WP3: Intelligent control and decision-making

Synergia Consortium Meeting

23-09-2025

Tamas Keviczky

Delft University of Technology

Agenda

- Short pitches
  - T3.1 Soil Health Digital Twin – *Diya Samit / Mathias Funk / Bahar Barati (TU/e)*
  - T3.3 Optimal decision making in agricultural systems – *Menno van Zutphen (TU/e)*
  - T3.4 Greenhouse climate control – *Ioannis Panagopoulos (TUD)*
  - T3.5 Optimal decision making in feeding dairy cows – *Maedeh Sadeghi (WUR)*
- Short presentation
  - T3.6 Dynamic modelling and optimization of mixed cropping systems – *Maarten de Jong (TUD)*

Soil Health Digital Twin

Synergia WP3 Meeting

Diya Samit, Bahar Barati, Mathias Funk
TU/e Industrial Design

Overview

- Design concept of digital twin for soil health assessment by farmers
- Soil health probe PoC
- Digital Twin (data infrastructure + dashboard) PoC

Related publications

Đan Vy Vu, Mathias Funk, Yi-Ching (Janet) Huang, and Bahareh Barati. 2024. Addressing Uncertainty in Biodesign through Digital Twins: A Case of Biofabrication with Mycelium. ACM Trans. Comput.-Hum. Interact. 31, 6, Article 69 (December 2024), 28 pages. https://doi.org/10.1145/3685271

Samit, D., Funk, M., and Barati, B. (2025) Sensing Soil Habitability: Relational Data for Multispecies Attunement, IASDR 2025: Design Next, 2-5 December, Taipei, Taiwan. To appear.

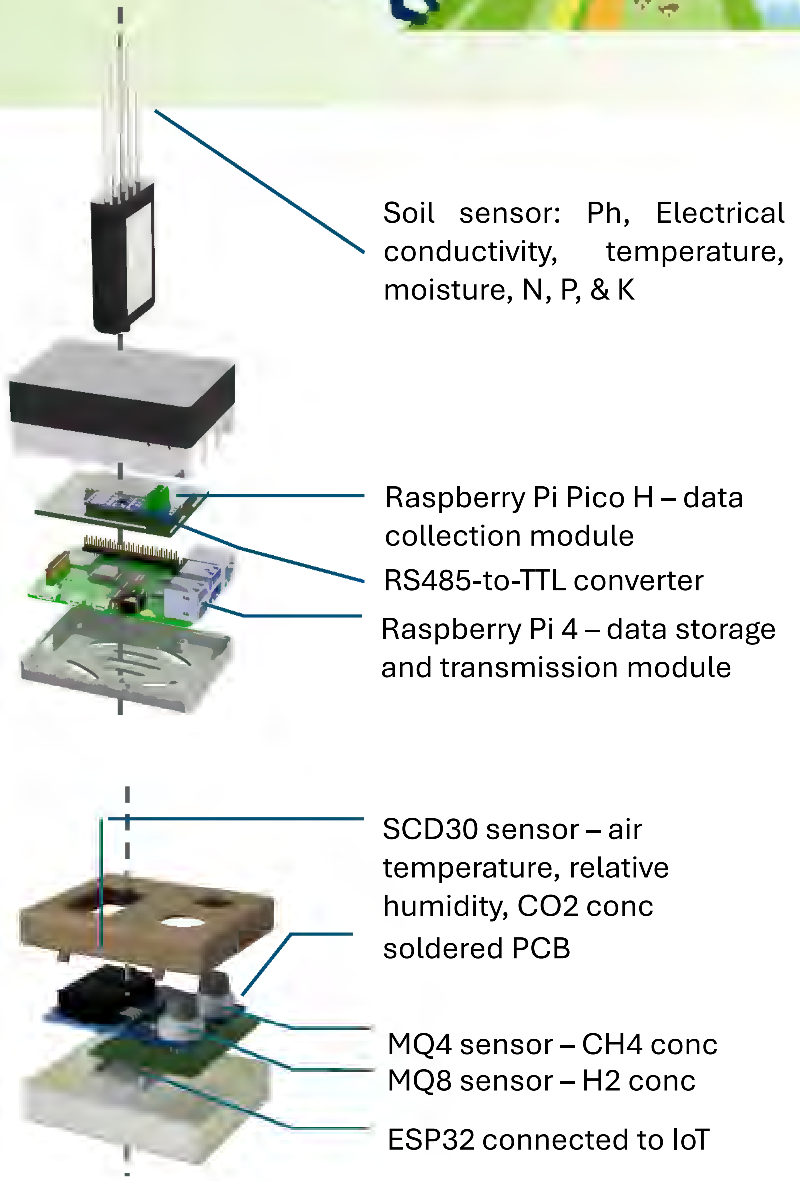
Soil health assessment

- Farms in transition to different cropping models operate under uncertainty (weather conditions, inter-related crops, nutrition exchange, soil health)
- Sensor data can provide decision-making support in terms of crop change, nutrition, and pest prevention
- Empower farmers to make sense of their journey with easy-to-use, meaningful tools for day-to-day operations:
  - Soil health probes (1..n)
  - Dashboard (1)

Soil health probe

We designed a soil health probe that is

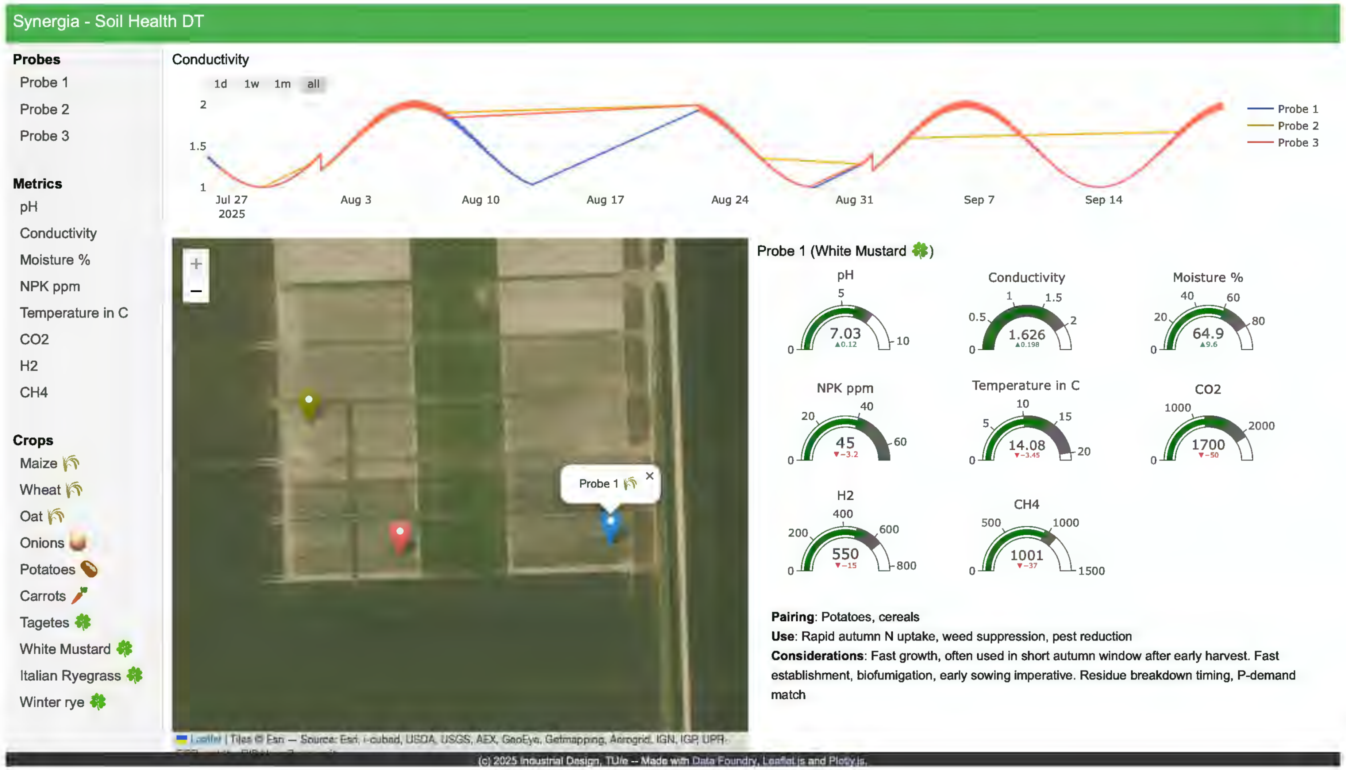
- Easy to build using open-source designs, code and instructions
- Robust to operate over time
- Versatile for diverse soils and weather conditions
- Configurable connectivity, data upload frequency and GPS location



Digital Twin (dashboard)

We designed a dashboard that presents collected data in a structured form, using:

- Map overview to locate probes in context
- Timeseries visualization to show historical sensors data per probe
- Gauge visualization for different sensor values per probe
- Crop and cover crop recommender based on soil parameters



Summary

- Design concept of digital twin for soil health assessment by farmers
- PoC of Soil Health Probe & Digital Twin (probes + data infrastructure + dashboard)

Dissemination plan

- Open-source schematics, code, and build instructions for the soil probe
- Open-source code and setup instructions for the dashboard
- Shareable communication artifacts and report on WP3.1

Visit our demo!

Optimal decision making in agricultural systems

Synergia WP3 Meeting

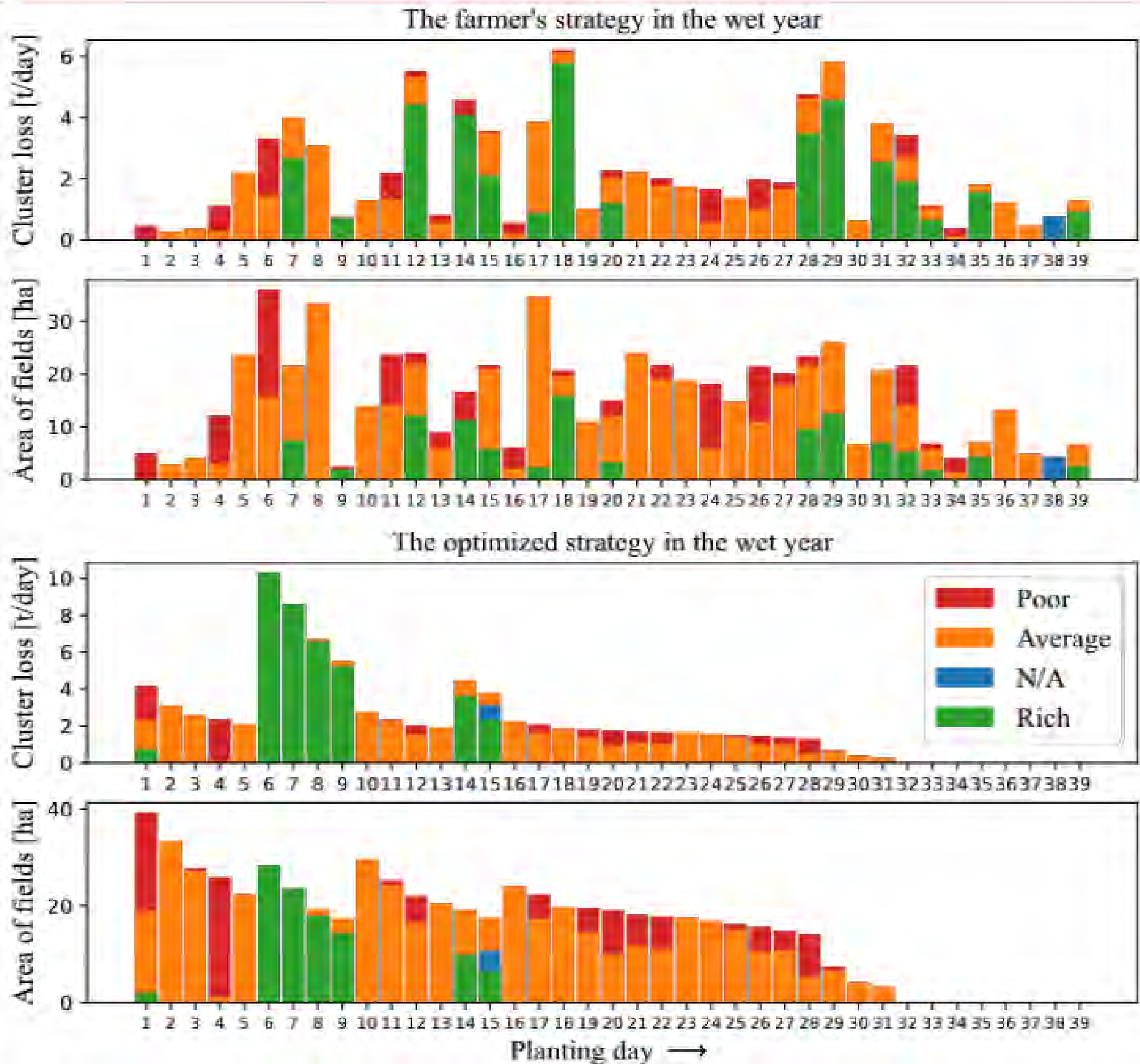
Menno van Zutphen
TU/e Control Systems & Technology

Some of the work performed so far

- Planting period optimization
- Encouraging predictability
- Optimal exploration vs. exploitation trade-off

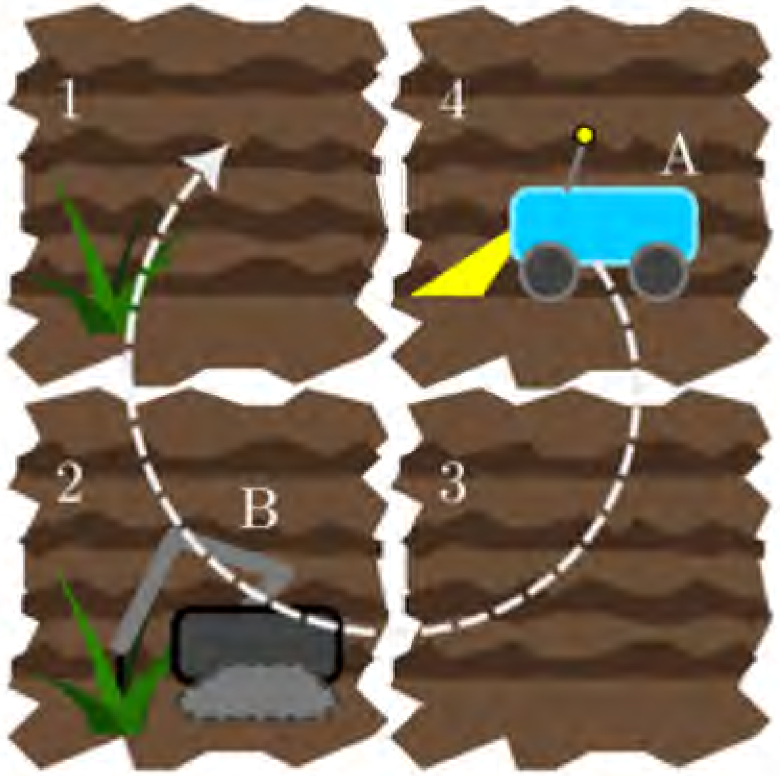
Planting period optimization

Farmers collect more and more data, allowing decision impact to be quantified. This enables optimization of such (planting period) decisions. We propose a flexible data-driven approach to optimize planting period decisions to maximize profit without additional investment.



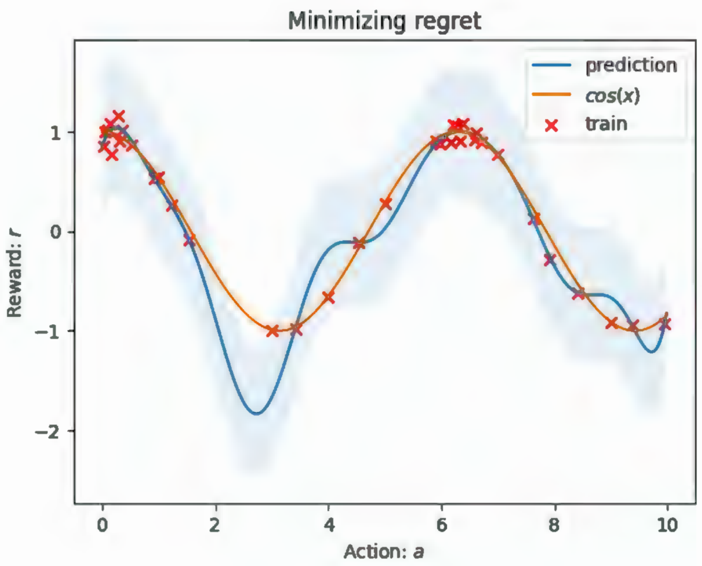
Encouraging predictability

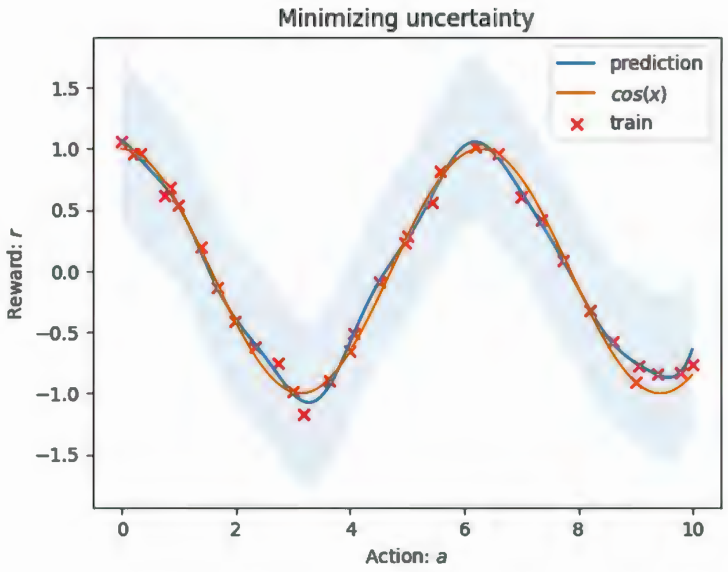
We designed a convex algorithm to regulate unpredictable behavior in, e.g., field robots. The method was shown to prevent unpredictable behavior at a minimal performance cost.



Optimal exploration vs. exploitation trade-off

We present a new method for reinforcement learning that improves the balance between exploration and exploitation, specifically designed for farm optimization. The approach allows farmers to choose a time horizon to maximize profit over or, alternatively, to focus on system characterization when profit is not the primary goal. This flexibility makes the method ideal for both practical farming applications and research-oriented exploration.





More recent results

- Practical approximations to intractable problems
- Extending the predictability encouragement to continuous spaces
- Risk-aware optimal decision making

Goals and work planned

- Autonomous mobile seeding platform

Greenhouse climate control

Synergia WP3

Ioannis Panagopoulos
TU Delft, Delft Center for Systems and Control

4th Autonomous Greenhouse Challenge

4th Autonomous Greenhouse Challenge

Oogst [per pot]

Team	Vers-gewicht [g]	Droog-gewicht [%]		Inkomsten [€/pot]	Straf-punten [€/pot]	Kosten [€/pot]		Teeltduur [dagen]	Plantdicht-heid [potten/m2]	Netto winst [€/m2/dag]	Teelt ranking		IPM punten	IPM Ranking		Gewogen gemiddelde	Eind-uitslag
IDEAS	219	6.8		€1.80		€-1.19		71	40	€0.34	1		70	3		1.5	**1**
Agrifusion	258	7.2		€1.84		€-1.47		79	25	€0.12	3		83	1		2.5	**2**
MuGrow	252	7.3		€1.86		€-1.49		70	33	€0.17	2		55	5		2.75	**3**
Trigger	268	5.9		€1.80	€-0.20	€-1.48		80	33	€0.05	4		70	3		3.75	**4**
Tomatonuts	283	6.0		€1.80	€-0.10	€-1.66		80	23	€0.01	5		77	2		4.25	**5**
Reference	275	6.6		€1.80		€-1.42		74	25	€0.13							

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Greenhouse climate control

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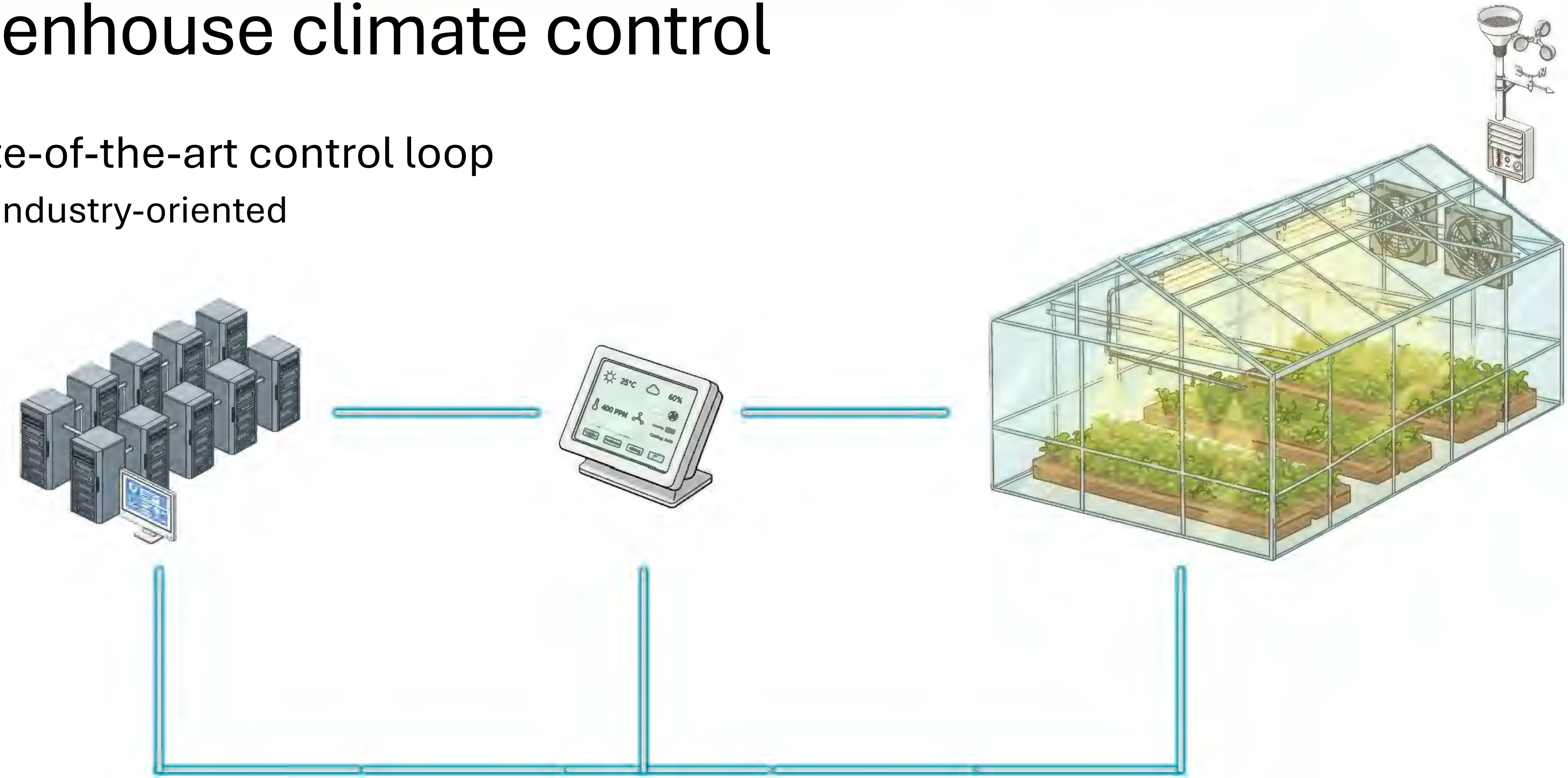
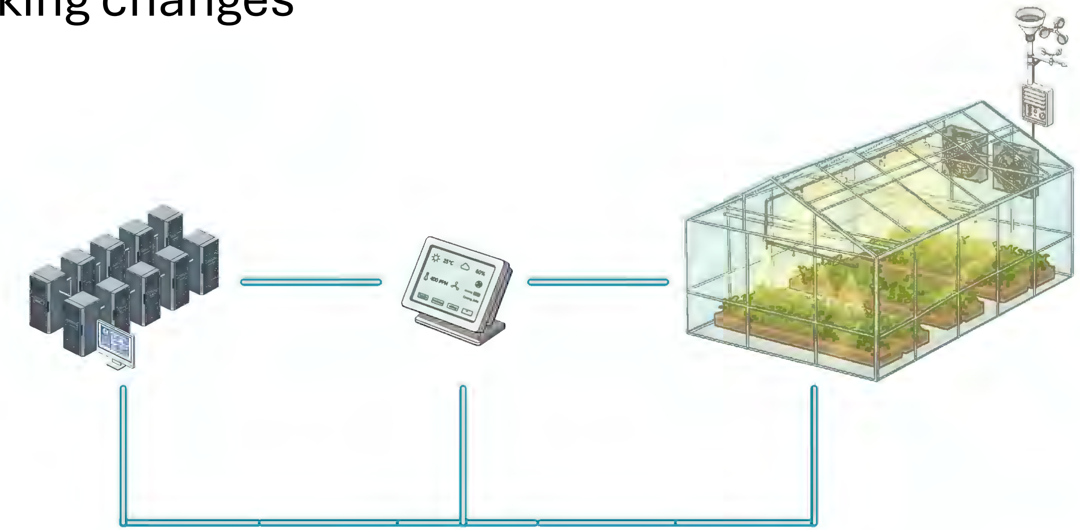
Greenhouse climate control

- State-of-the-art control loop
  - Industry-oriented



Future work

- Automate Climate Control
  - Under more realistic assumptions
  - To improve economic performance
- Adapt State-of-the-Art to Industrial Practice (Hoogendoorn, Van der Hoeven)
  - Without groundbreaking changes



Optimal decision making in feeding dairy cows

Synergia WP3

Maedeh Sadeghi
Agricultural Biosystems Engineering, Wageningen University

What to feed the cows?

- Cow's milk production
- Farm's profitability
- Health of cow
- Carbon footprint

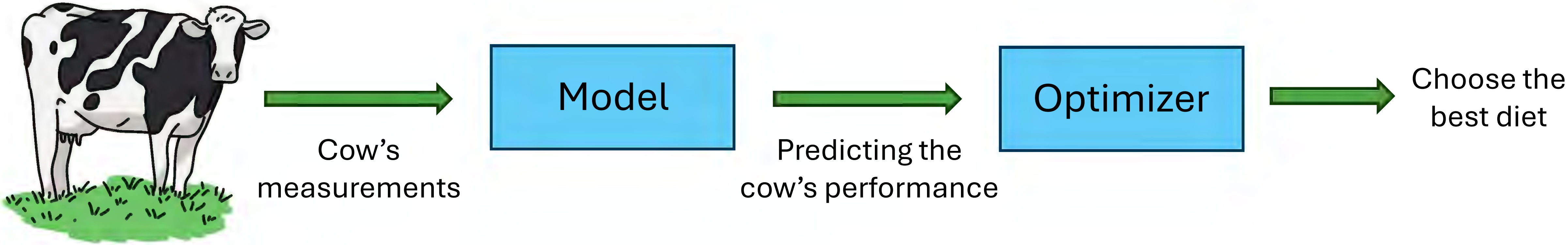
Dairy farming is unsustainable and not fully efficient.

This PhD:

- Semi-supervised tool to optimize diet of dairy cow to:
  - Decrease enteric methane production
  - Decrease feeding cost
  - Maintain the milk production level
  - Maintain the cow's health

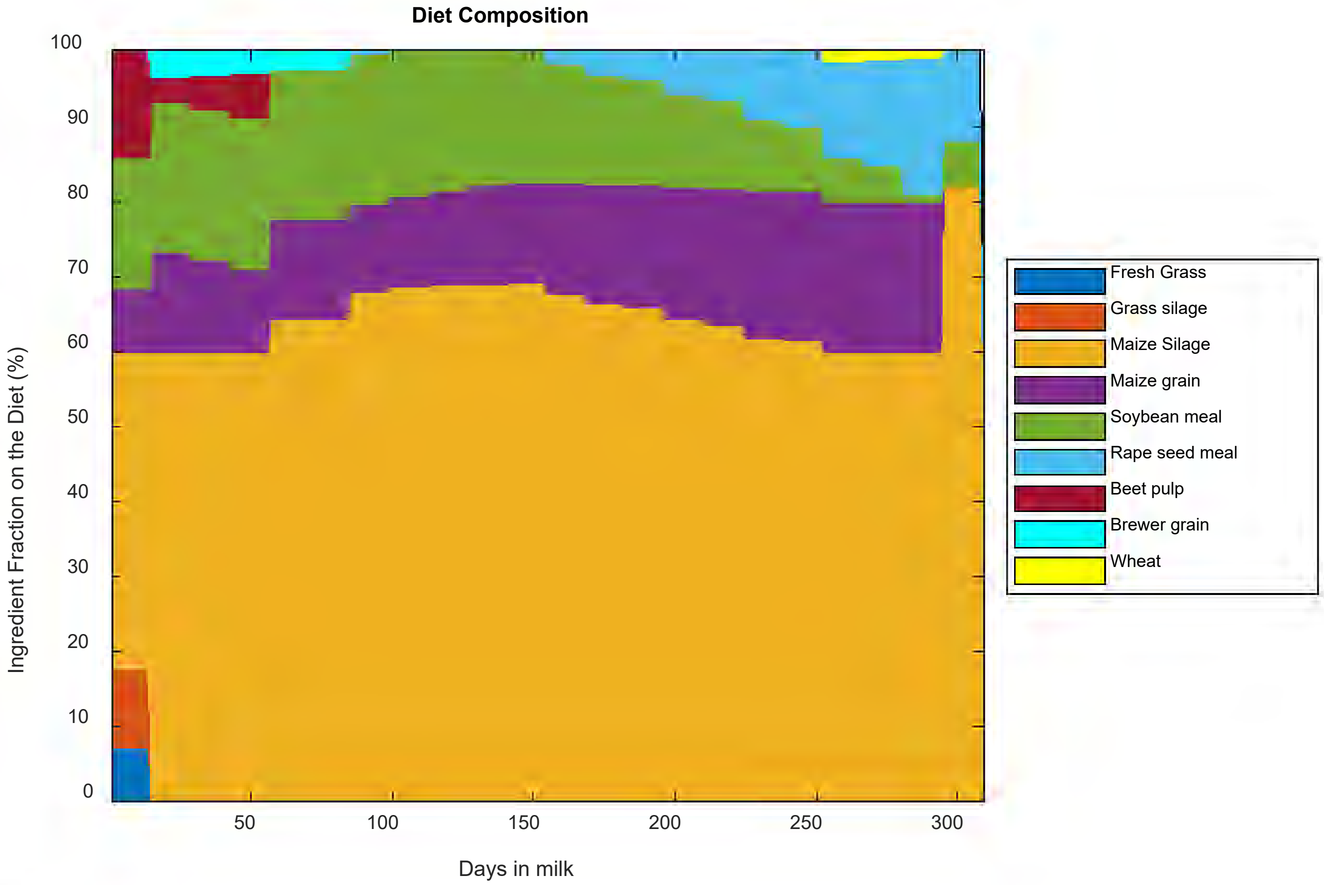
Next Food Collective
WAGENINGEN UNIVERSITY & RESEARCH
NWO
Synergia

How does it work?



Results

	Individual level performance (average per day)	
	Optimized diet	Reference diet
Feed margin (Euro/day)	13.59 (4.6%)	12.99
Methane (g/day)	398 (-7.6%)	431



Conclusion

- Change of diet, especially concentrate ratio, over time is needed

Future work

- Extend the tool to different individual cows, collaborating with Lely

Dynamic Modelling and Optimization of Mixed Cropping Systems

Maarten N. de Jong
R.D. McAllister and G. Giordano

Delft University of Technology, The Netherlands

September 2025

General Themes

- **Identify** the optimization problem in mixed cropping

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- **Model** the system dynamics mathematically

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- ▷ **Identify** the optimization problem in mixed cropping
- ▷ **Model** the system dynamics mathematically
- ▷ **Formulate & solve** the model-based optimization

Optimal Planting and Harvesting Within a Season

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Optimal Planting and Harvesting Within a Season

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Our contribution

A unified framework that incorporates all three systems

A Simple Model of Coupled Plant Growth

- We model crop interactions with the **competitive Lotka–Volterra equations**, a classic framework for population competition.

$$\dot{x}_i(t) = \rho_i\, x_i(t)\left(1 - \frac{x_i(t) + \sum_{j=1}^{n} \alpha_{ij} N_j(t) x_j(t)}{\omega_i}\right)$$

$x_i(t)$ average plant size of species i

$N_j(t)$ plant density of species j

ρ_i intrinsic growth rate

ω_i maximum mature size

α_{ij} competition coefficients

Model Fitting

Goal: fit model $\rightarrow$ capture representative crop dynamics

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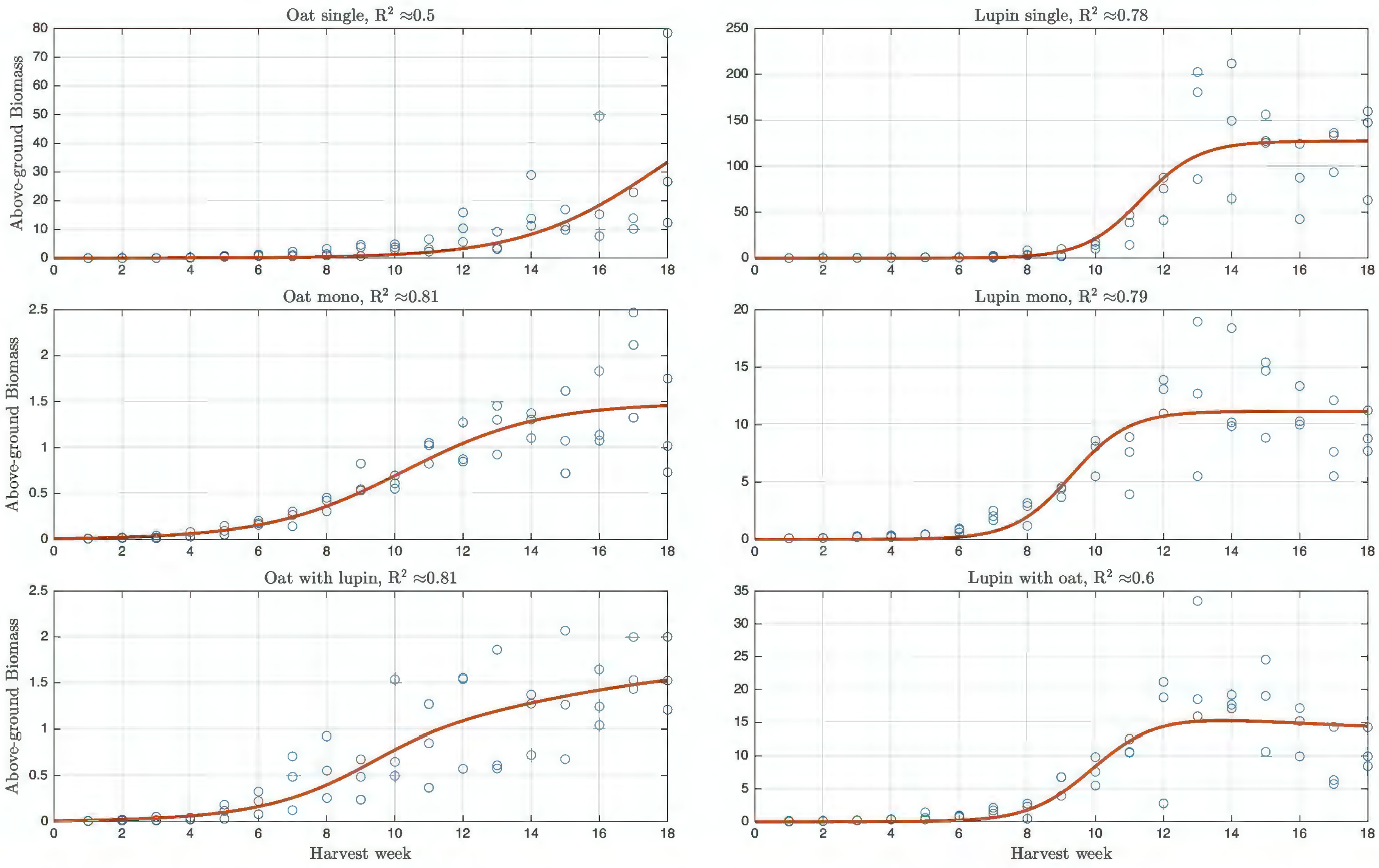
Data: Engbersen et al. (2021)
Oat and lupin biomass tracked under three treatments:

- **Single**: no competition
- **Monocrop**: intraspecific competition
- **Intercrop**: inter- & intraspecific competition

Design: replacement planting

Measurements: weekly biomass (destructive sampling)

Model Fitting



Equilibrium-Based Optimal Densities

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Dynamic system:

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Economic optimisation problem:

with crop revenue π and seed costs δ:

$$\max_{\bar{x}, \bar{N}} \pi^\top (\bar{N} \circ \bar{x}) - \delta^\top \bar{N}$$

$$\text{s.t. } M(\bar{N}) \cdot \bar{x} = \omega$$

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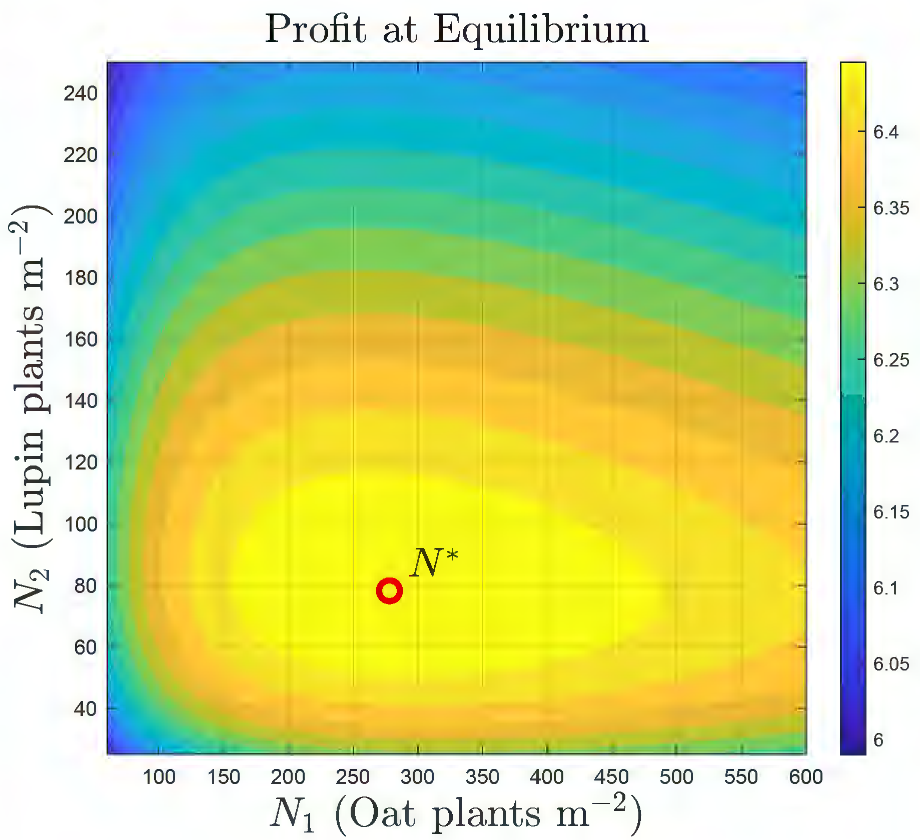

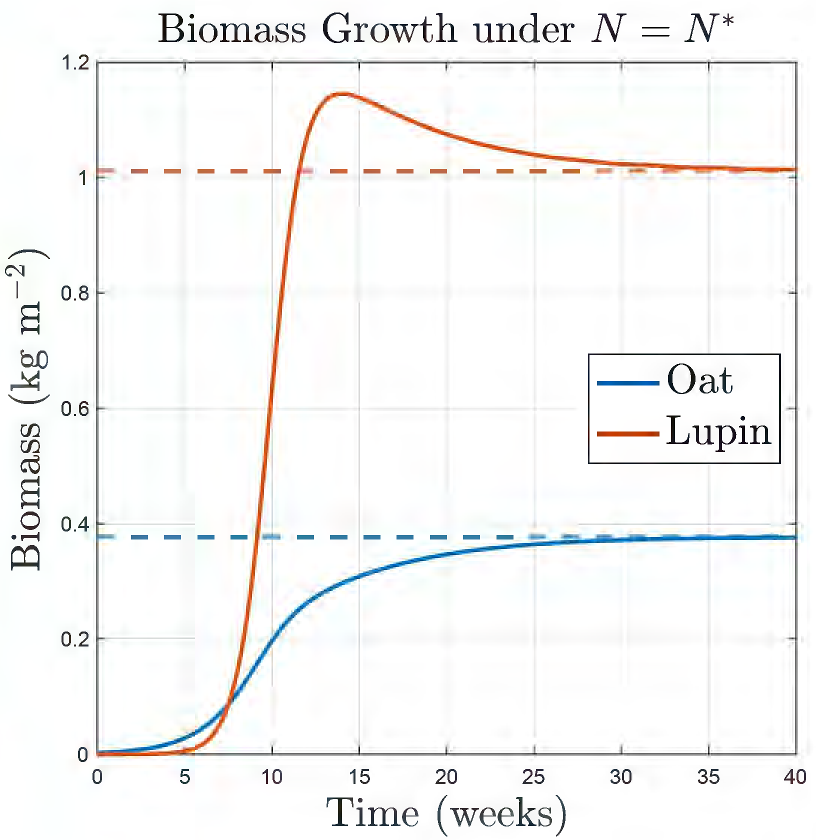

Limitations and Next Steps

Limitations of equilibrium-based optimisation:

- Crops may not reach equilibrium within realistic time horizons
- Harvesting earlier can sometimes be more profitable

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Moving beyond equilibrium:

- Incorporate **transient dynamics** explicitly in optimisation
- Allow **flexible timing** of sowing and harvesting

Coupled Crop Growth as an Impulsive Control System

Key idea: sowing and harvesting are much faster than growth $\Rightarrow$ model them as *instantaneous impulses*.

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Impulsive updates (at times k):

$$\begin{aligned} x_k^+ &= (\mathbb{1} - h_k) \circ x_k + \beta_0 \circ s_k, \\ N_k^+ &= (\mathbb{1} - h_k) \circ N_k + u_k \circ s_k, \end{aligned} \qquad k \in \{0, \dots, T-1\}$$

Control variables:

- $s_k \in \{0,1\}^n$: sowing decisions
- $h_k \in \{0,1\}^n$: harvesting decisions
- $u_k \in \mathbb{R}^n_{\geq 0}$: sowing densities

Optimal Sowing and Harvesting

Setup:

- Initial state: empty field, $x(0) = N(0) = 0$
- Prices: crop revenue π, seed costs δ
- Fixed costs: sowing ζ, harvesting ξ
- Time horizon T (number of impulse times)

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- Time horizon T (number of impulse times)

Objective: maximise profit

$$\max_{\mathbf{u},\mathbf{s},\mathbf{h}} \sum_{k=0}^{T-1} \left[\pi^\intercal (h_k \circ N_k \circ x_k) - \delta^\intercal (s_k \circ u_k) - \zeta^\intercal s_k - \xi^\intercal h_k \right]$$

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Subject to system dynamics:

$$\begin{aligned}
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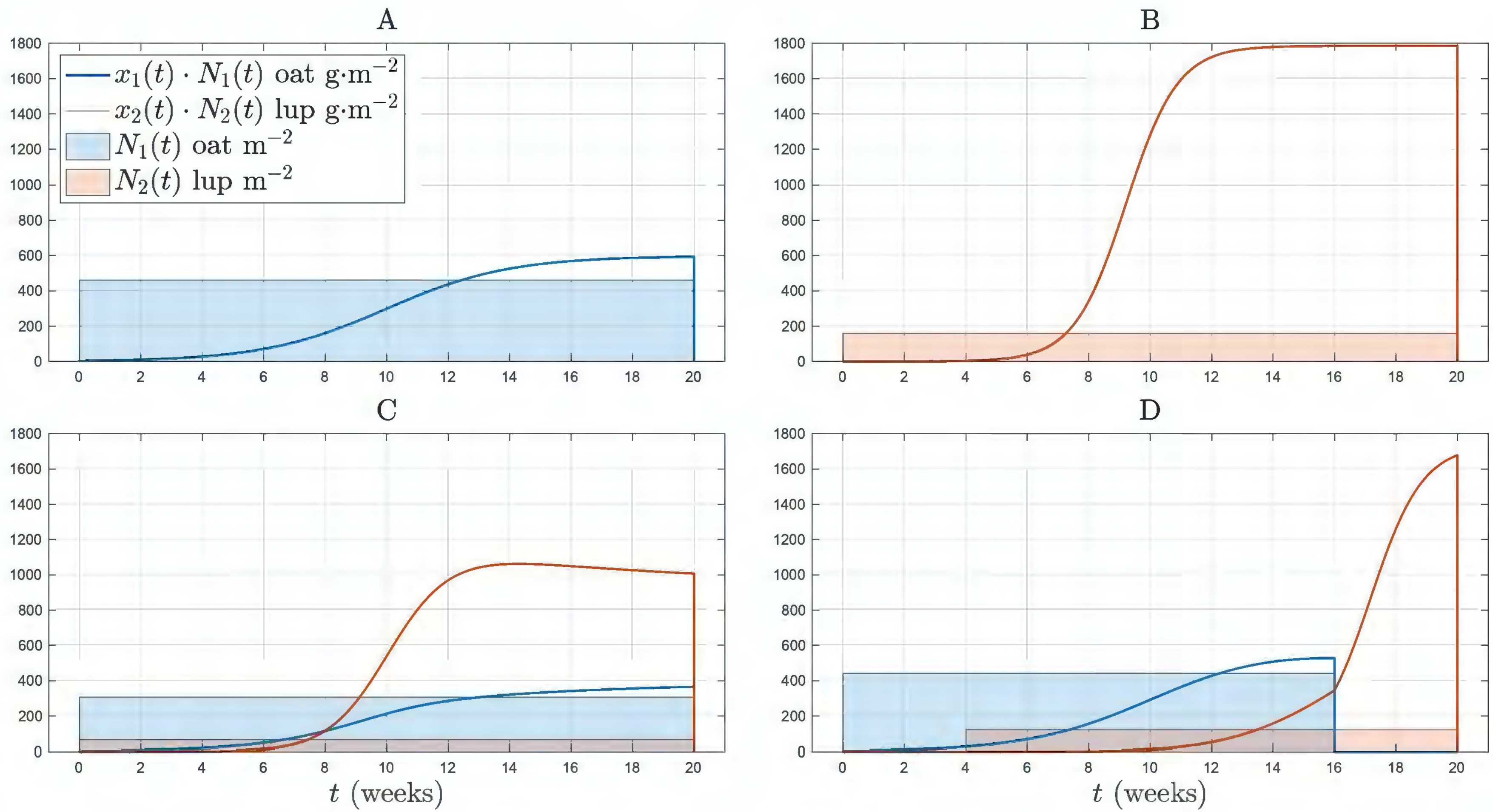
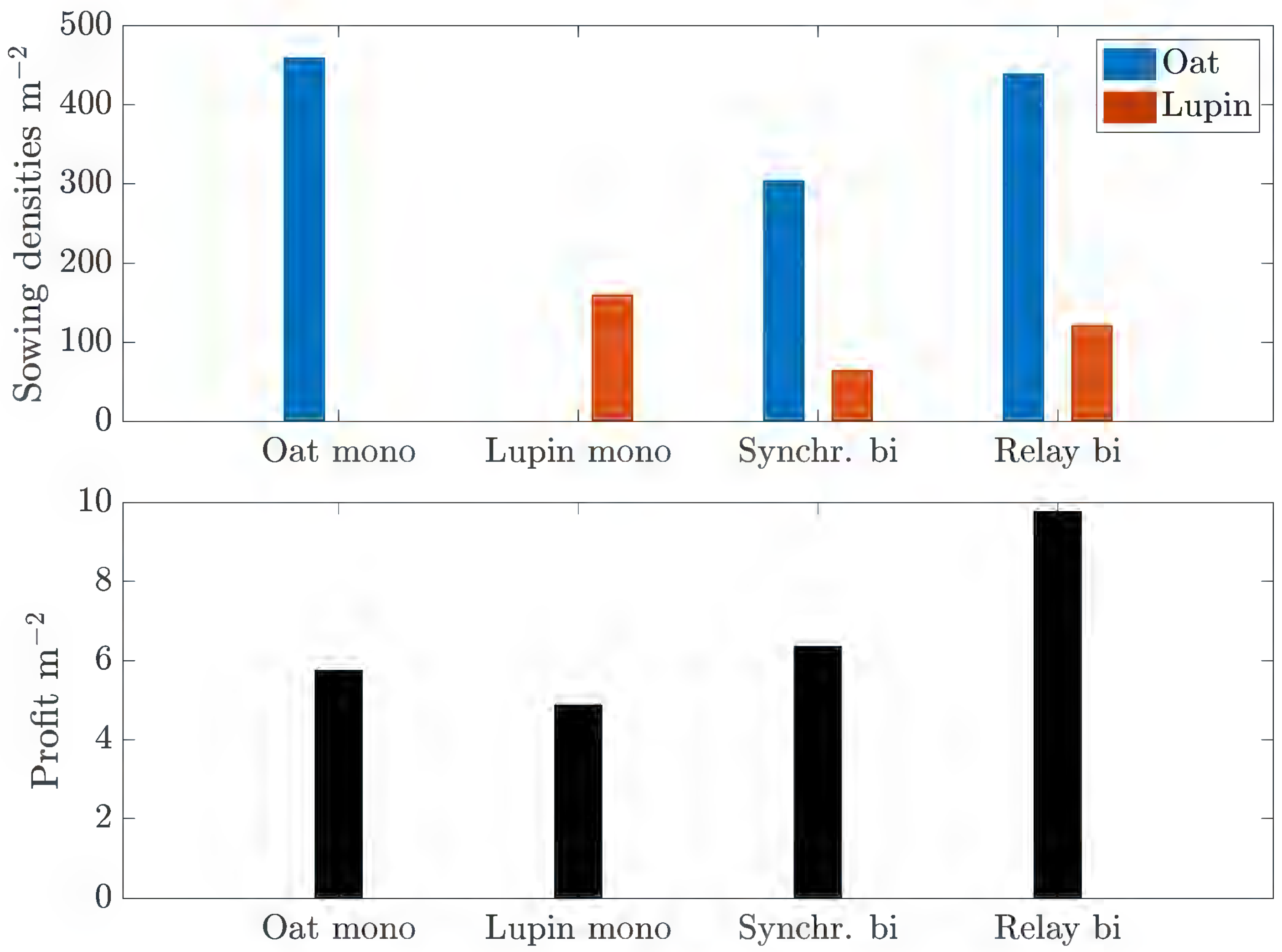
\end{aligned}$$

Resulting Schedules under Various Constraints



Comparing Sowing Densities and Profits



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Our framework:

- Models crop growth as an **impulsive control system**
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What it offers:

- Tailorable to specific cropping systems
- Can reveal unintuitive optimal strategies
- Links **ecology** $\leftrightarrow$ **farm economics**

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Next steps:

- Model refinements:
  - Plant density dynamics $N(t)$
  - Size-asymmetric competition
  - Other factors (weeds, fertilizer, . . .)
- Evaluation with FSPM simulations / field experiments
- Extension to multi-season optimisation