Representation and functions of shoot apical meristems in FSPMs

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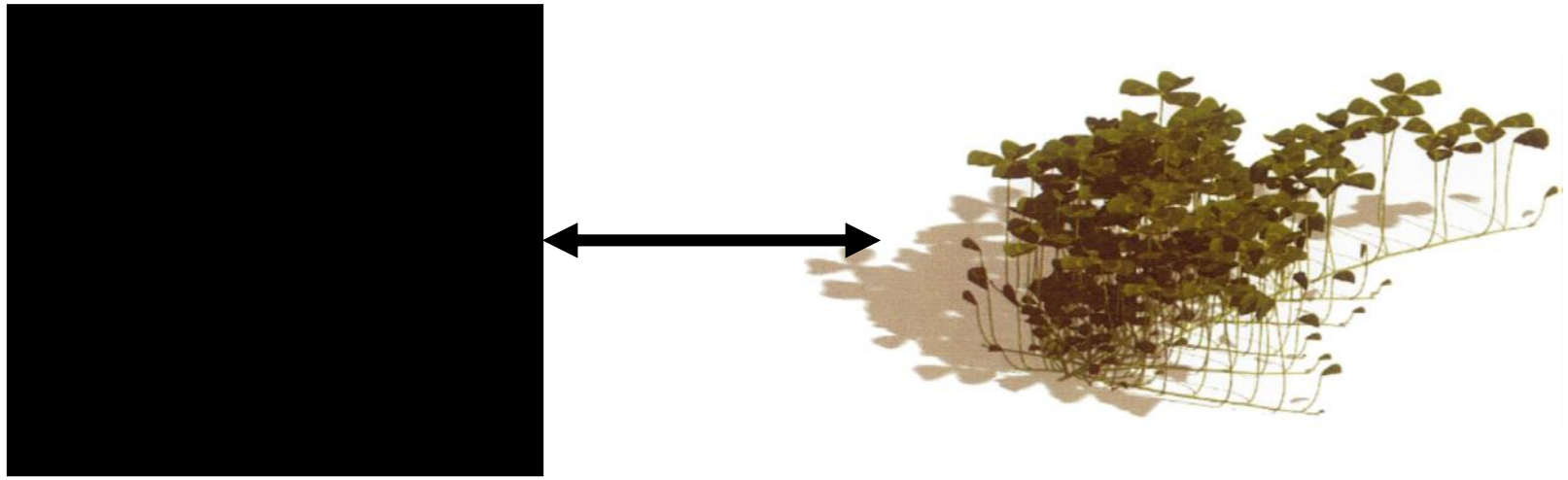
1- Introduction

What are FSPMs?

- Functional Structural Plant Models are:
  - Plant models focusing on the functioning of the individual plant in its environment (endogenous/external)
  - Architectural: they include a fine representation of the plant-environment interface
  - Mechanistic: they allow the phenotype of plants to be decomposed into elementary traits
- Few interactions between the community of FSPM and that of SAMs (gene network, cell biology, SAM geometry…)
- Role of SAMs in plant development is mostly implicit, based on empirical functions

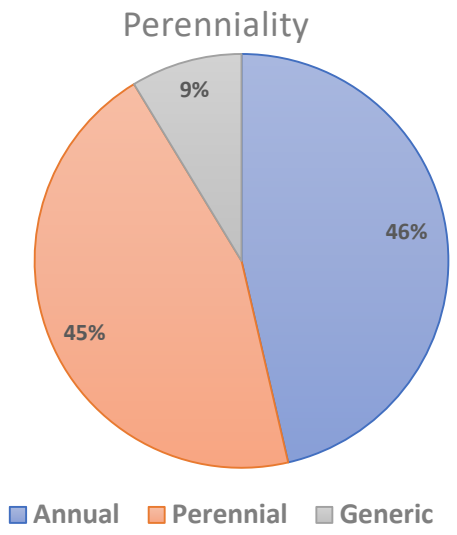


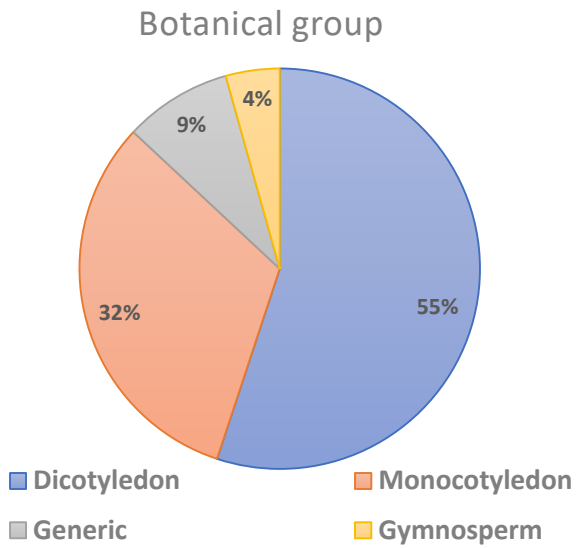
2 - A review of the integration of SAMs in FSPMs

2- Integration of SAMs in FSPMs – A Review

Characteristics of reviewed FSPMs

Review of 69 FSPMs (1996 – 2021)





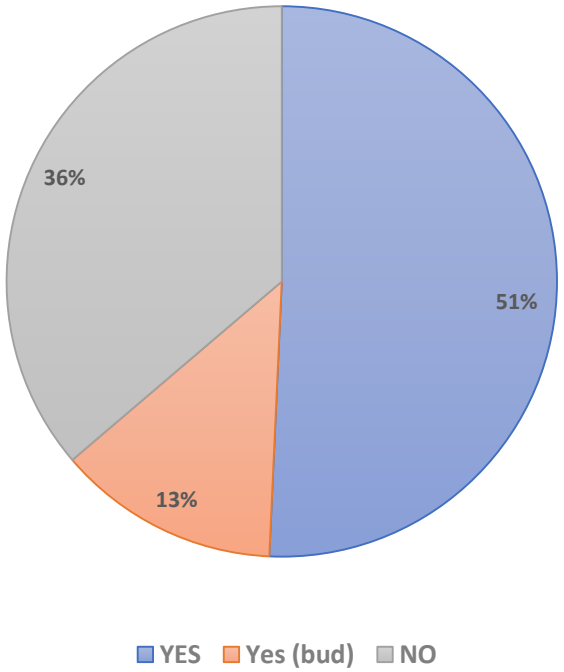
Species	Count
Wheat	6
Generic	6
Trees	4
Grapevine	3
Perennial ryegrass	3
Maize	3
Rice	3
Arabidopsis	3
Cotton	3
Tomato	2
Pea	2
Rapeseed	2
Rose	2
Apple tree	2
Pinus	2
Barley	2
Sunflower	2
Vicia faba	1
Alfalfa	1
Chickpea	1
Palm	1
Mango	1
Walnut	1
Alder	1
Fruit tree	1
Peach	1
Cucumber	1
Seagrass	1
Grasstree	1
Coniferous	1
Cauliflower	1
C4 grasses	1
Brassica nigra	1
Soybean	1
Arundo donax L.	1
Almond	1

A large diversity of species, architectures, biological groups… and of SAMs !

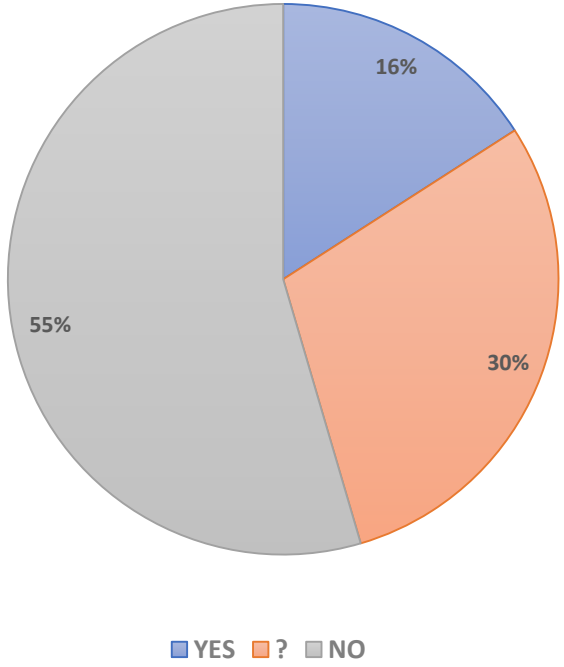
2- Integration of SAMs in FSPMs – A Review

Representation of SAMs in FSPMs

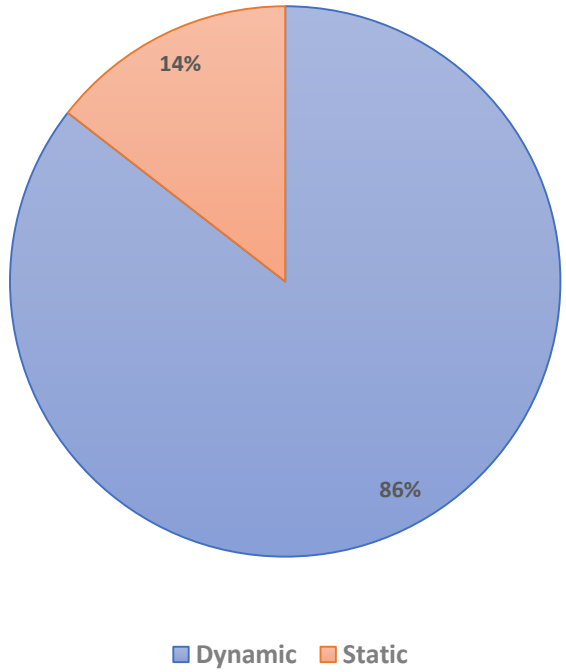
Explicit SAM module ?



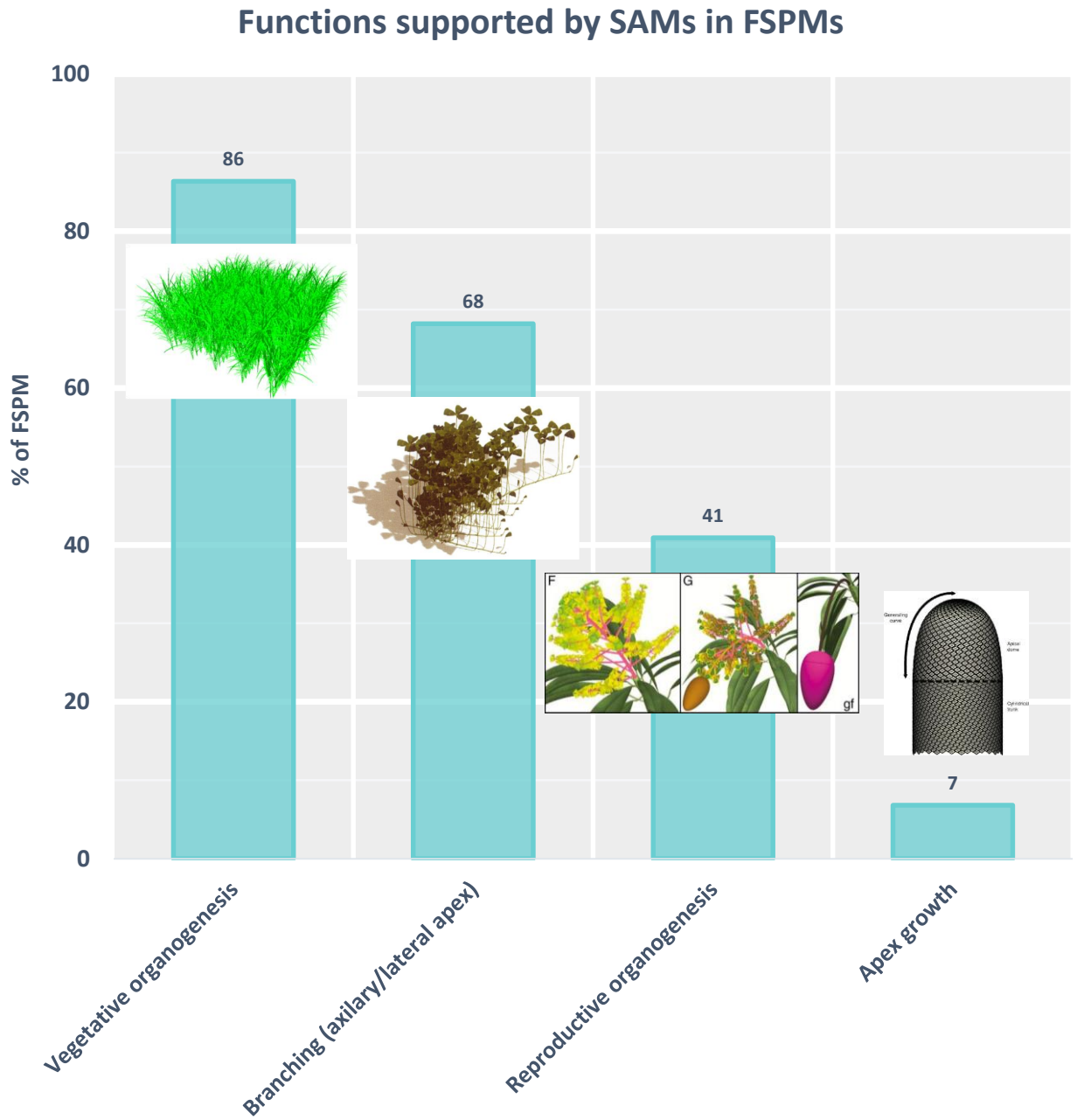
Geometrical representation of the SAM in dynamic FSPM?



Dynamic vs static FSPM

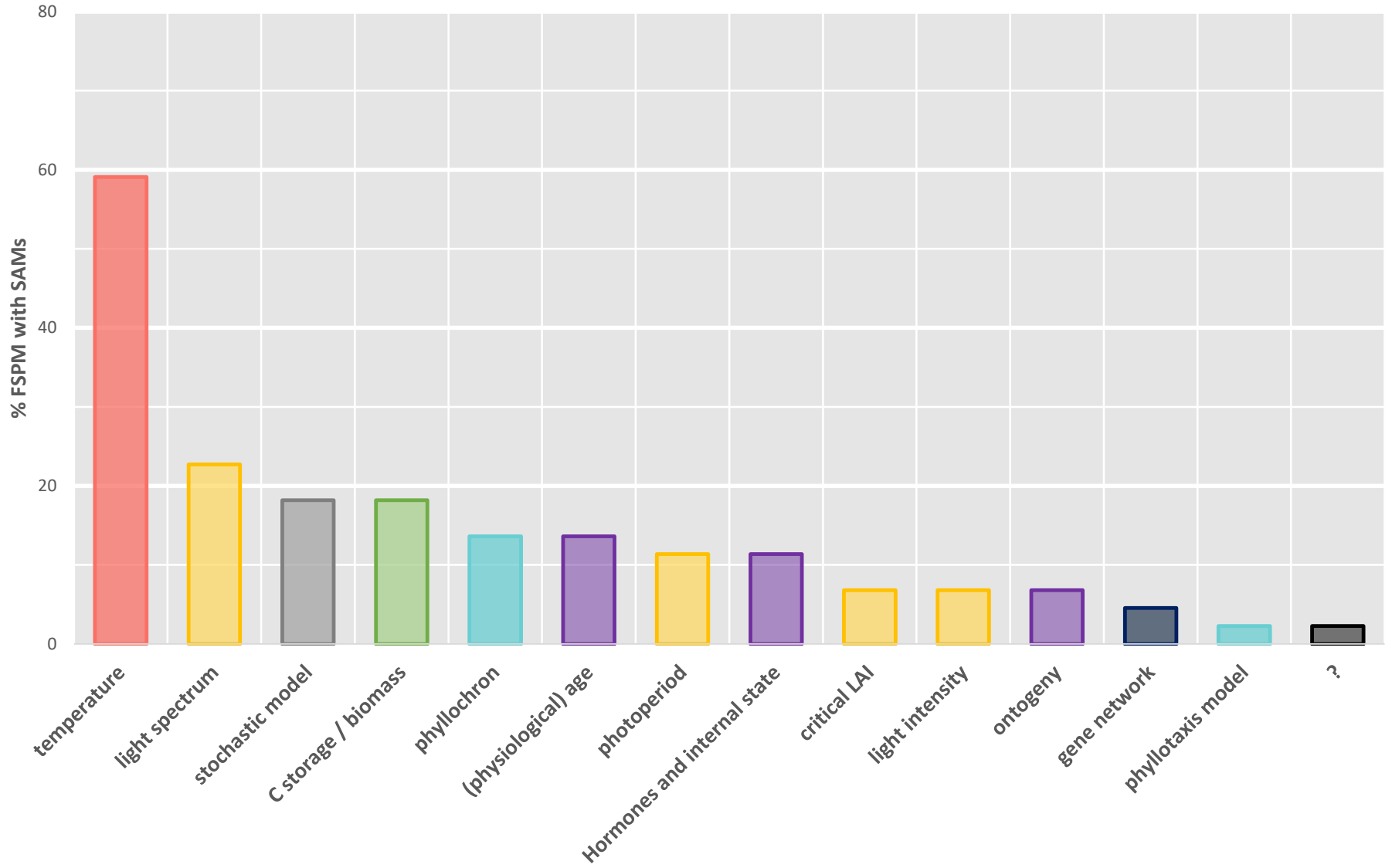


2- Integration of SAMs in FSPMs – A Review



2- Integration of SAMs in FSPMs – A Review

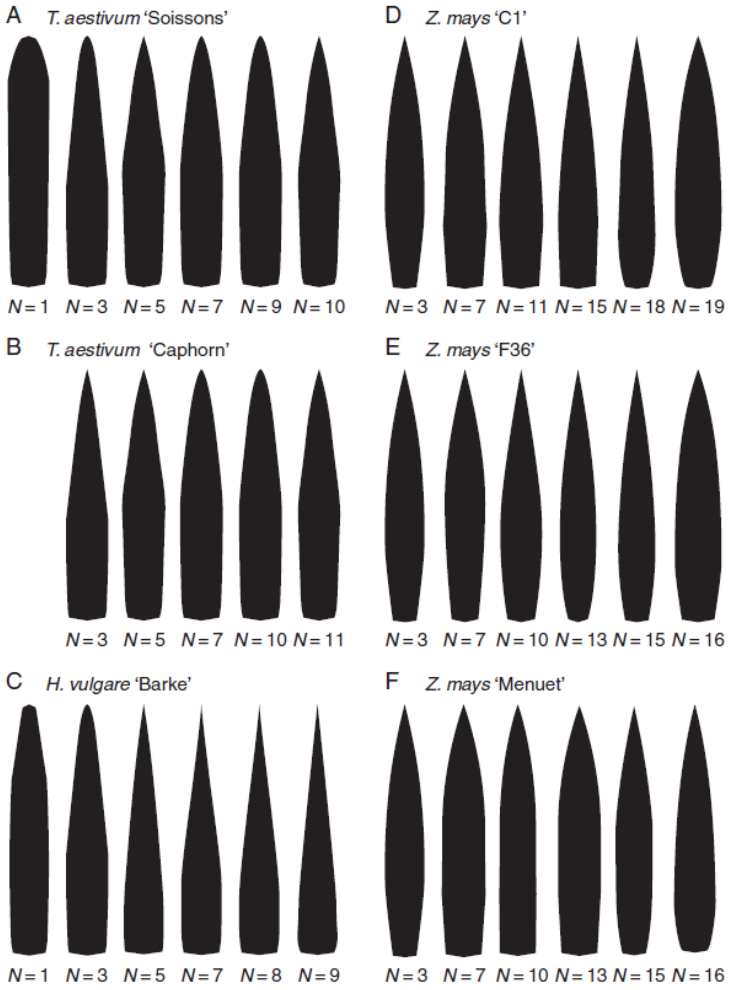
Regulation of SAMs functioning in FSPMs



3 - Why the latest knowledge on SAMs should be better integrated into FSPMs?

3- SAMs -> FSPMs

Plasticity of growth and development



Dornbusch et al. 2011

Although FSPMs aim at simulating plant plasticity, a lot of empirics / fixed traits

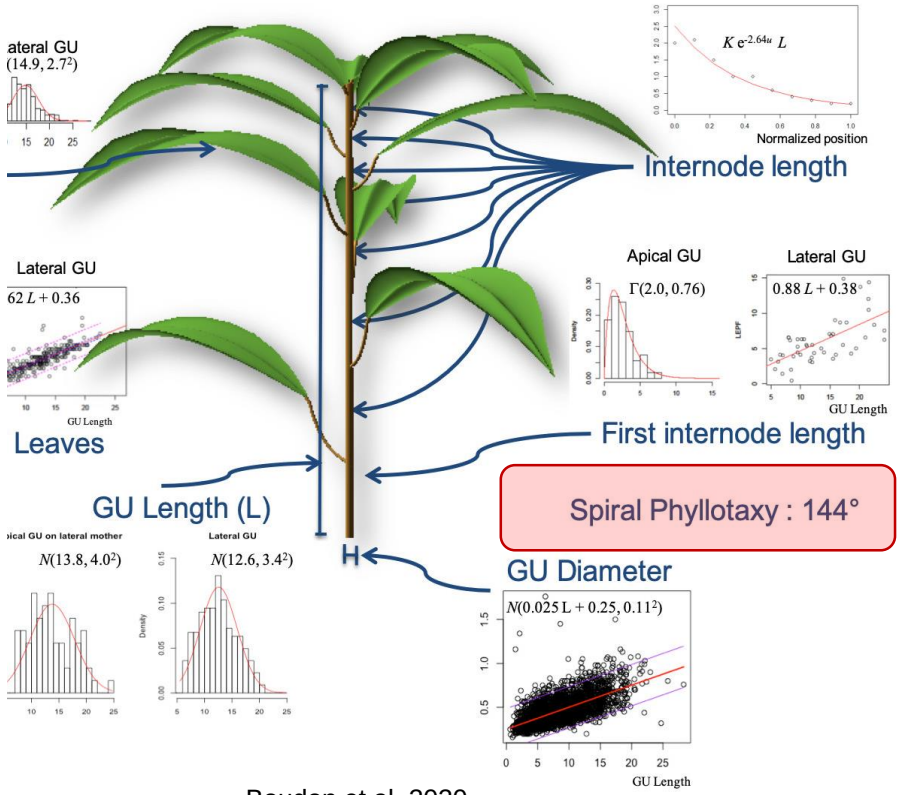
1- Leaf shape :

- High genetic diversity x environmental plasticity
- Large impact on plant – environment interactions (light, water, diseases…)
- Role of SAMs in the ontogenic gradient?

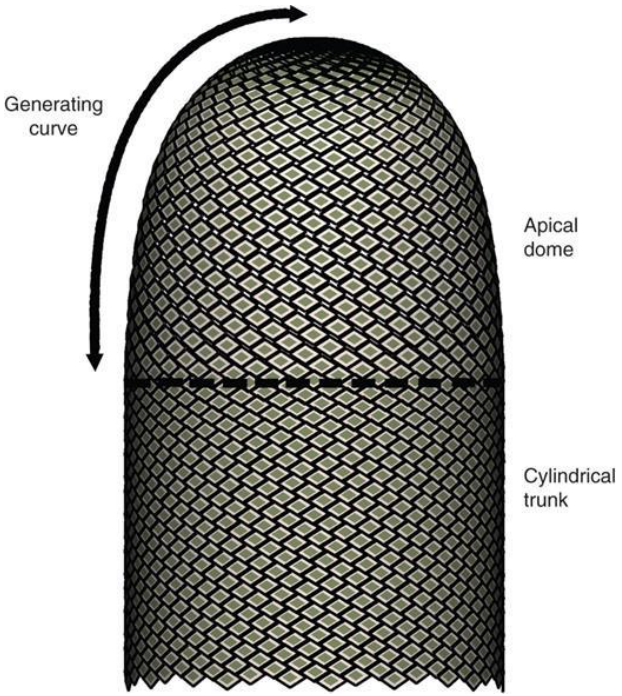
3- SAMs -> FSPMs

Plasticity of growth and development

2- Phyllotaxy: empiric in a large majority of FSPMs, despite more geometric and mechanistic approaches



Boudon et al. 2020



Ridley's model

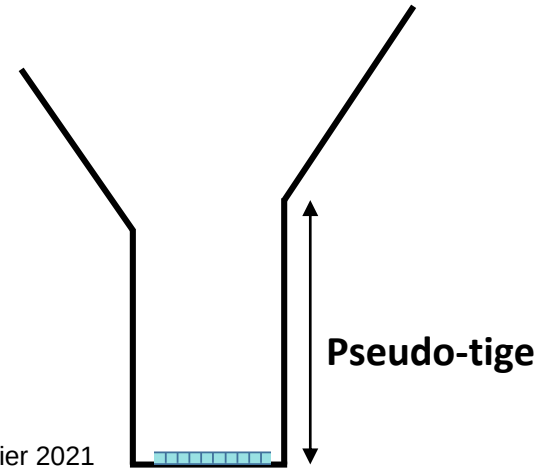
Dale et al., 2014

3- SAMs -> FSPMs

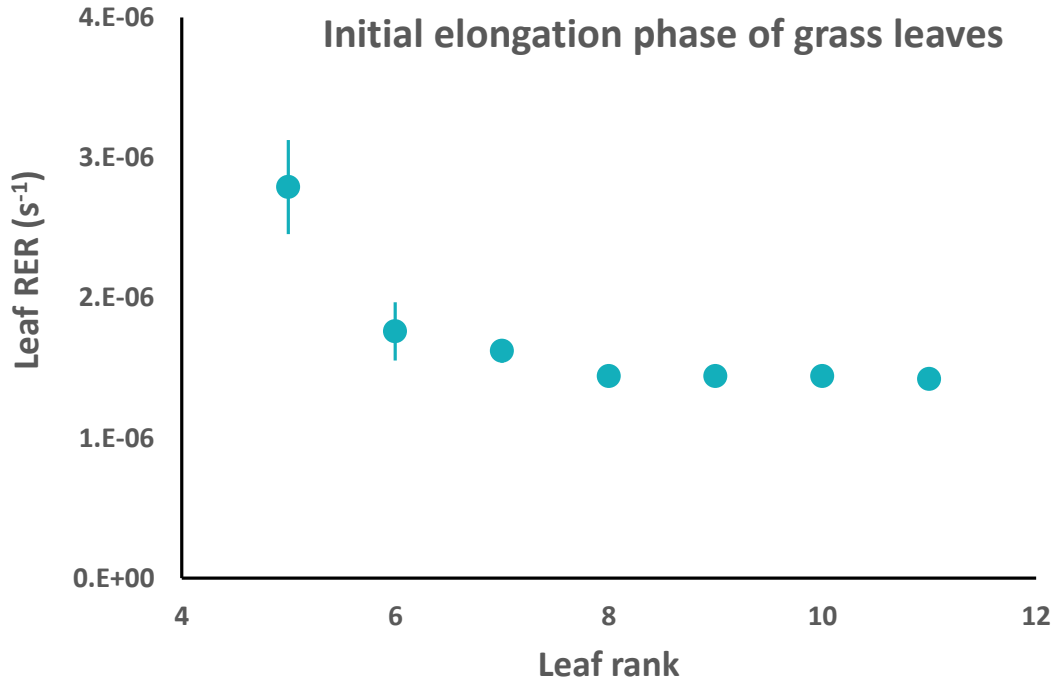
Plasticity of growth and development

3- Initial size and properties of primordia :

- Initial dimensions and biomass often constant. *(See talk of J-L Durand)*
- Some ontogenic gradients are difficult to predict with models



Gauthier 2021



Ljutovac 2002

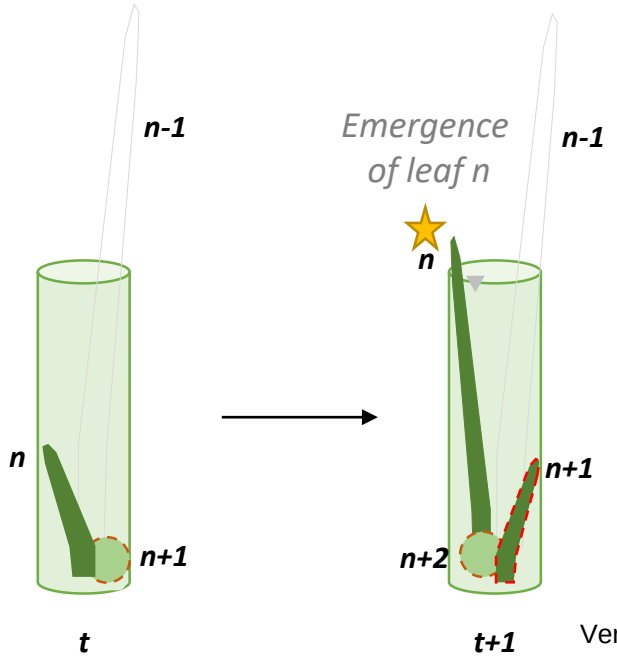
- Could these properties emerge from FSPMs with an explicit integration of SAM functioning and geometry?

3- SAMs -> FSPMs

Plasticity of growth and development

4- Rate of primordia initiation :

- Mainly driven by temperature or stochastic model of phenology in FSPMs
- In some FSPMs, driven by the phyllochron



Verdenal et al., 2008 ; Rouet et al., 2022

- Integration of SAM functioning could help to understand the role of exogeneous and endogenous factors.

➢ What is the minimal level of integration?

3- SAMs -> FSPMs

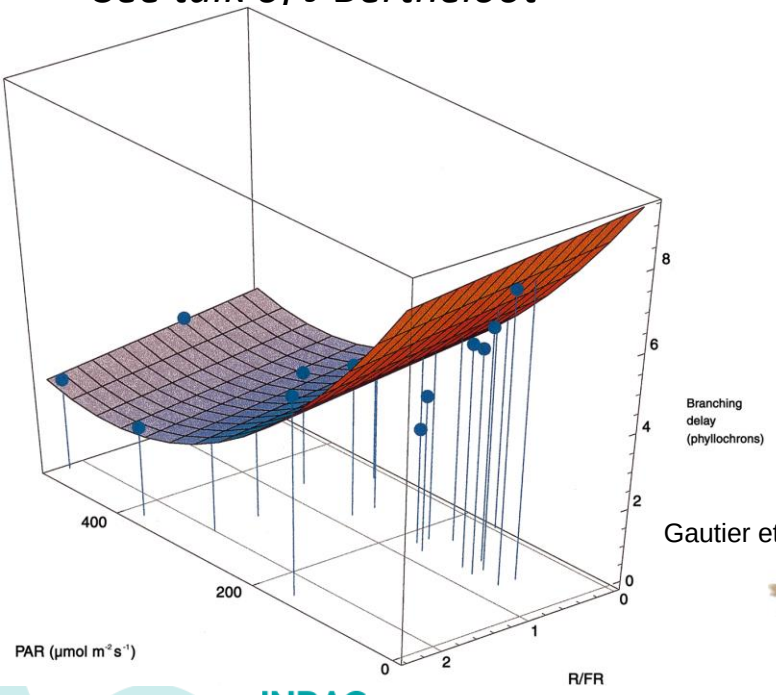
Branching and lateral meristems

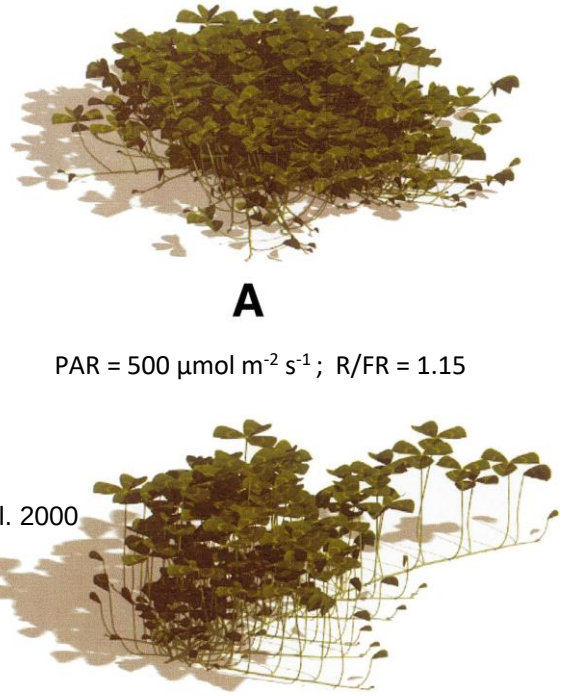
- Branching strongly determines plant architecture and their competitive ability
- Light intensity and spectrum (R:FR) known to affect the transition from latent to active SAM.

Open questions : localization of the perception sites, signal integration at the SAM level, temporal integration of the signals?

- How to integrate the effects of external (light, temperature, photoperiod…) and internal factors (hormones, sugars, age…)?

-> See talk of J Bertheloot

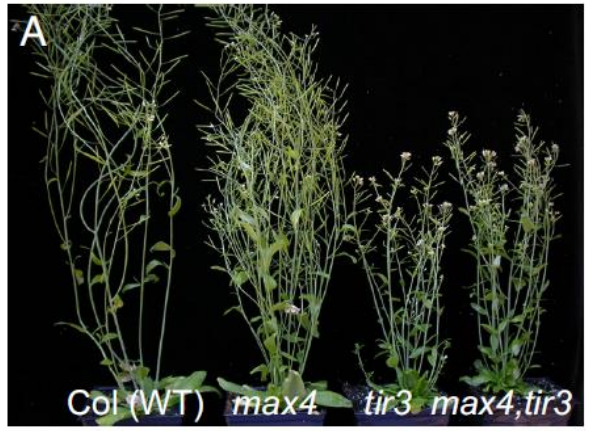


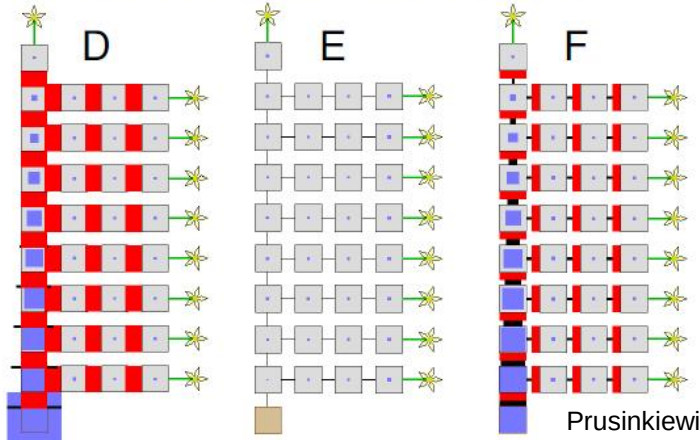


PAR = 500 µmol m^{-2} s^{-1} ; R/FR = 1.15

PAR = 150 µmol m^{-2} s^{-1} ; R/FR = 0.1

Gautier et al. 2000



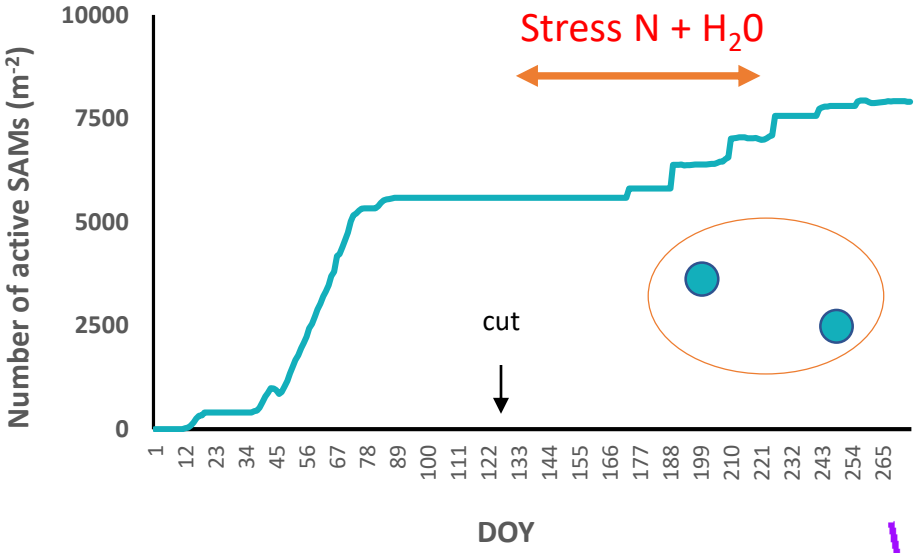


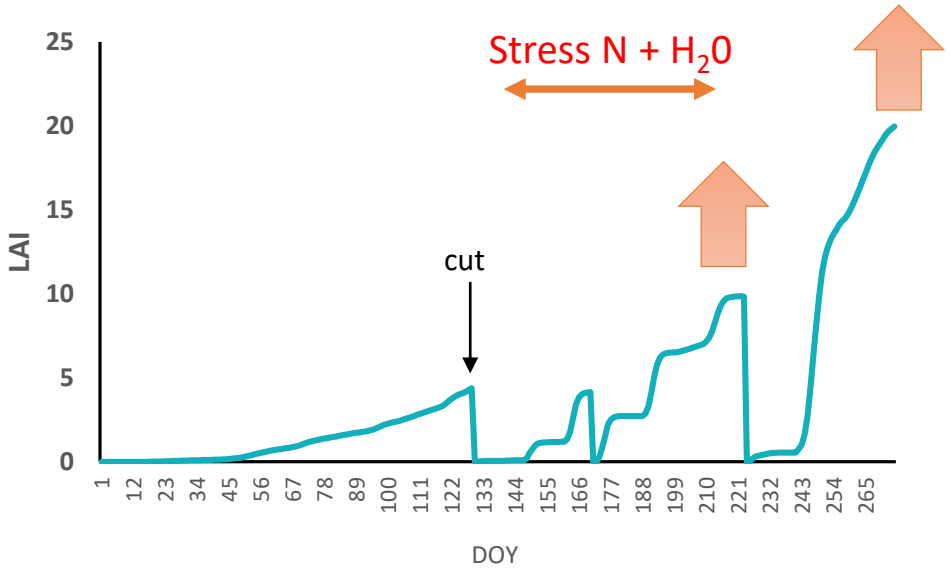
Prusinkiewicz et al. 2009

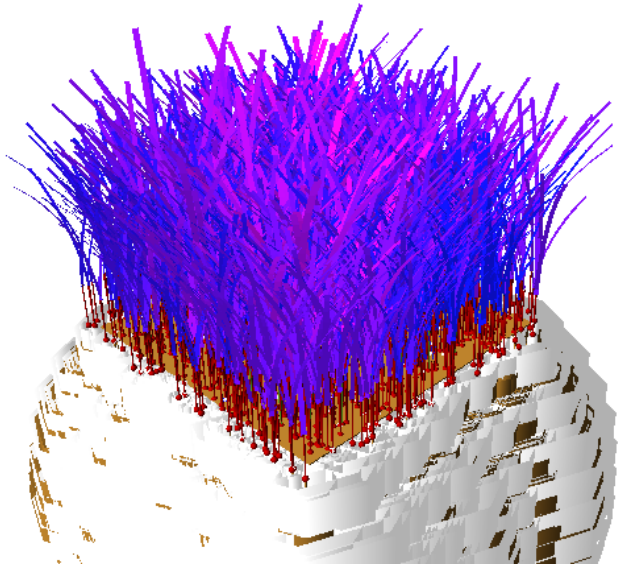
3- SAMs -> FSPMs

Branching and lateral meristems

- In FSPMs, the number of SAMs rises very rapidly but we lack knowledge about their death (dormancy)







Louarn, pers comm

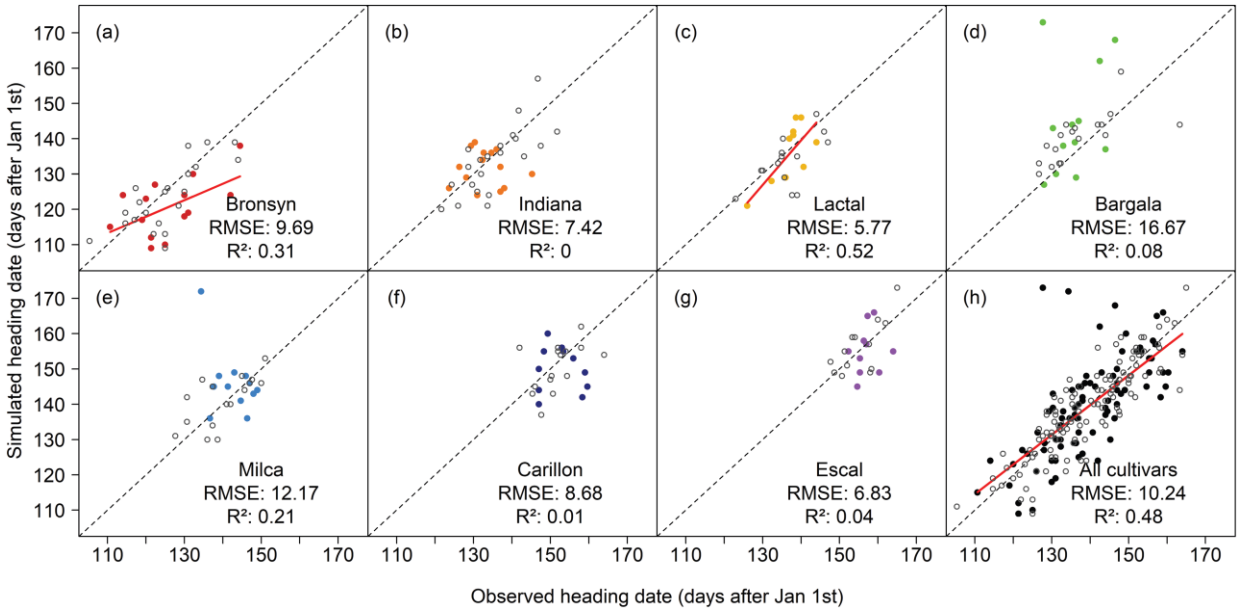
- Number of active SAMs very sensitive in most FSPMs
- Need for better integration of stop/death conditions
- Integration of multiple stress

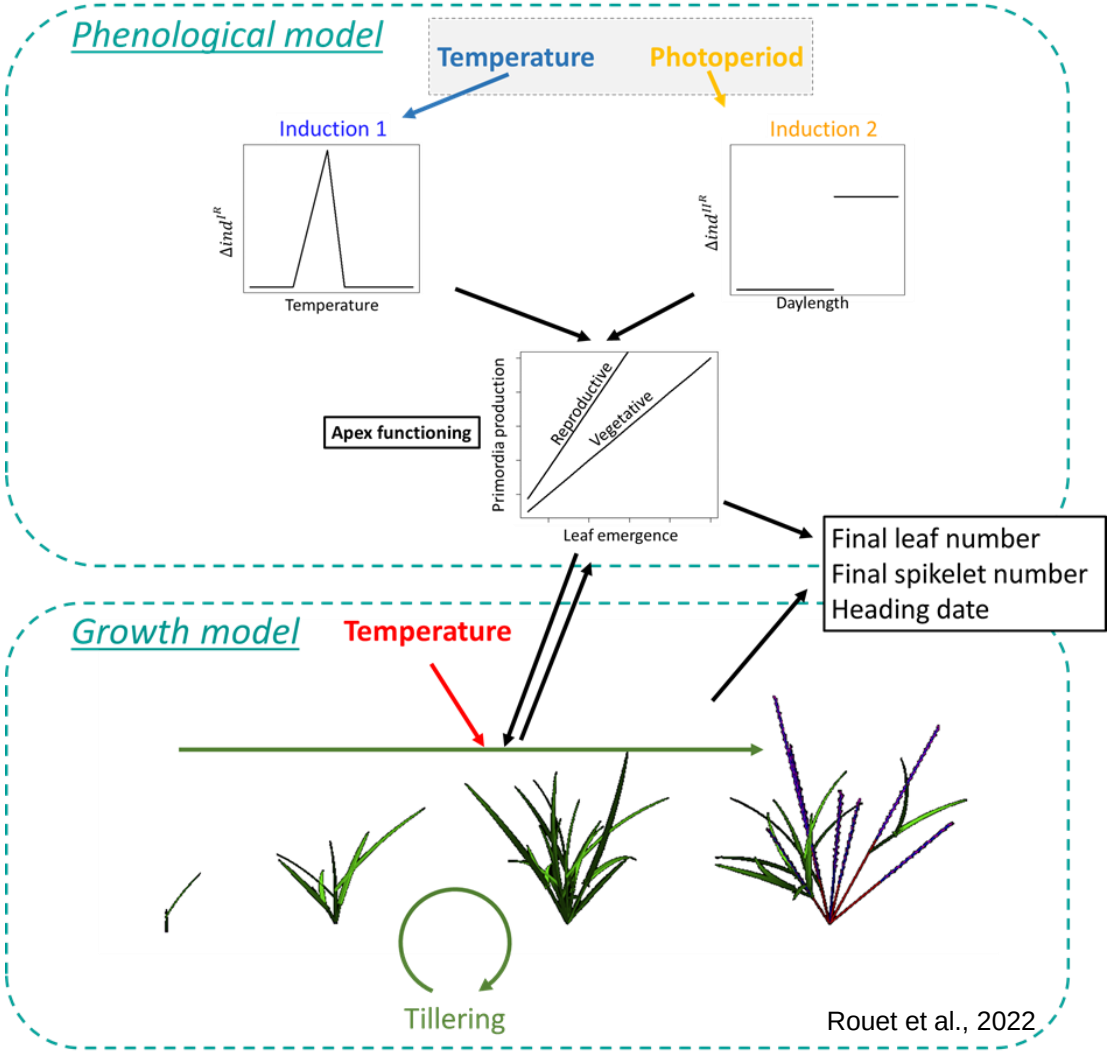
3- SAMs -> FSPMs

Floral transition

Major stage of plant phenology which affects the sink: source relations, production of fruits, perenniality

- Integration of environmental factors at SAM scale
- Exploration of genetic diversity



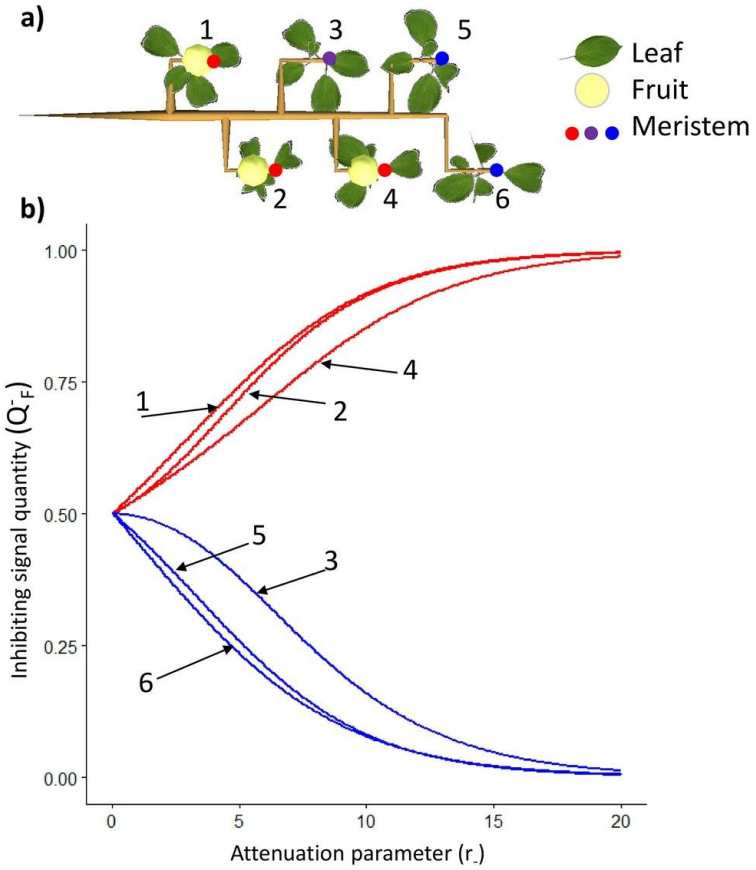


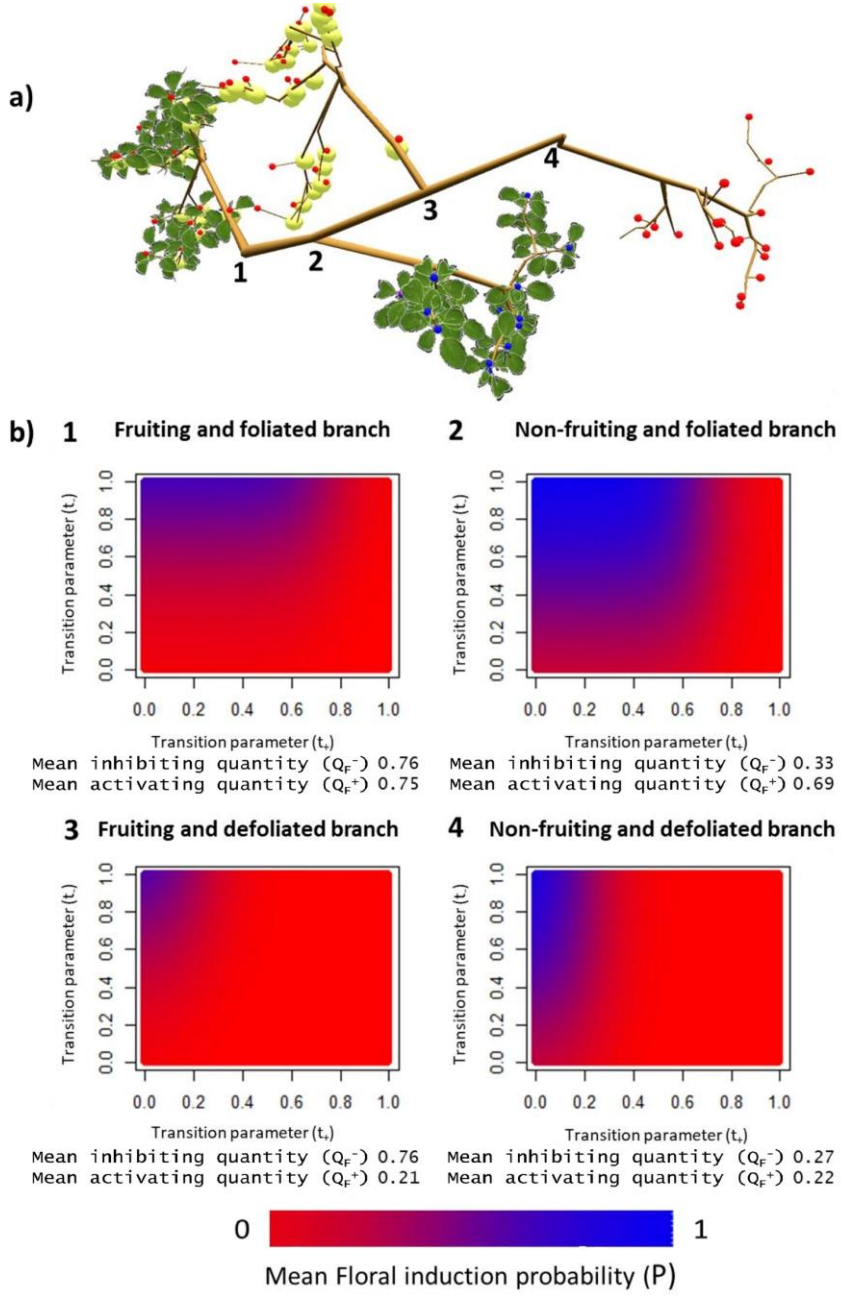
Rouet et al., 2022

3- SAMs -> FSPMs

Floral transition

- Integration of hormonal signal transport and defoliation

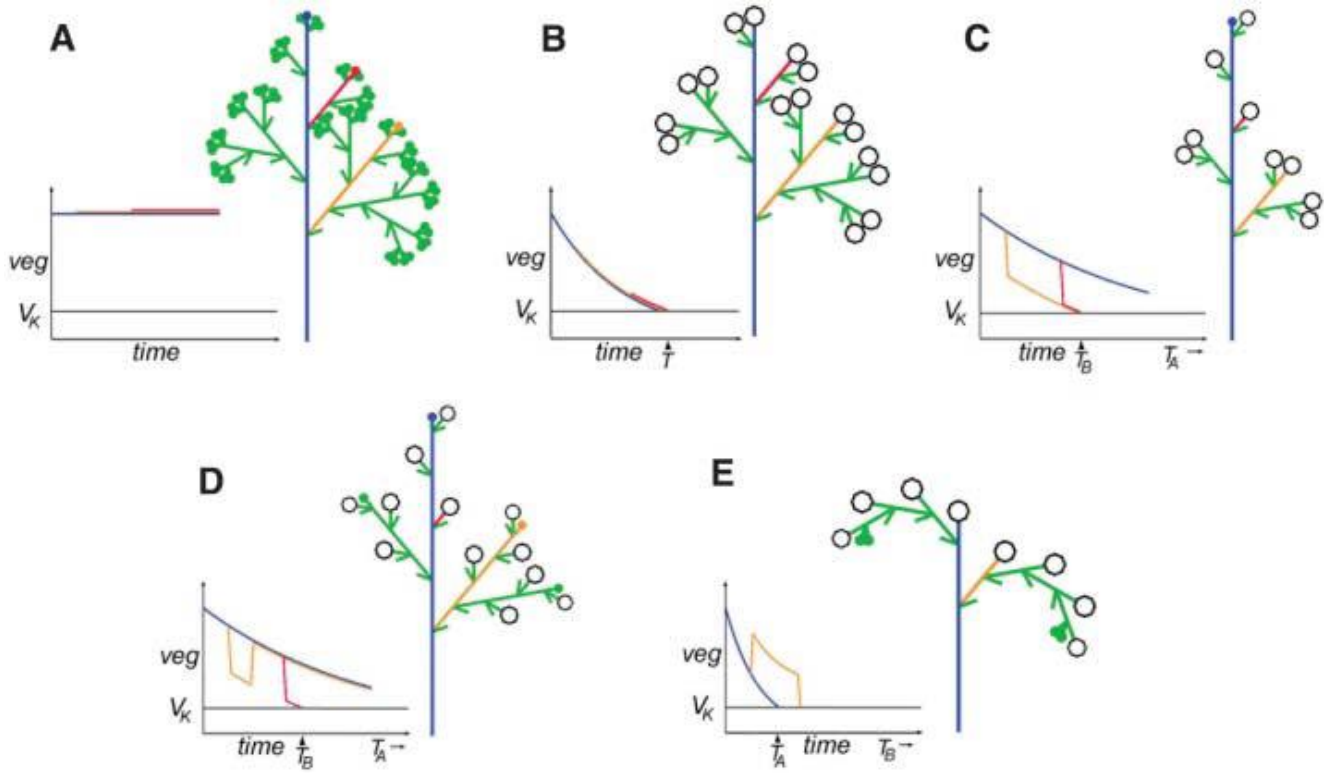




Belhassine et al. 2020

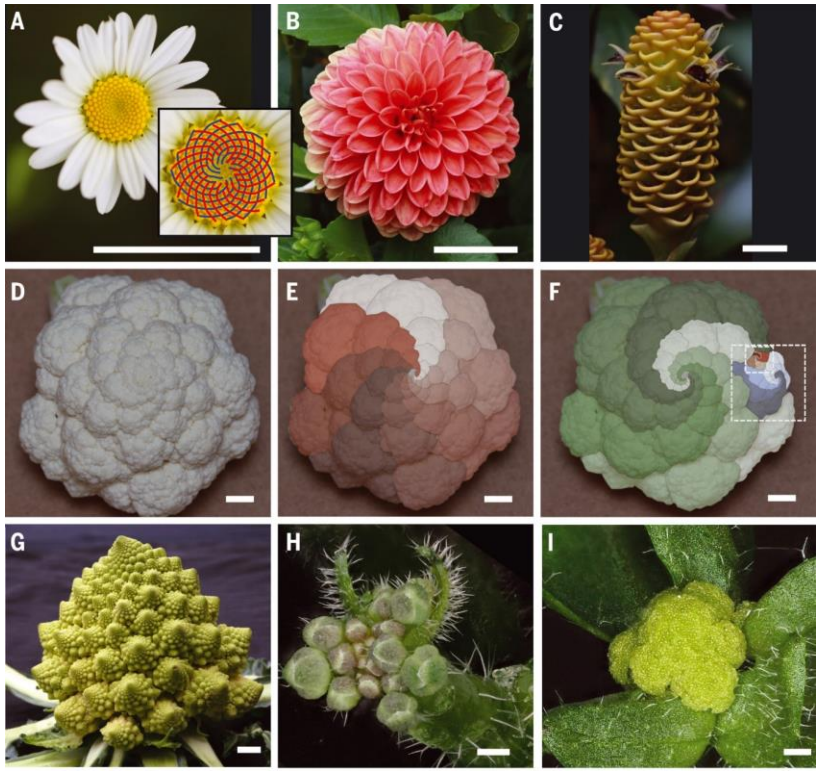
3- SAMs -> FSPMs

Floral transition & inflorescence architecture



Evolution and Development of Inflorescence Architectures

Prusinkiewicz et al. 2007



Integration of floral gene network

Azpeitia et al.., 2021

(See talk of C Godin)

4 – How can the FSPMs help to better understand the functioning of SAMs?

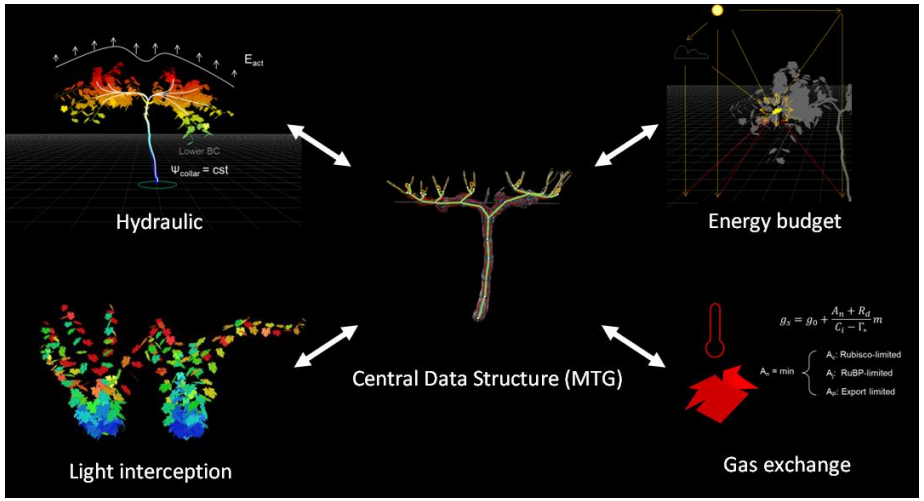
4- FSPMs -> SAMs

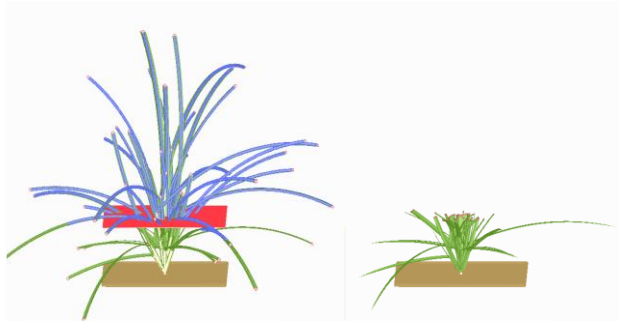
Dia sur formalisme? Notamment Lsystem?

4- FSPMs -> SAMs

Plante – environnent interactions

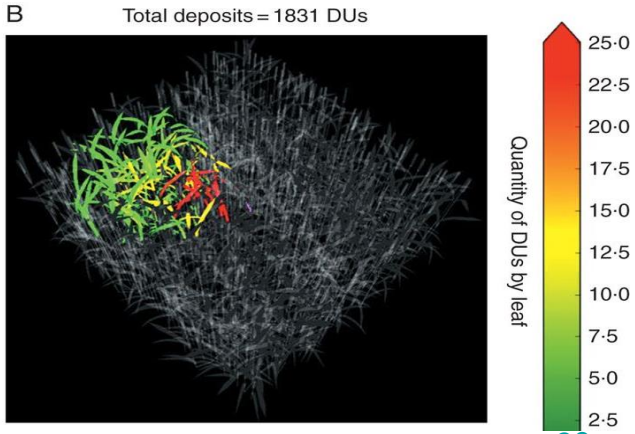
- Fine representation of plant - environment interactions : resource capture/availability, physical state at plant and organ scale
- Can address heterogeneous stands with inter- or intraspecific variability
- Plant response to specific managements of the architecture: mowing, pruning, diseases





Verdenal et al. 2008

VGL: graminées / légumineuses avec partage lumière

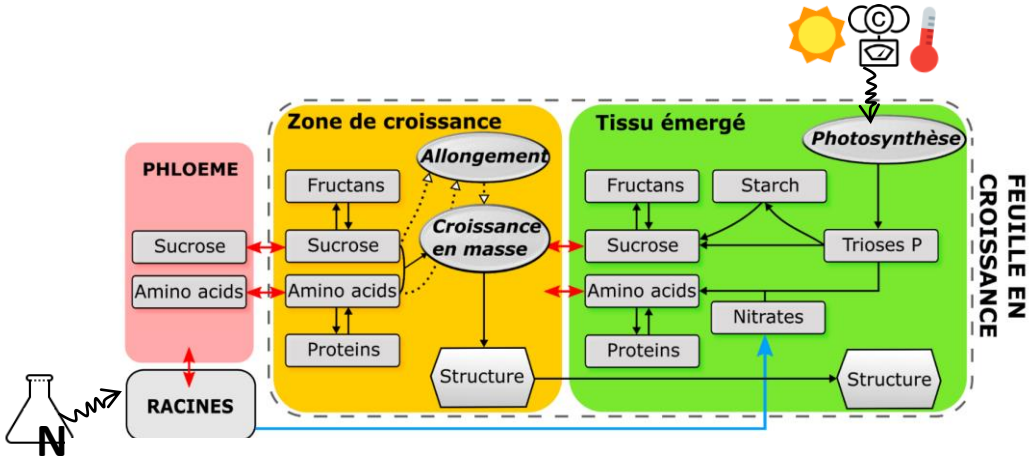


Garin et al. 2014

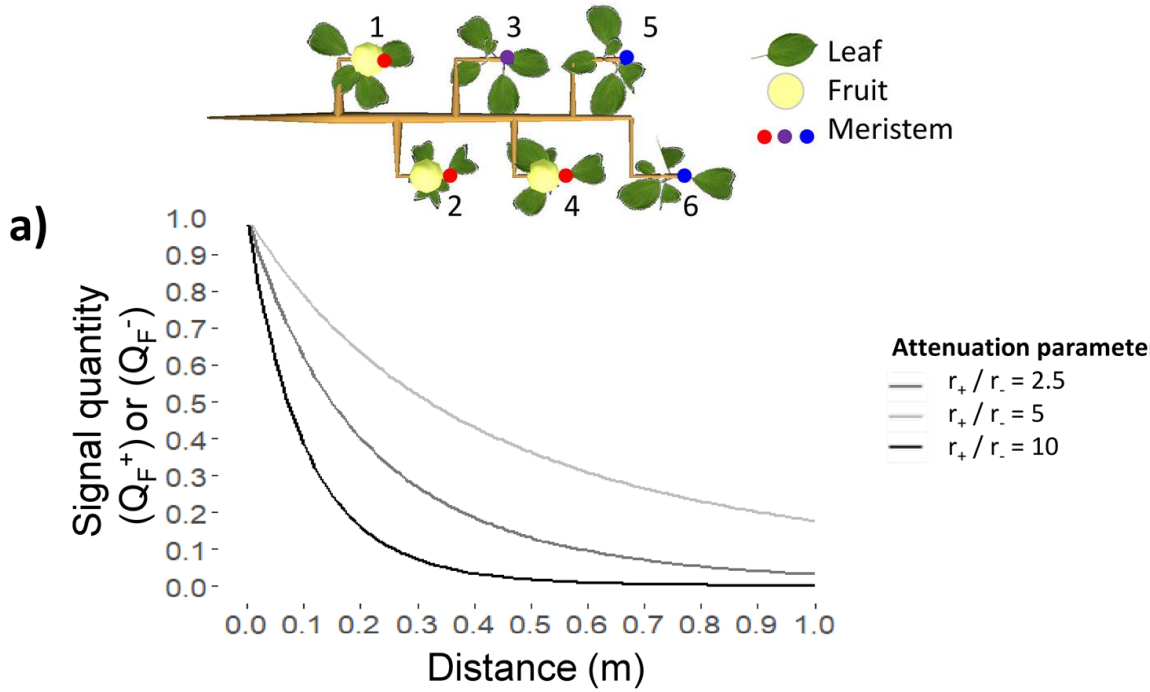
4- FSPMs -> SAMs

Functional and Structural models

- FSPMs simulate spatially distributed processes in the architecture
- Provide access to metabolites / substrates / water / hormones concentration at SAM level
- Account for inter-organ competition and transport



Gauthier et al., 2020



Belhassine et al. 2020

Conclusions

FSPMs <-> SAMs

- 2 communities that should continue to collaborate to better understand how the plant phenotype is formed
- Disentangle and quantify the role of the different external and internal factors
- How to integrate the different scales between the gene network and the whole plant?

INRAE

Thank you !