“Evaluation of the STICS soil-crop model for modelling arable intercrops”

6 MONTHS AGO...I was just a new researcher in agroecology

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AND NOW: Investigation on the strategy to model species interactions in mixed annual crops

What do we want to model?
Which temporal and spatial scales are relevant?
Which processes should be included or excluded from the model?
Which formalisms are relevant?

→ Which modelling methodology?
INTERCROPS = at least two species growing together and coexisting for a time
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**Challenge:**

*intensive sole crops*: environment optimized through **external inputs**

*multispecific crops*: better resource use efficiency through **positive interactions between plant species** (concepts of ecology)
INTERCROPS = at least two species growing together and coexisting for a time

Advantages of intercrops (IC) over sole crops (SC):
• equal or higher yield when resources are limiting
• better resistance to pests
• higher resilience to stress (e.g. climate change)

Challenge:
intensive sole crops: environment optimized through external inputs
→ multispecific crops: better resource use efficiency through positive interactions between plant species (concepts of ecology)
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Example for grain yield:
• 58 organic field experiments (France and Denmark)
• from 2001 to 2010
• large range of cereal-legume mixtures

Comparison of grain yield between IC and SC

→ IC = higher efficiency via complementarity N use

Bedoussac et al. (2015)
The need for a modelling approach

**Why is a modelling approach needed?**

Broad spectrum of...

- ...species (and cultivars)
- ...pedo-climatic conditions
- ...agricultural practices

→ all combinations can’t be tested in the field

**Intercropping MODELLING** = Interesting tool to support the design of new optimal mixtures under varying conditions
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Intercropping MODELLING = Interesting tool to support the design of new optimal mixtures under varying conditions

Existing modelling tools in agronomy:
• dynamic crop models simulating soil-crop systems
• BUT mainly dedicated to sole crops
• adaptation to simulate intercrops by extrapolation
  → e.g. STICS (Brisson et al., 2004)
Evaluation of the STICS soil-crop model for modelling arable intercrops

Simplified principles of STICS – Sole Crop (http://www6.paca.inra.fr/stics_eng):

- generic, in steadily progress, many scientific papers

Methodological comparison of calibration procedures for durum wheat parameters in the STICS model
Solenne Guillaume, Jacques-Eric Bergez, Daniel Wallach, Eric Justes

Quantifying and modelling C and N mineralization kinetics of catch crop residues in soil: parameterization of the residue decomposition module of STICS model for mature and non-mature residues
E. Justes, B. Mary, B. Nicolardot

Adaptation of the crop model STICS to intercropping: Theoretical basis and parameterisation
N. Brisson, F. Buissière, H. Oizé-Lafontaine, R. Tournebize, H. Sinquert
Simplified principles of STICS – Sole Crop (http://www6.paca.inra.fr/stics_eng):

- **System (SC)**
  - Biomass
  - LAI
  - [N]
  - Harvested organs
- Water, [Nmin]
Evaluation of the STICS soil-crop model for modelling arable intercrops

Simplified principles of STICS – Sole Crop (http://www6.paca.inra.fr/stics_eng):

**INPUTS**
- Climate, soil, plant
- Agricultural practices
- Water, [Nmin]

**System (SC)**
- Biomass
- LAI
- [N]
- harvested organs

**OUTPUTS**
- Crop phenology and growth
  - Phenological stages, LAI, biomass, roots (density, depth)
- N balance
  - [N]crop, [N]soil, mineralisation (humus, residus), N leaching
- Water balance
  - Evaporation, transpiration, [water]soil, leaching
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Simplified principles of STICS – Sole Crop: (http://www6.paca.inra.fr/stics_eng):

**INPUTS**
- System (SC)

**Main simulated processes**
- Biomass
- LAI
- [N]

**OUTPUTS**
- Crop phenology and growth
  - Phenological stages, LAI, biomass, roots (density, depth)
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- Water, [Nmin]
Evaluation of the STICS soil-crop model for modelling arable intercrops

Simplified principles of STICS - InterCrop (http://www6.paca.inra.fr/stics_eng):

System (IC) = two species instead of one

Species 1 (dominant)
- Biomass
- LAI
- [N]
- harvested organs

Species 2 (understorey)
- Biomass
- LAI
- [N]
- harvested organs

Water, [Nmin]
Evaluation of the STICS soil-crop model for modelling arable intercrops

Simplified principles of STICS - InterCrop (http://www6.paca.inra.fr/stics_eng):

**System (IC) = two species instead of one**

**Adapted processes = resource uptake**

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Water, [Nmin]
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Simplified principles of STICS - InterCrop: (http://www6.paca.inra.fr/stics_eng):

- **System (IC) = two species instead of one**
- **Adapted processes = resource uptake**

- **Light sharing**
  - Direct and diffuse light, sun position
  - Light interception via Beer-Lambert
  - Cover geometry (rectangle, triangle)
  - Partition daytime radiation in-between the two canopies

- **Species 1 (dominant)**
  - Biomass
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Light sharing

Water requirements (resistive scheme)
ETP with Shuttleworth-Wallace
Simplified principles of STICS - InterCrop: [http://www6.paca.inra.fr/stics_eng](http://www6.paca.inra.fr/stics_eng)

- **System (IC)** = two species instead of one
- **Adapted processes** = resource uptake
- **Light sharing**
- **Water requirements (resistive scheme)**
  - ETP with Shuttleworth-Wallace
- **$N_{species}$ uptake** = f(root depth, distribution, i.e. soil offer, $N$ demand, water content)
Simulation case (Bedoussac et al. 2010): Winter pea / durum wheat in alternate rows, no fertilisation France (Toulouse, SW), period 2005-2006
Evaluation of the STICS soil-crop model for modelling arable intercrops

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- Aerial biomass (t.ha$^{-1}$)
- N taken by the plant (kg.ha$^{-1}$)

Well simulated for the two species

Nitrogen competition and uptake
Evaluation of the STICS soil-crop model for modelling arable intercrops


**Aerial biomass (t.ha⁻¹)**

Simulated vs. Observed:
- Well simulated for the two species.

**N taken by the plant (kg.ha⁻¹)**

Simulated vs. Observed:
- Well simulated for the two species.

**Height (m)**

- Pea: Underestimated for pea.
- Wheat: Slightly underestimated for wheat.

**LAI (m².m⁻²)**

- Pea: Slightly overestimated for pea.
- Wheat: Slightly underestimated for wheat.

Nitrogen competition and uptake.

Competition for light.

Already shown in pea / barley intercrops (Corre-Hellou et al. 2009).
Appropriate use of crop production models:

- Sole crops
- Alternate rows
- Global crop yield
- N and water balances at larger scales

...depends on the goal you have...

“A model’s structure depends on the model’s purpose because the purpose helps decide which aspects of real system are essential to model and which aspects can be ignored or described coarsely” (Grimm and Railsback, 2005).
No spatial heterogeneity:
extrapolation of a sole crop → could simulate alternate rows but not different spatial patterns
Limitations of crop production models

**No spatial heterogeneity:**
extrapolation of a sole crop → could simulate alternate rows but not different spatial patterns

![Diagram showing sole and intercrops compared to usual crop models](image-url)
Limitations of crop production models

**No spatial heterogeneity:**
extrapolation of a sole crop → could simulate alternate rows but not different spatial patterns

- **Sole crops**
- **Intercrops**
  - ≈ sole crops
  - “real” mixtures

**Usual crop models**

- ![Smiling face](image)
- ![Frowning face](image)
Limitations of crop production models

No spatial heterogeneity:
extrapolation of a sole crop → could simulate alternate rows but not different spatial patterns

→ no possibility to test different spatial patterns
Limitations of crop production models

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**Species interactions** (facilitation, niche complementarity, competition): not explicitly considered (via functional traits for instance)
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Individual scale: Morphological, phenological, physiological traits
Plasticity

Traits: From Garnier and Navas (2012)
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Two plants:
Optimise resource use via niche complementarity and facilitation

Golberg (1990)
Limitations of crop production models

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Species choice driven by a thought about complementary traits more than on individual traits, important to identify ideotypes.

Golberg (1990)
Limitations of crop production models...and what is needed

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extrapolation of a sole crop → could simulate alternate rows but not different spatial patterns

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Recent reviews:
Towards a more mechanistic model including explicitly species interactions
Designing ad hoc models for a specific purpose

“New models are required to represent, assess and design sustainable multispecies cropping systems”
(Malézieux et al. 2009)

“...interactions could be better understood through **resources-based modelling** to explore how specific traits can be **optimized for complementarity**”
“the challenge of intercropping systems is how best to **combine traits of different plants to improve overall performance**”
(Brooker et al. 2015)

“The **combination of targeted functional traits** can be based on current knowledge of the relationship between traits and functions (...) or from a **mechanistic model**” (Gaba et al. 2015)
Goal:
Design species (phenotypes) combinations the most appropriate to their local environment, using a trait approach and developing an individual-based model.

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**Perspectives to simulate species interactions in annual intercrops**

**Goal:**
Design species (phenotypes) combinations the most appropriate to their local environment, using a trait approach and developing an individual-based model.

1. **Identify processes involved in species interactions**
2. **Formalisms used to represent these processes in existing models**
3. **Conceptual model** (all steps documented)

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The efficiency of a durum wheat-winter pea intercrop to improve yield and wheat grain protein concentration depends on N availability during early growth. *Plant and Soil* 330, 19–35


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