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Department für Wasser-Atmosphäre-Umwelt

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$A_gM_{net}^+$ INTERNATIONAL SUMMER SCHOOL IN AGROMETEOROLOGY AND CROP MODELLING 2017

overview of models

Modelling intercrops

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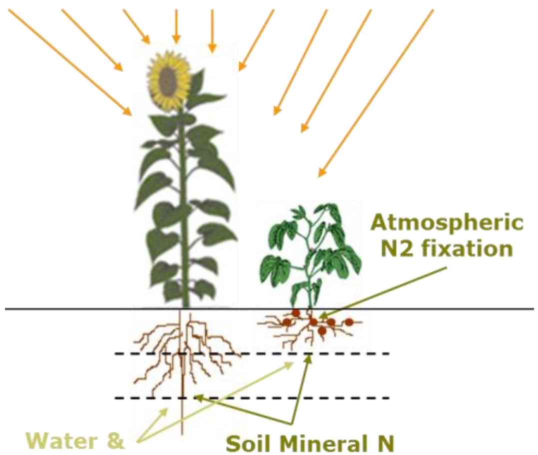
Intercropping : definition and examples

- **Simultaneous** growth of **two or more species** in the same field for a **significant period** without necessarily sowing and harvesting them together (Willey 1979)
- **Traditional practice** more or less developed covering a wide range of systems
- **Application of natural ecosystems ecology principles** to a better use of resources in time and space and pest regulation



Annual crops

Pasture

Agroforestry

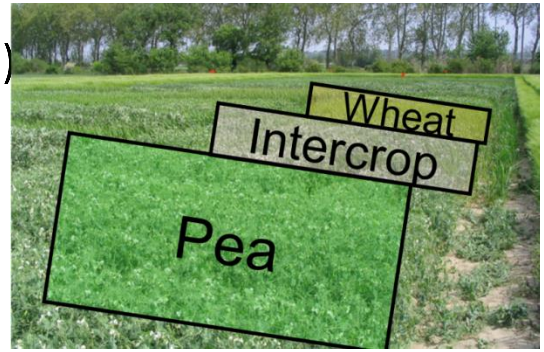
Trees & pasture

Trees & trees

Interests of intercrops for low input

Lots of references for cereal-legume intercrops

- **Improve cereal grain quality** (grain protein content)
  (Jensen 1996; Hauggaard-Nielsen &al 2001, 2009; Bedoussac & Justes 2010)
- **Increase global yield** (compared to low input sole crops)
  (Hauggaard-Nielsen &al 2001; Zhan &al 2010; Bedoussac & Justes 2010)
- **Reduce weeds** (compared to legume)
  (Hauggaard-Nielsen &al 2001; Corre-Hellou &al 2011)
- **Potentially reduce pests (e.g.pea aphids) and diseases**
  (Altieri 1999; Corre-Hellou and Crozat 2005; Ratnadass et al. 2012)
- **Reduce the nitrate leaching risk** (compared to sole legumes)
  (Hauggaard-Nielsen &al 2003, 2009; Bedoussac & Justes 2010)
- **Increase yield stability** (compared to sole crops)
  (hypothesis widely cited but no demonstration published)
- **Increase or stabilize over years the farmer gross margin**
  (Bedoussac 2009; Pelzer &al 2012)



But a lack of genericity

A need for modelling intercrops

Many levers to evaluate showing limits of experimental approaches

Ex: Wheat-Pea with 3 cultivars of each, 3 Nitrogen levels, 3 densities and 3 replicates → 243 plots

- **Species and cultivars ?**
  The best intercrop is not mixing the best sole crops cultivars
- **Sowing ?**
  Densities, Dates, Pattern (line, mix, strip…)
- **Fertilization ?**
  Amount, Fractioning, N, P, K…
- **Pest control ?**
  Weeds, insects, diseases,…
- **Rotation and resiliency ?**
  Climate change,…

How to model intercrops & for which purpose ?

Separated rows

Strip intercropping

Mixed on the row

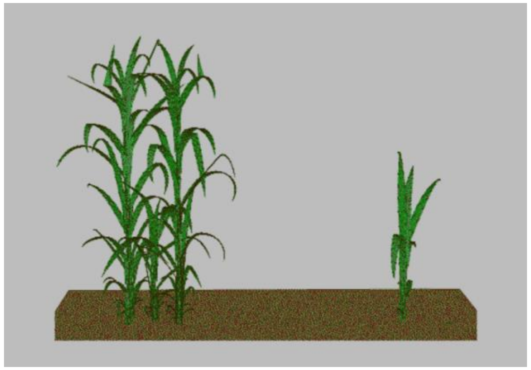
Two main complementary approaches

Crop models

- The object simulated is the volume of vegetation
- Environment treated by analogy to a continuous medium mostly not homogeneous

Virtual plant models

- Integration from organ to plant and plant to stand
- Environment perceived at the level of the organ



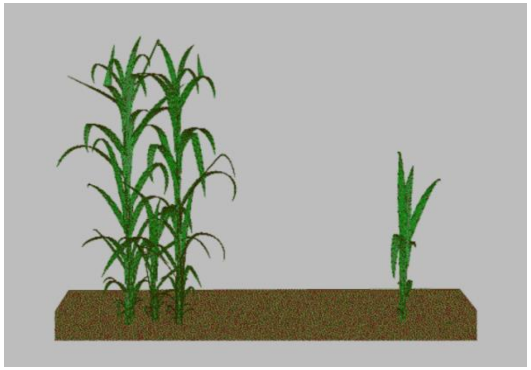
Crop models vs virtual plant models

Crop models

- Aggregate representation → limiting representation of processes such as genotypic differences
- Less suitable for describing heterogeneous stands
- Availability of relatively "complete" models

Virtual plant models

- Less aggregated representation → facilitating expression of knowledge but sensitive to missing knowledge
- Suitable for describing heterogeneous stands
- Development of models “underprocess"



The STICS Model: Origin and strategy

- First meeting design, in ECOSPACE project (1996):
- A single model for
  - Different crops
  - Remaining general, robust, simple, operational, flexible
- Must integrate knowledge of specialists and generalists
- Mechanistic soil-crop model
- Dynamic functioning of the thermal balance, radiative balance, budgets of water, C and N balances across crop cycle

STICS TEAM PROJECT: E. JUSTES, M. LAUNAY, S. BUIS, D. RIPOCHE + 15 SPECIALISTS

Global presentation of the STICS model

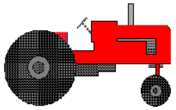
Crop genericity

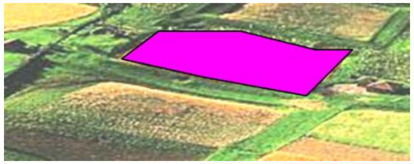
Plant

Wheat, corn, soybean, sorghum, salad, tomato, pasture, beet, pea, sunflower, rapeseed, vine, banana, sugarcane, …

Formalisation

Practice





Brisson et al. (1998, 2002, 2003, 2008)

Conceptual modularity

- Development
- Foliar growth
- Radiation interception
- Biomass growth
- Yield elaboration
- Root growth
- Water transfers
- Nitrogen transfers
- Management of technical interventions

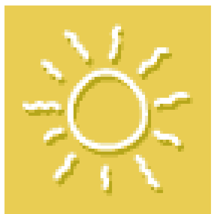
Principle of growth in STICS

Thermal time

Phenology

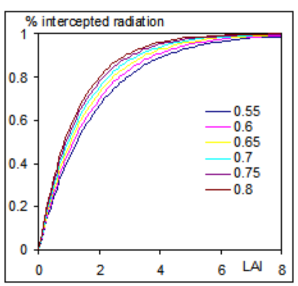
Leaf area index

Incident energy PAR_{inc} (400-700 nm)



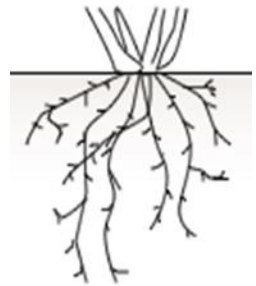
1. Efficiency of interception

intercepted radiation (%)



Intercepted energy
independant on growth

Water & N availability



2. Efficiency of conversion : RUE

Grains

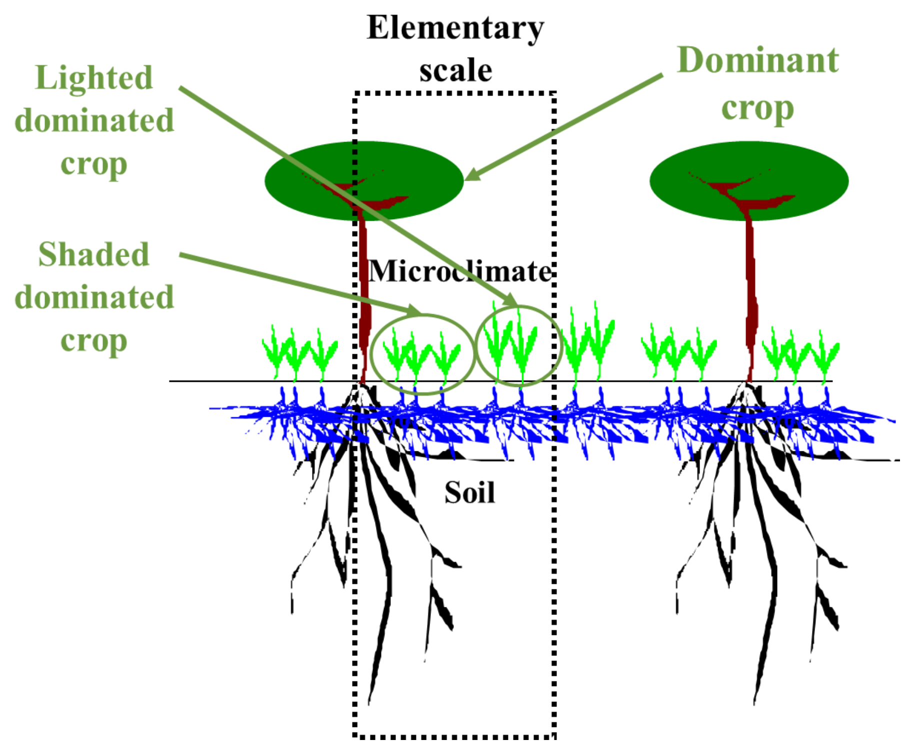
Straws

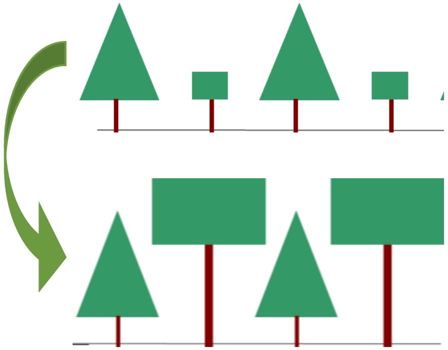
3. Allocation between roots and aerial parts

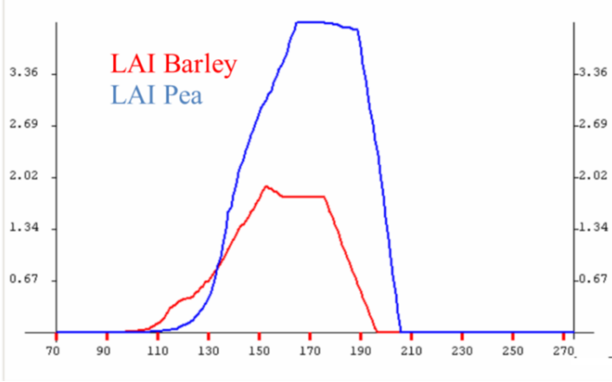
Crop biomass

Intercropping in STICS

- Only 2 crops
- Row pattern
- Variable inter-row distance
- Sowing & Harvest variable
- Competition for:
  - light, water & N =f(rate of root in depth & density/soil layer, LAI expansion, growth rate)
- Niche complementary for N:
  - N2 fixation=f(soil nitrate concentration)







FLORSYS, a virtual field model

Adapted from N. Colbach INRA

INPUTS

Pedoclimate

Cropping systems (Species/genotype, techniques)

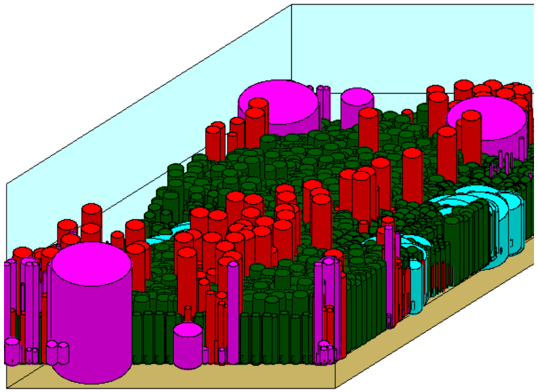
FLORSYS

Colbach et al (2007, 2014, 2016), Gardarin et al. (2012) Munier-Jolain et al (2013, 2014), Mézière (2015)

OUTPUTS

Demography and seed production

Yield



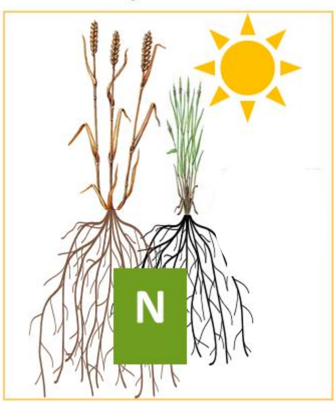
1 species/genotype

= 1 combination of traits

- -Phenology
- -Aboveground morphology
- -Belowground morphology
- -Resource acquisition

Response to environment

Competition



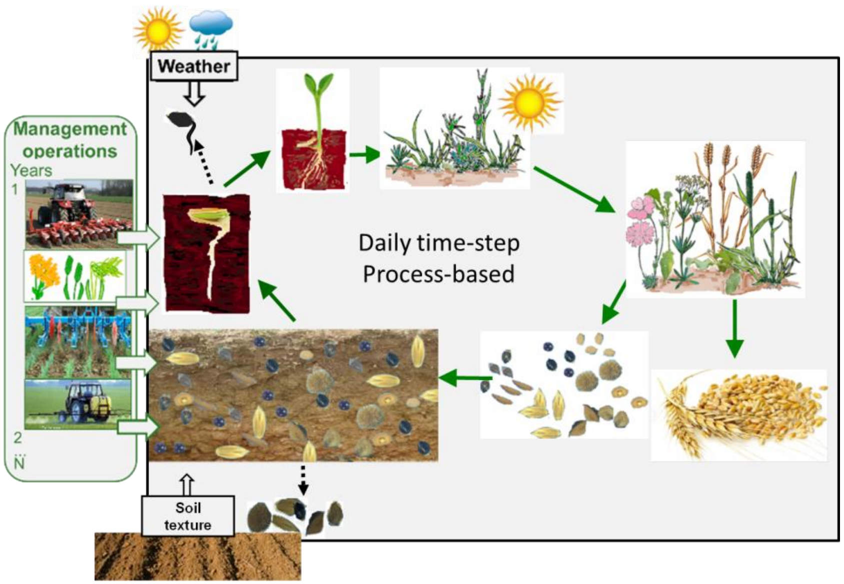
1 plant = 1 cylinder

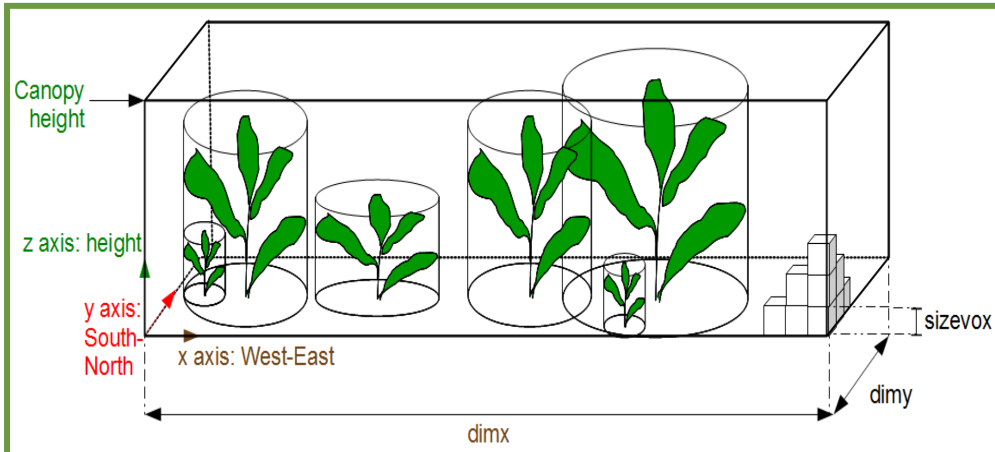
«Individual-based» model

The virtual field FLORSYS

Adapted from N. Colbach INRA

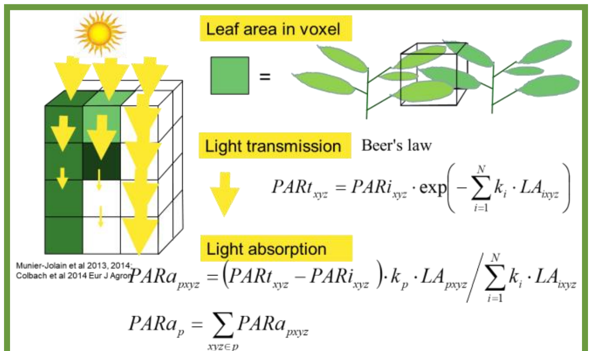
Generic life-cycle valid for both crop and weed annuals

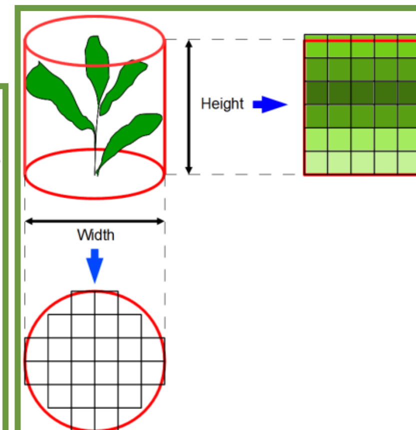




Species or variety = combination of traits
x seed mass
x relative growth rate
x base temperature
x specific leaf area at stage i
x change in SLA when shaded

For each plant and day

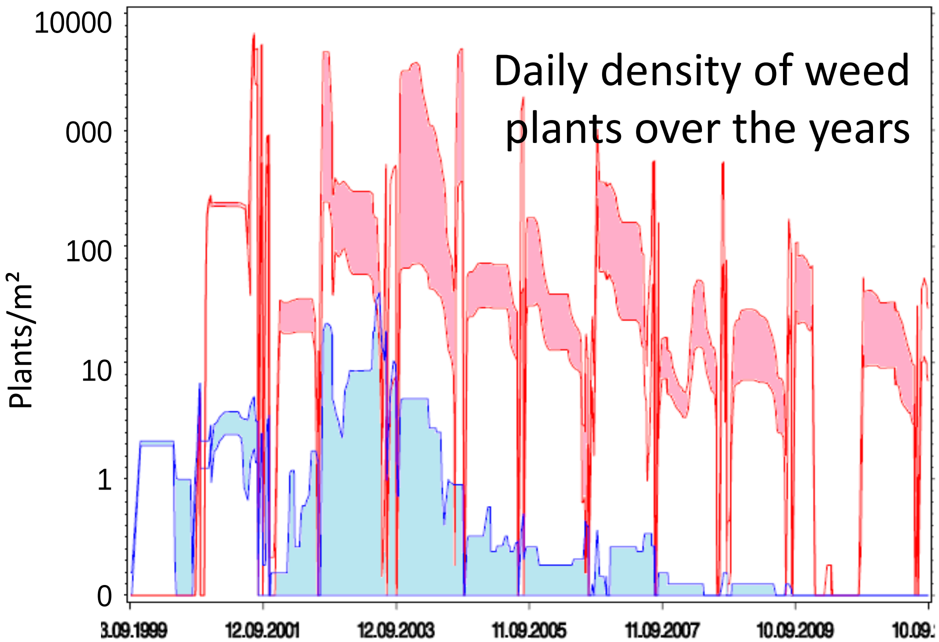




Outputs of FLORSYS model

Adapted from N. Colbach INRA

Yield and weeds



Crop production
Yield
Enery production

Weeds impacts

Benefits

- Plant biodiversity
- Ressources
- Less environmental impacts (N, erosion...)

Harmfulness

- Yield losses
- Herbicide use
- Promosion of parasites

Some perspectives for FLORSYS

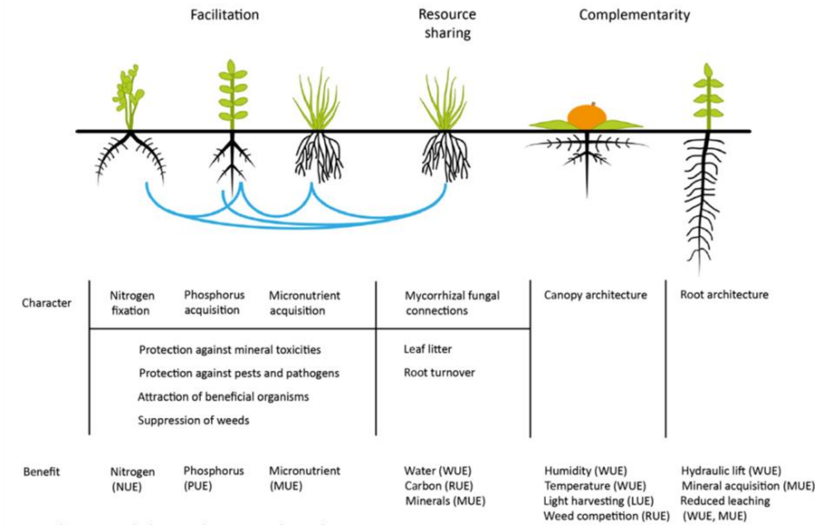
- **Search for ideotypes for multiperformant weed management**
  - Identify for contrasting cropping systems, ideal combinations of crop and mixture traits to ≠ weed management objectives (low yield loss or herbicide use)
- **Search for multiperformant weed management strategies**
  - Identify for these ideotypes ideal crop management strategies with optimization algorithms using FLORSYS
- **Multicriteria evaluation of varieties and mixtures**
  - Test varieties and mixtures x cropping systems proposed by experts with FLORSYS simulations
- **Sensitivity of weed management strategies to climate change**
  - Simulate the best options with future weather scenarios

Adapted from N. Colbach, INRA

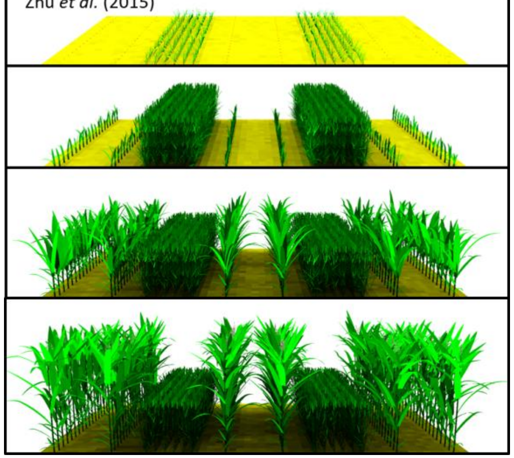
Functional-structural plant (FSP)

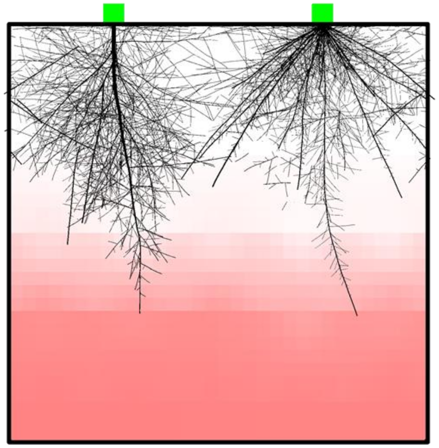
Adapted from
J. Evers & N. Anten
Wageningen

- FSP models are suitable tools to
  - Capture interactions between species above and belowground
  - Capture these interactions regarding acquisition of light, water, N and P
- Need for generic FSP model for improved mechanistic understanding



Brooker *et al.* (2015), New Phytol

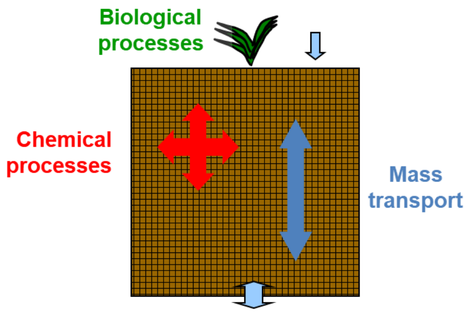

Zhu *et al.* (2015)

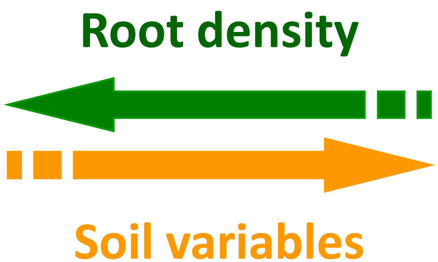

De Vries *et al.* (unpublished)

Root architecture & reactive transport

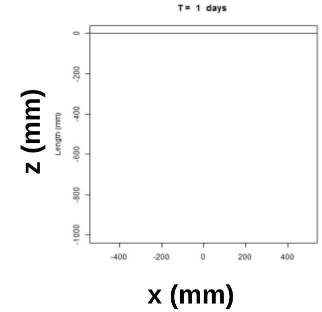
Adapted from Gérard F. et al. (2017) Plant & Soil 413, 161-180.

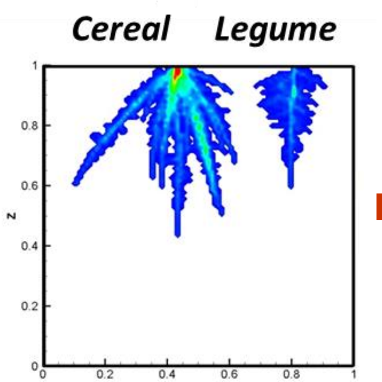
Reactive transport model Min3P





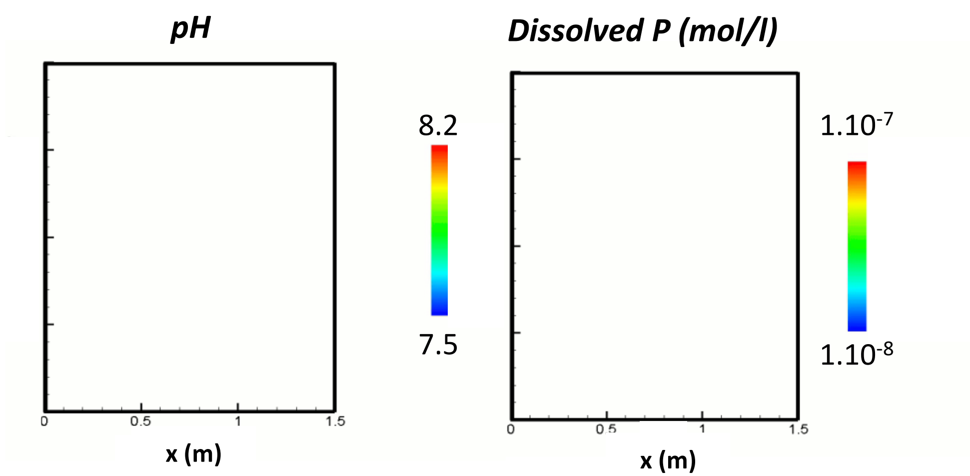
Root model ArchiSimple





P acquisition facilitated in intercrop

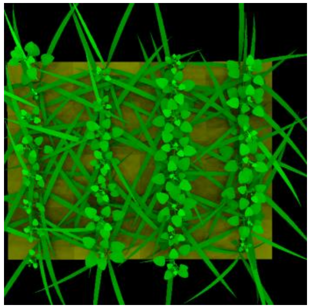
Rhizosphere acidification → Dissolved P increases

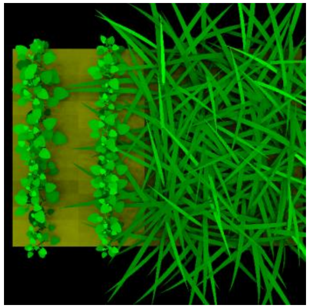


Need for coupling with above-ground plant model

Towards a generic FSP model

- To explore and analyse
  - functioning and performance of mixtures
  - plant traits, planting patterns, virtual G*E*M
- Able to capture plant-plant interaction by simulating mechanisms
  - Plant growth based on C & N capture
  - Competition for resources above & below
  - Plastic responses to neighbour presence
  - Non-resource plant communication
- The model must be
  - Calibrated and tested on experimental data
  - Roots is a challenge





Contribution of modelling to intercrops

- Tool for diagnosing Intercropping functioning
  - Describes mechanisms
    - Growth, effects of stress and competition
    - In dynamic and with interactions

- Tool for virtual experiment
  - Evaluation of impacts of certain factors or techniques
  - Allowing access to outputs difficult to measure
  - In various pedoclimatic conditions
    - Climatic series, cross conditions medium / technical practices combination

Current limitations of modelling

- Limiting factors not formalized in the model(s)
  - Elements (P, K, S,…)
  - Pests (fungi, insects, weeds…)
- Extension or translation of the domain of validity and scope of the model(s)
  - New environmental conditions (low N mineral levels, high temperatures, …)
- Evolution of model(s) towards
  - Taking into account new processes
  - A complexification of modelled systems (ex: pests)
  - New uses

Model	Availability for species mixtures	Comments	Pests	Cropping practices taken into account
FSPM	✖	Linkage between soil and aerial modules to be done	No	Sowing rate and date, spatial pattern
STICS	✔	Improvements needed	No	Crop management plan. E.g.: sowing rate and date, tillage, fertilization
IPSIM	✖	To be developed	Weeds, diseases, animal pests	Cropping system: crop sequence and crop management plan
FLORSYS	✔	Light submodel parameterized. N and H20 submodel to be developed	Weeds	Cropping system: crop sequence and crop management plan
WEEDLC	✔	To be parameterized	Weeds	Weed management

→ Nobody is perfect, neither models

→ A model doing everything is utopia

→ Modelling is a complementary approach to experimentation