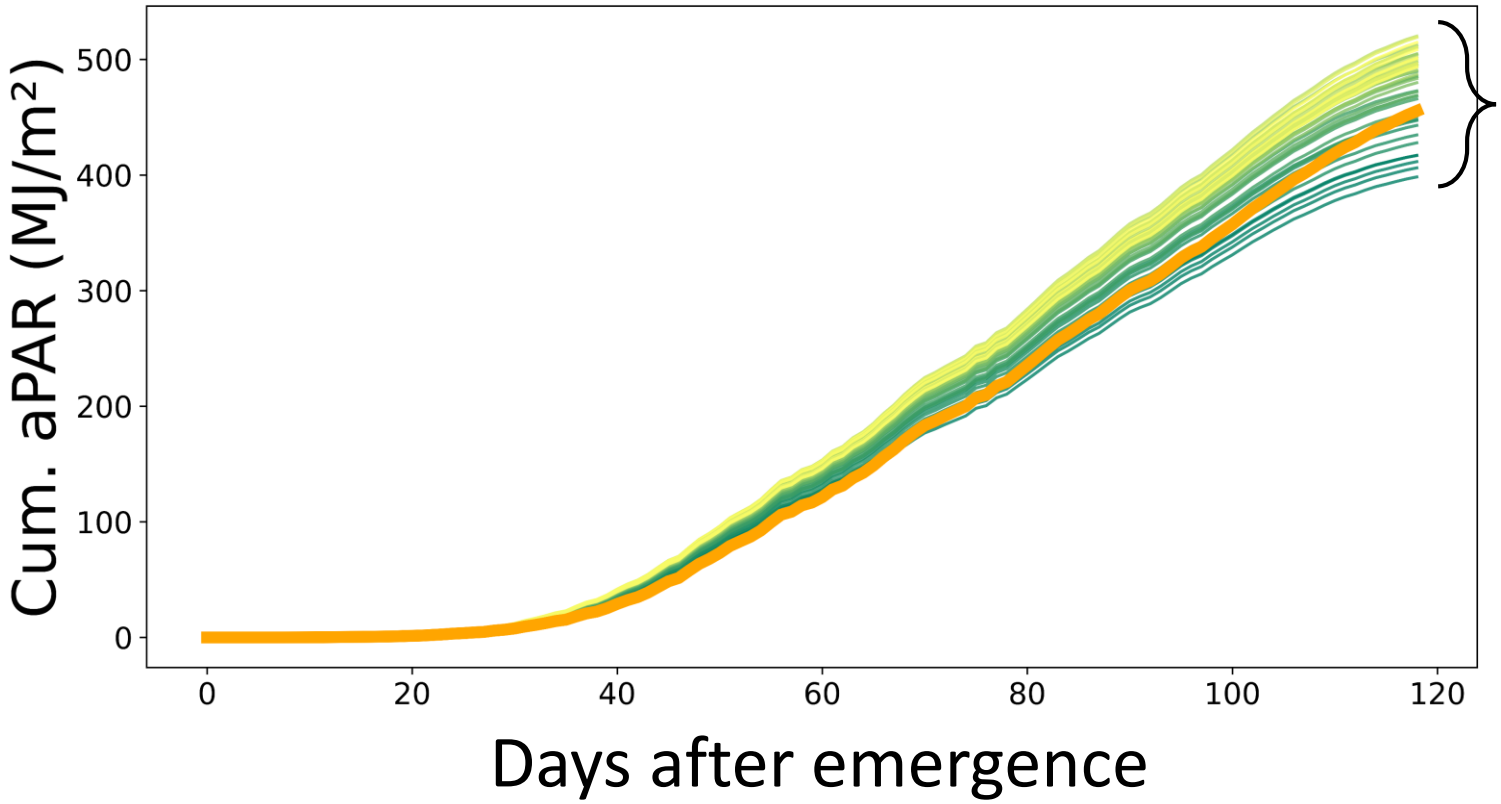
STICS first under- then over-estimates light interception

Leaf insertion angle impacts light extinction in the canopy

(Sinoquet and Caldwell, 1995; Truong et al., 2015; Perez et al., 2019)

Results - Light Interception 1D vs. 3D

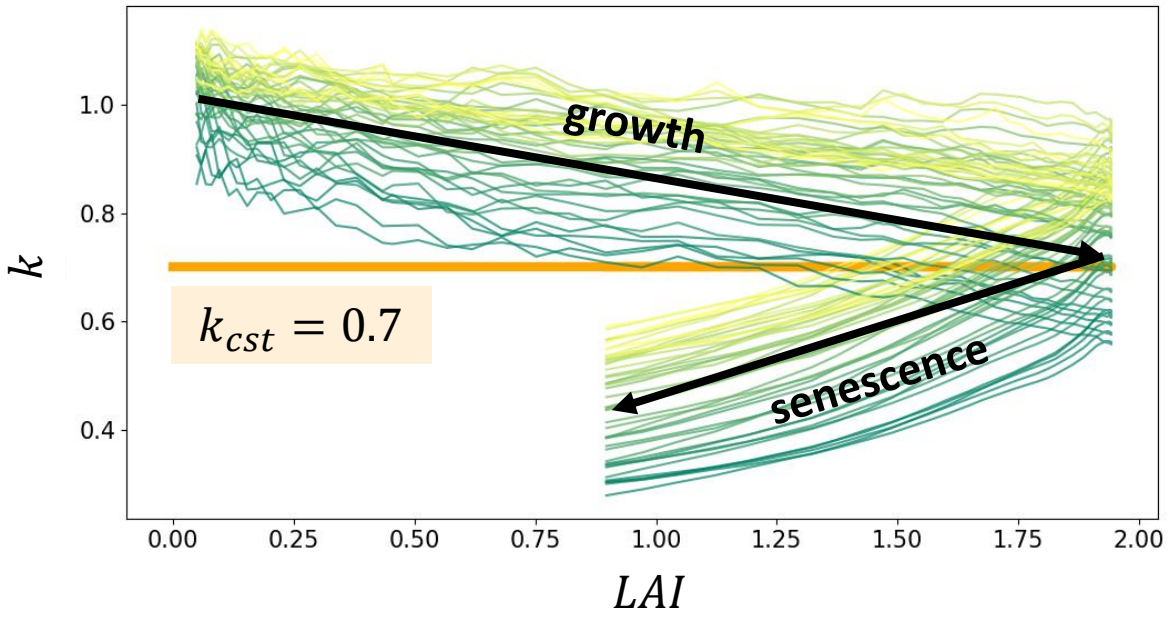
Cumulated aPAR of sorghum canopy computed on 3D scenes vs. in STICS



27 %
variability brought by architecture

Results - Emergent Extinction Coefficient

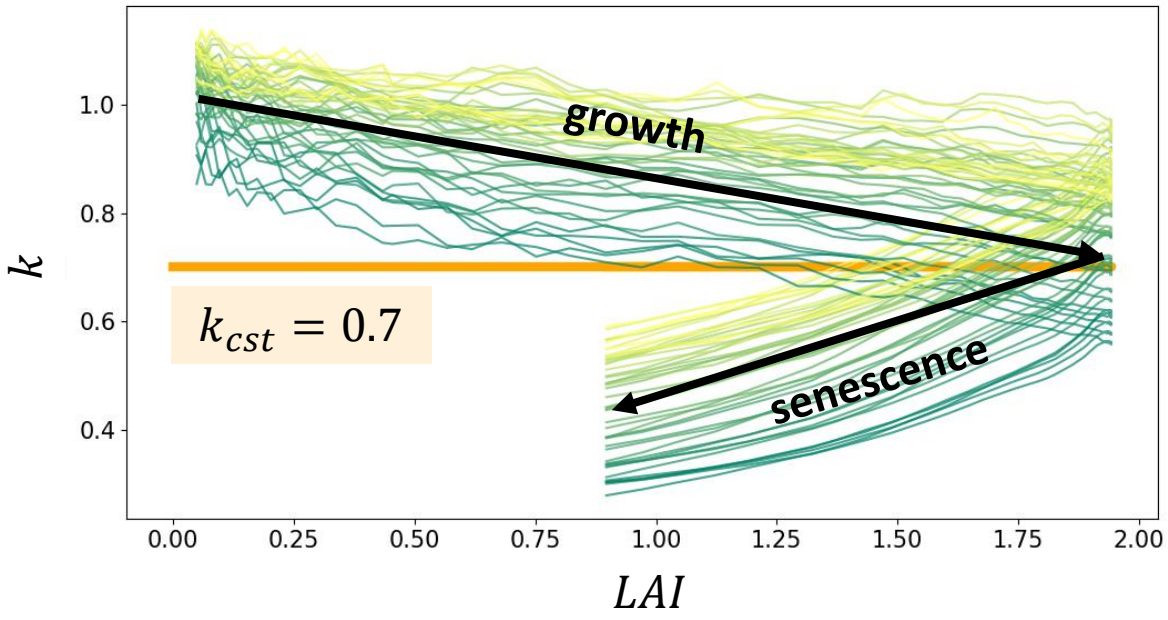
$$k_{3D}(LAI) = -\frac{1}{LAI} * ln(1 - faPAR_{3D}(LAI))$$

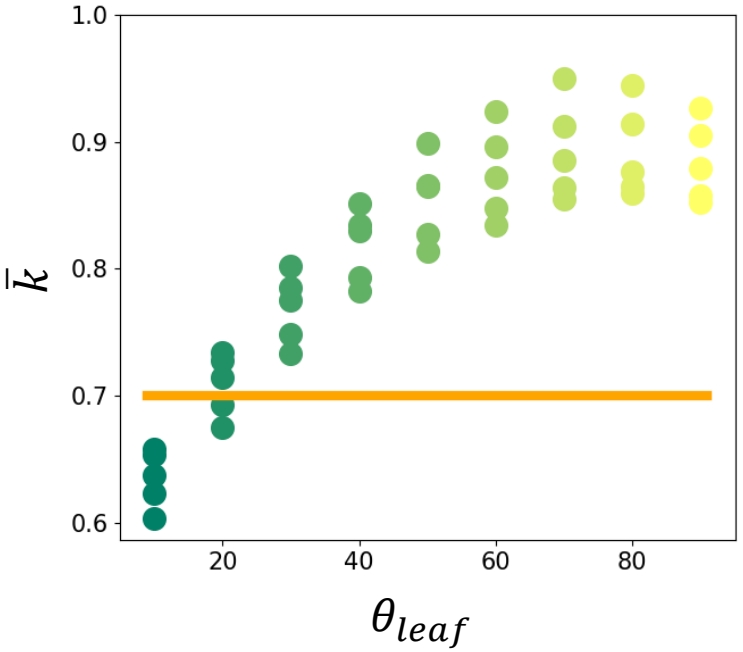


STICS

Results - Emergent Extinction Coefficient

$$k_{3D}(LAI) = -\frac{1}{LAI} * ln(1 - faPAR_{3D}(LAI))$$

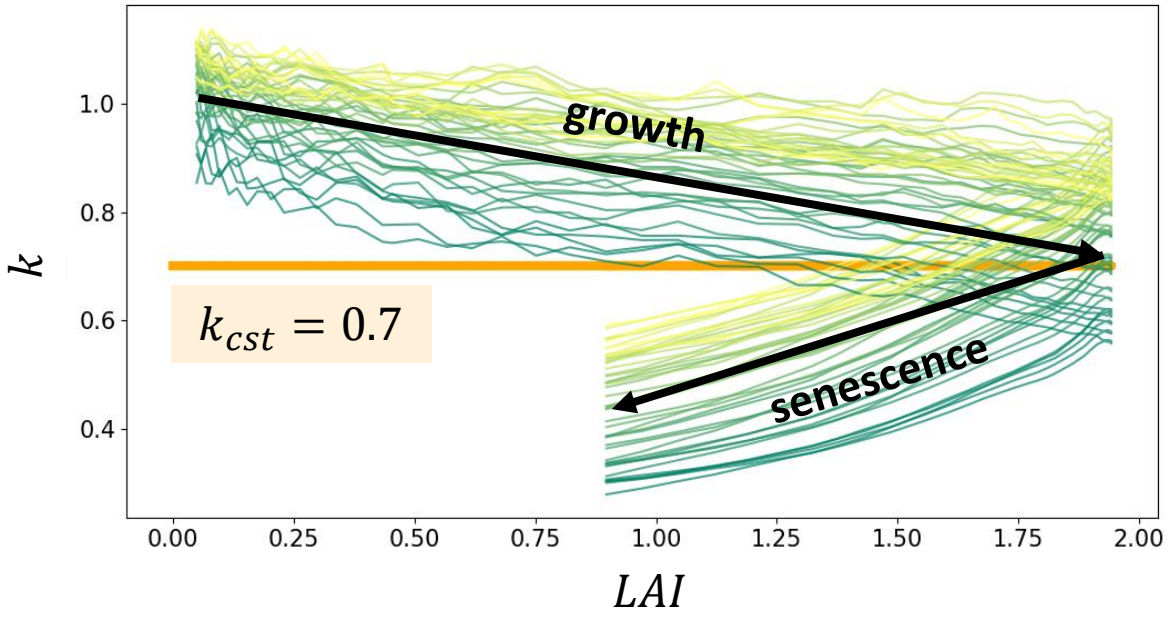




STICS

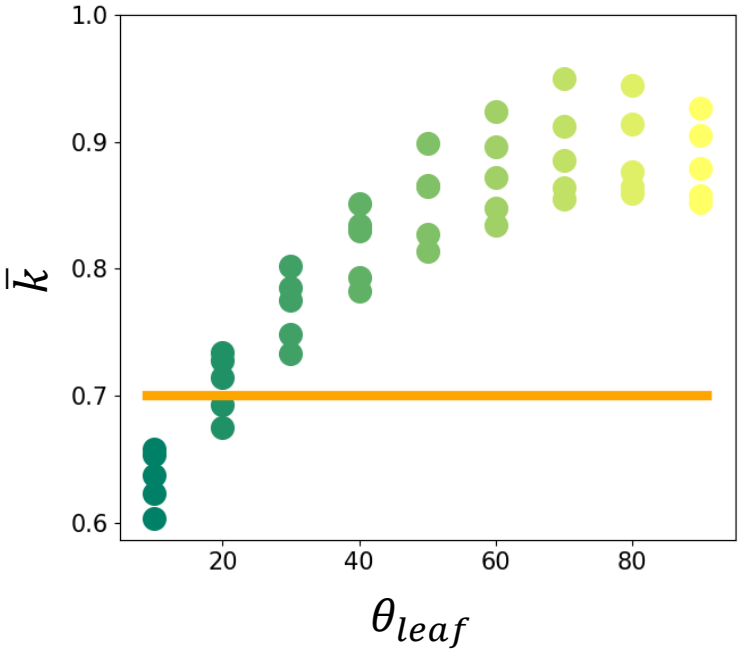
Results - Metamodel of Extinction Coefficient

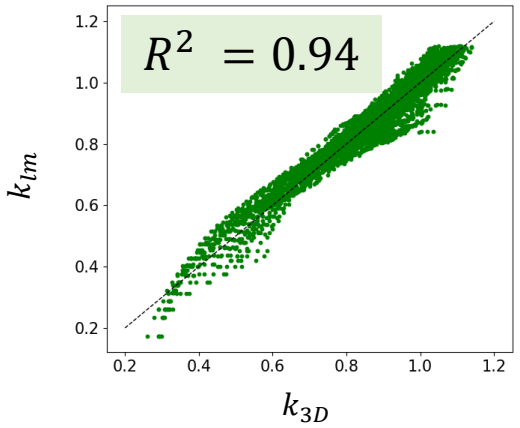
$$k_{3D}(LAI) = -\frac{1}{LAI} * ln(1 - faPAR_{3D}(LAI))$$



Metamodel:

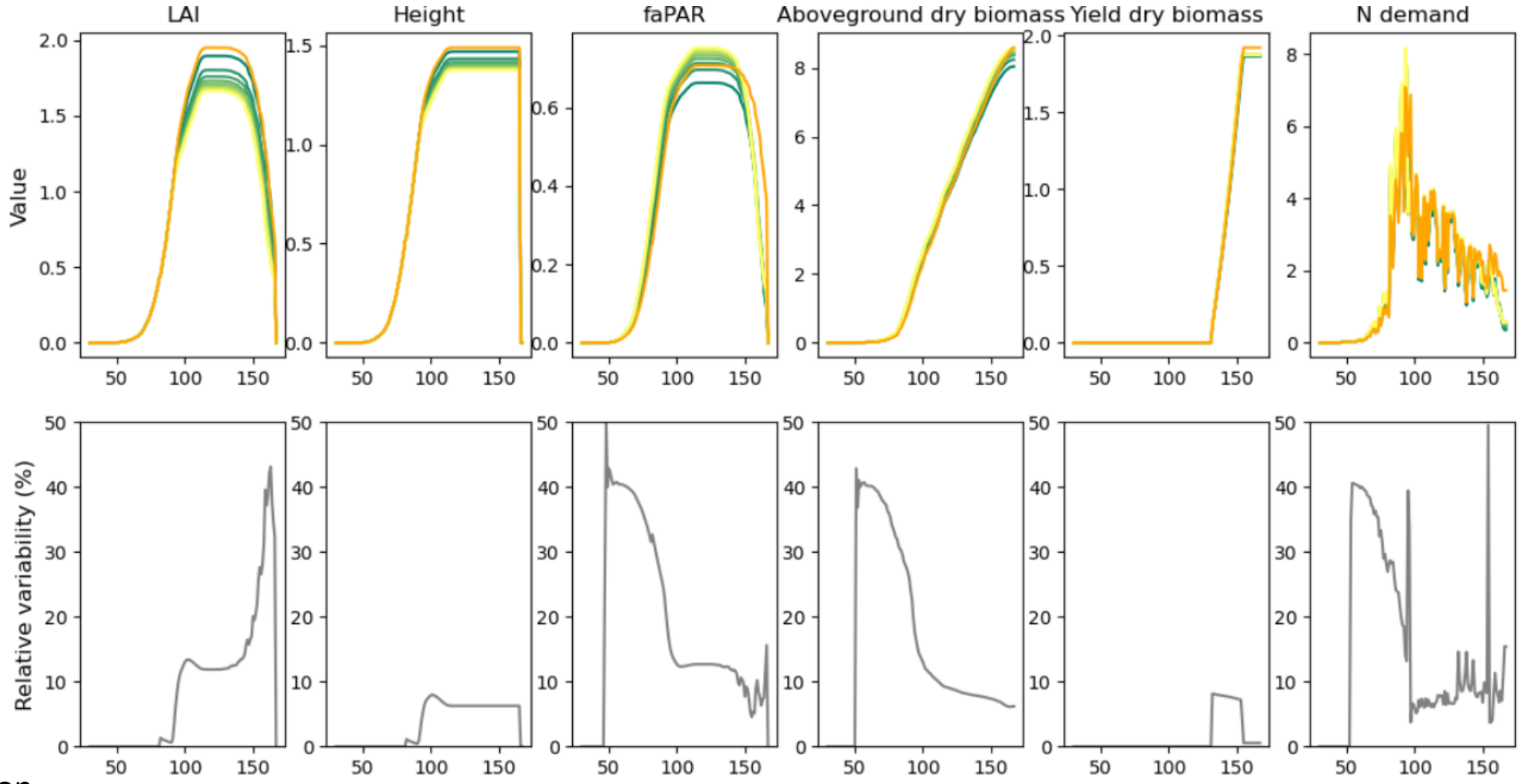
$$k_{lm} = -0.38 + 0.13 * log(\theta_{leaf}) - 0.12 * LAI + 0.94 * pLAI_{sen}$$





$BIC_{cst} = -1743$ **>** $BIC_{lm} = -15650$

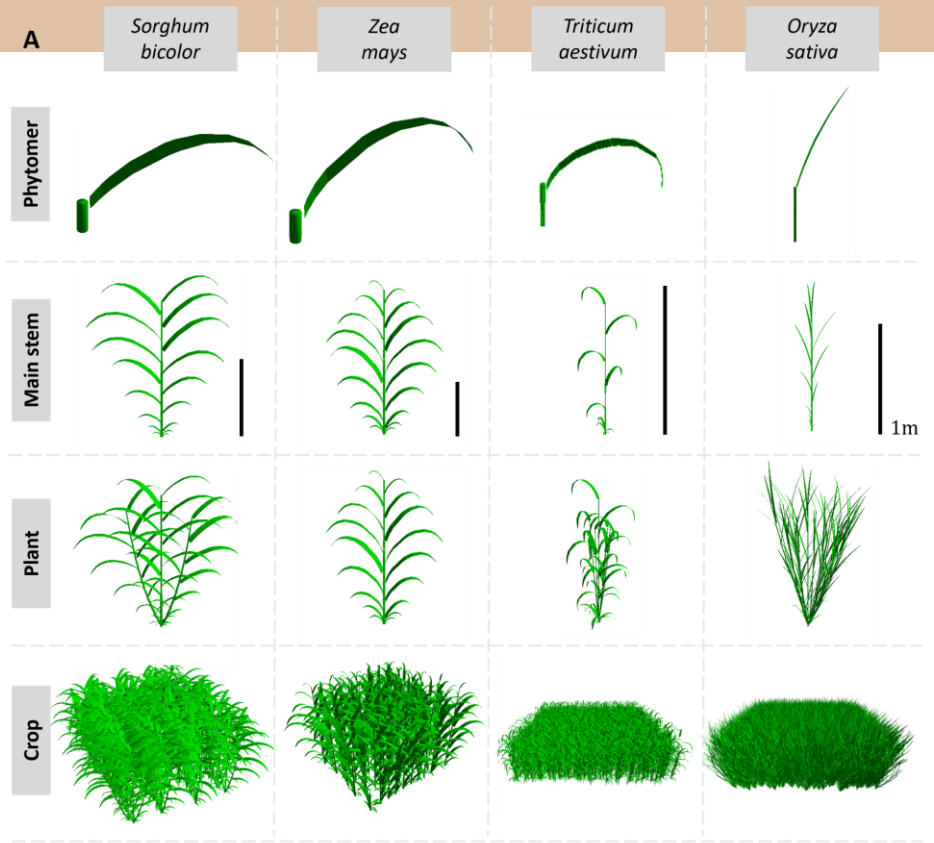
Results - Metamodel of k in STICS



Propagation of uncertainty → 6% 1%

Take home message

- **ArchiCrop:**
  - Efficient (~3s) constraint-based 3D architectural model
  - Simulates various cereals (with or without tillers)
  - Hybrid model : crop + FSPM



- **Multiscale comparison of light interception models:**
  - Architecture impacts light interception in 3D (27% for 2 parameters).
  - A metamodel for k can be computed without 3D representation ($R^2 = 0.94$). *(proof of concept)*

Future works:

→ Apply method on intercrops

→ Evaluate N demand process