Simulate soil C and N fluxes incorporating leguminous N fixation in agricultural systems

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Outlines of presentation

- SPACSYS model
- Two case studies
  - Intercropping system
  - N fixation of field pea
- General discussions

Questions to be addressed

Requirement of future farming systems - crop rotation

- Meet crop nutritional demands
- Minimise environmental impact
- Control weed, pest and disease

➡ How to design a rotation in an effective way?

Legume crops play an important role in the system, how to estimate the contribution of N fixation to soil C and N?

How does a leguminous crop affect C and N fluxes in an agro-ecosystem?

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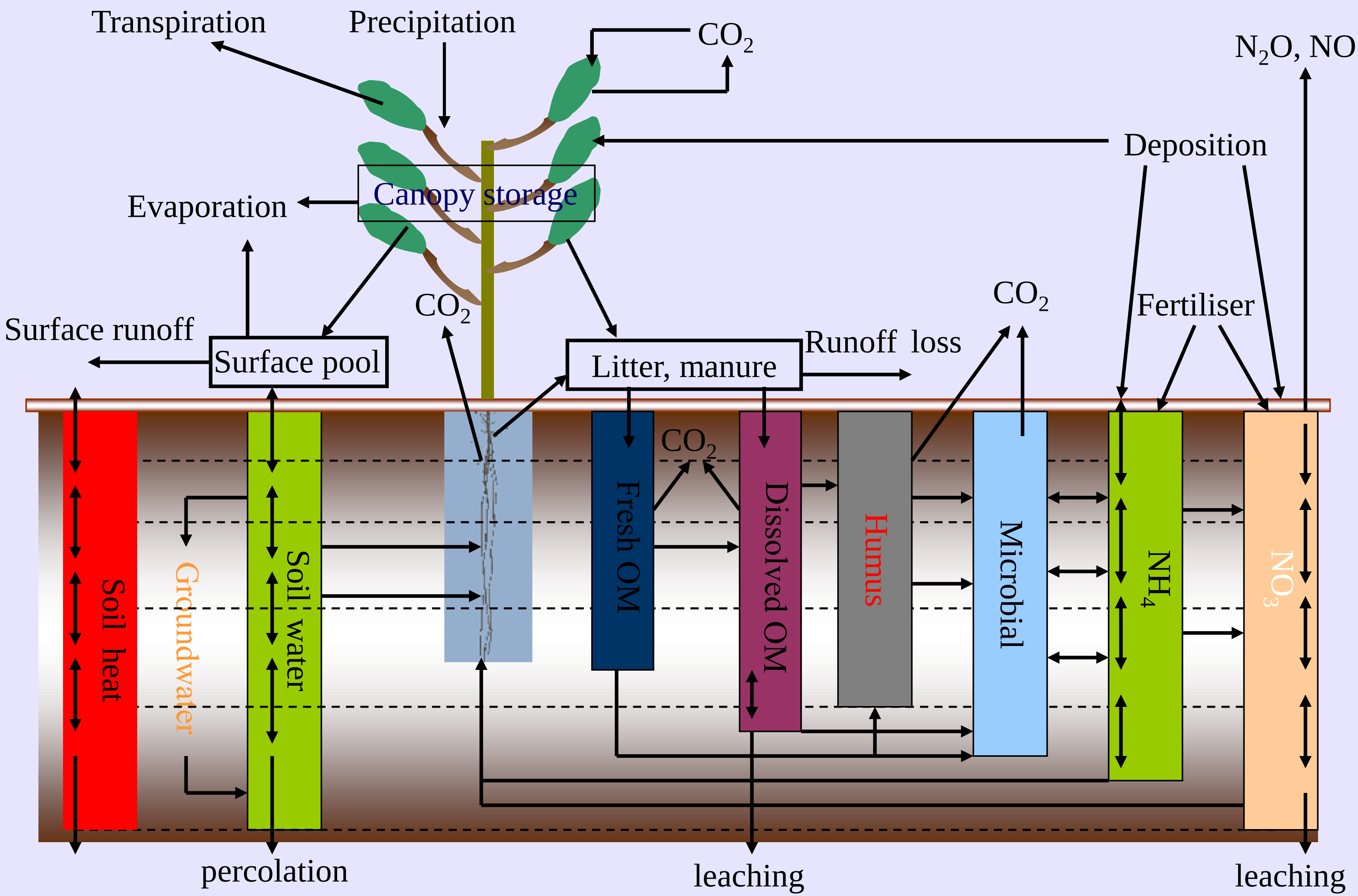
SPACSYS model

- Developed over 10 years & on-going improvement
- Mixed dimensional, multi-layer, weather-driven, daily-time-step and process-based dynamic simulation model with:
  - plant growth and development (above and below-ground, sole and intercropped)
  - N & C cycling
  - soil water movement
  - heat transformation

SPACSYS framework



Root development

BRANCHING PROCESS

Branching position

Branching orientation

GROWTH PROCESSES

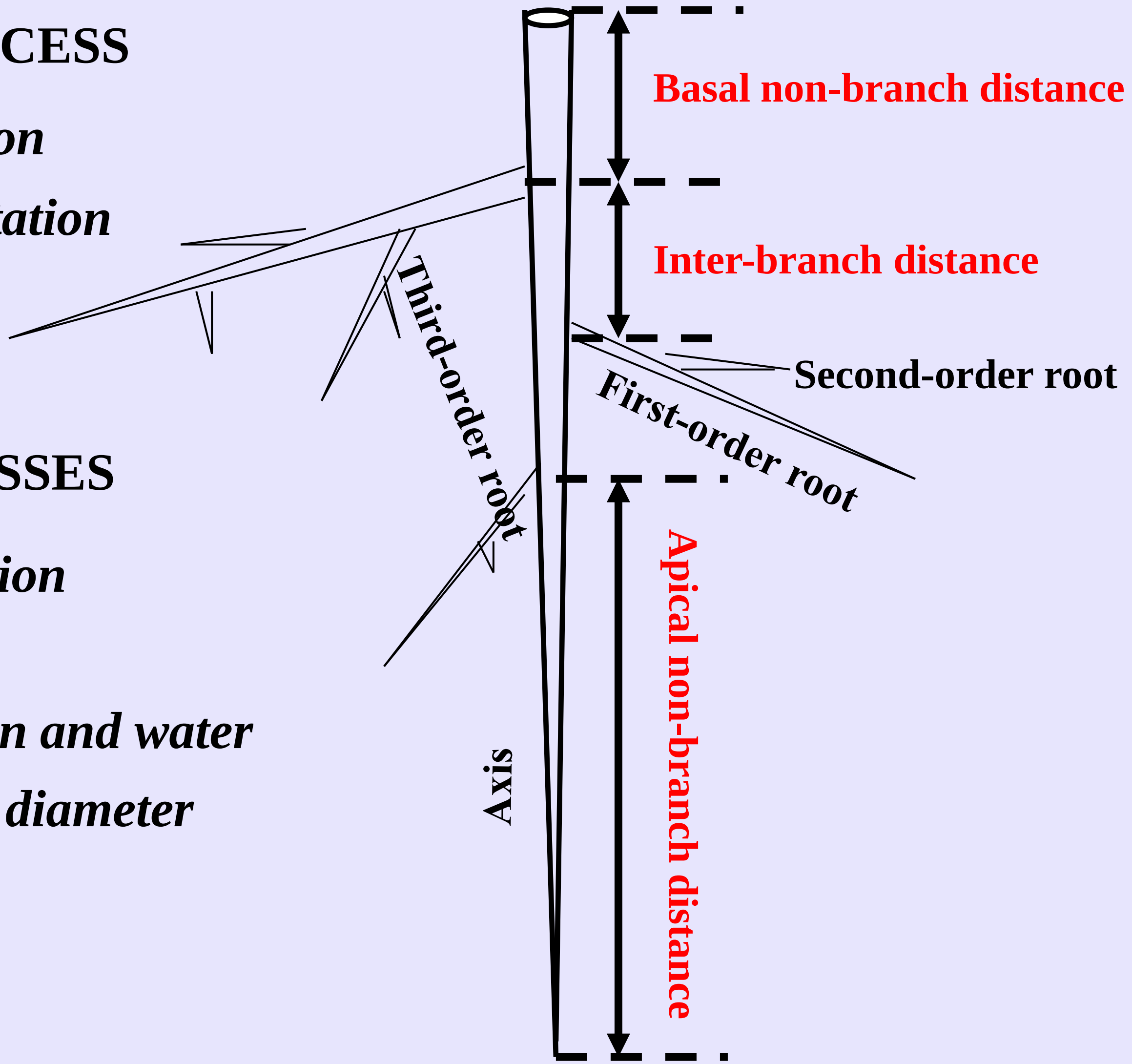
Elongation direction

Elongation rate

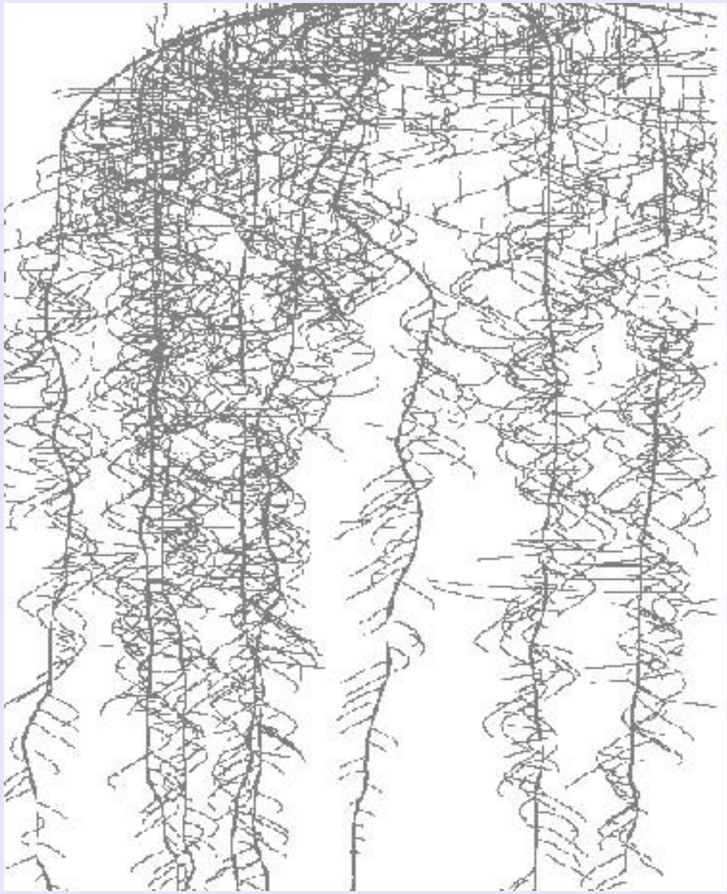
Uptake of nitrogen and water

Dynamics of root diameter

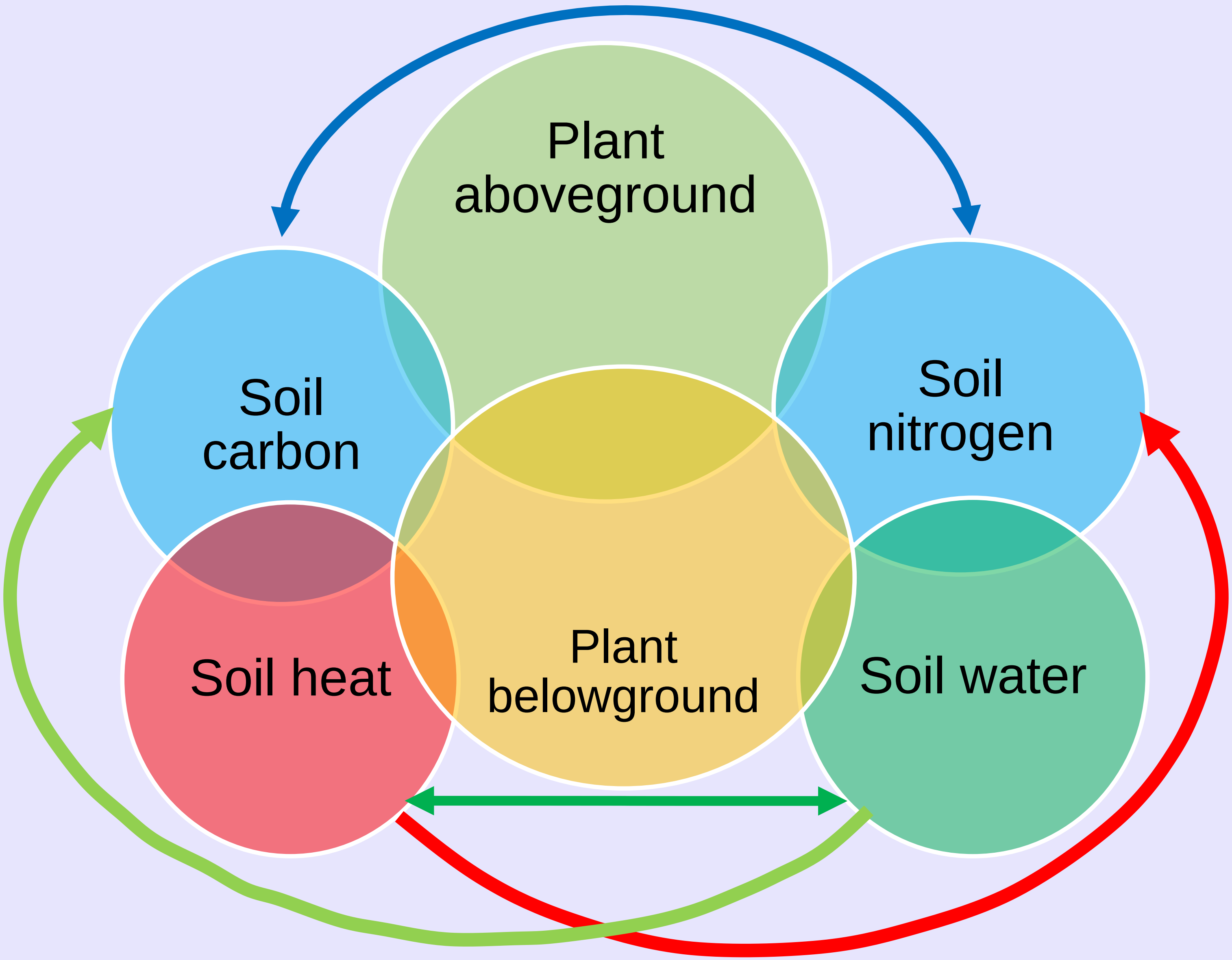
Mortality



Simulated root system of *Trifolium repens* 15 weeks after seedling transplant with SPACSYS



Interactions between components



Factors to control leguminous N fixation

- Biological capacity
  - Potential N fixation controlled by C supply or N sink strength or O_2 supply (controversial)
  - Nodule establishment
- Environmental conditions
  - Temperature
  - Soil moisture
  - Mineral N content in root zone
- Status of above-ground

Options to estimate N fixation in the model

- Option 1
  - based on root nodule biomass (Wu & McGechan, 1999)

  ⇨ ***sounds more mechanistic***

- Option 2
  - based on above-ground biomass (excluding grains)

  ⇨ ***more practical***

General algorithm to estimate N fixation rate

$$R_{Nfix} = NFix_{max} \cdot f_T \cdot f_W \cdot f_N$$

f_T : response function to soil temperature

f_W : response function to soil water content

f_N : effect of available inorganic N content

$Nfix_{max}$: maximum rate of biological N fixation

Maximum N fixation rate

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For Option 1:

$$NFix_{max} = \varphi \cdot \alpha \cdot W_{root}$$

For Option 2:

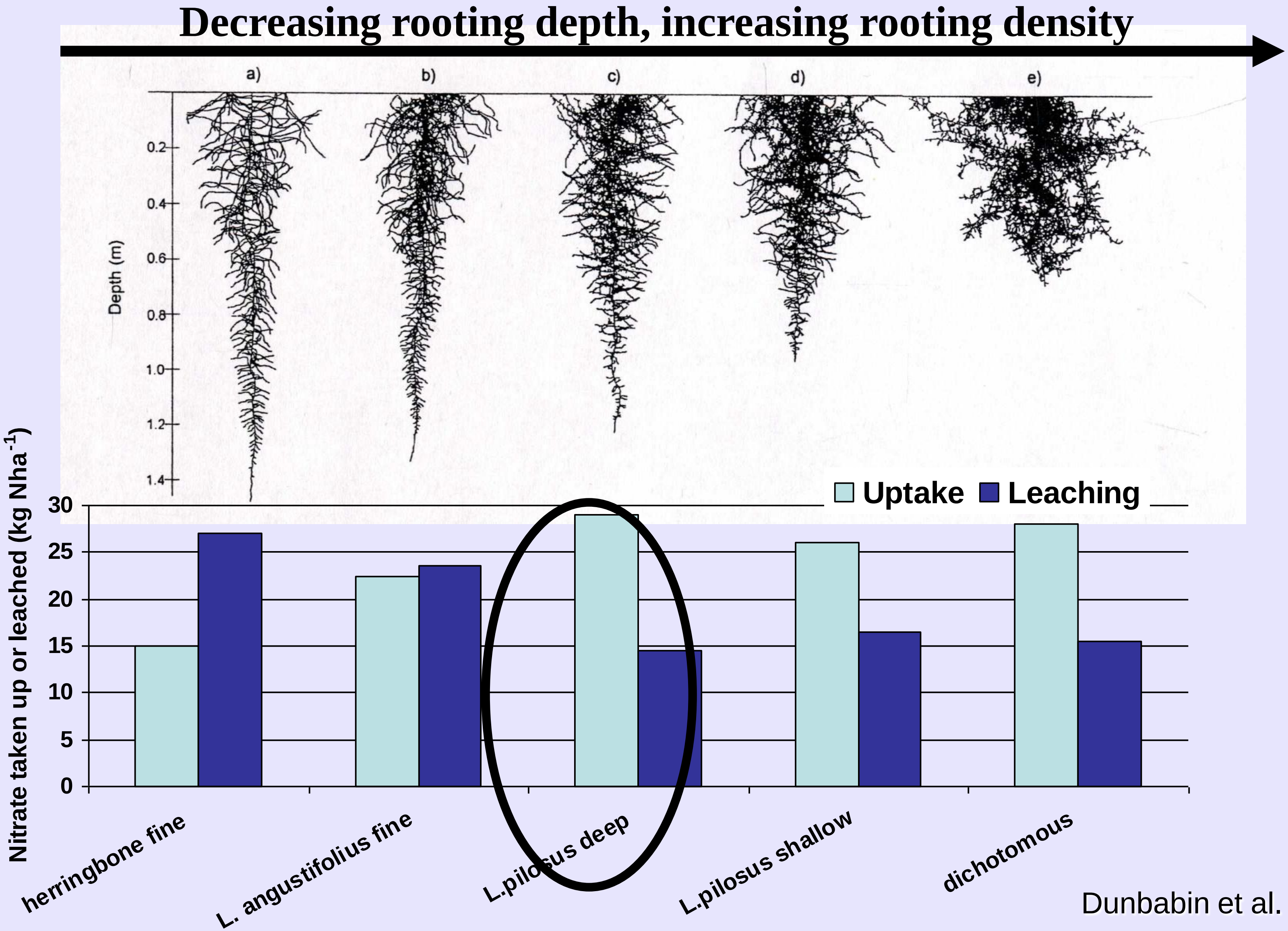
$$NFix_{max} = \min\left(\varphi \cdot W_{aboveground}, \frac{f_{nodule} \cdot C_{root}}{c} \right)$$

φ: fixed rate/potential capacity per unit DM
α: ratio of root DM and nodule DM
F_{nodule}: fraction of C used for N fixation in nodules
C_{root} : photosynthetic C assigned to nodulated root
c : C cost per unit fixed N

Intercropping
cereals with grain legumes

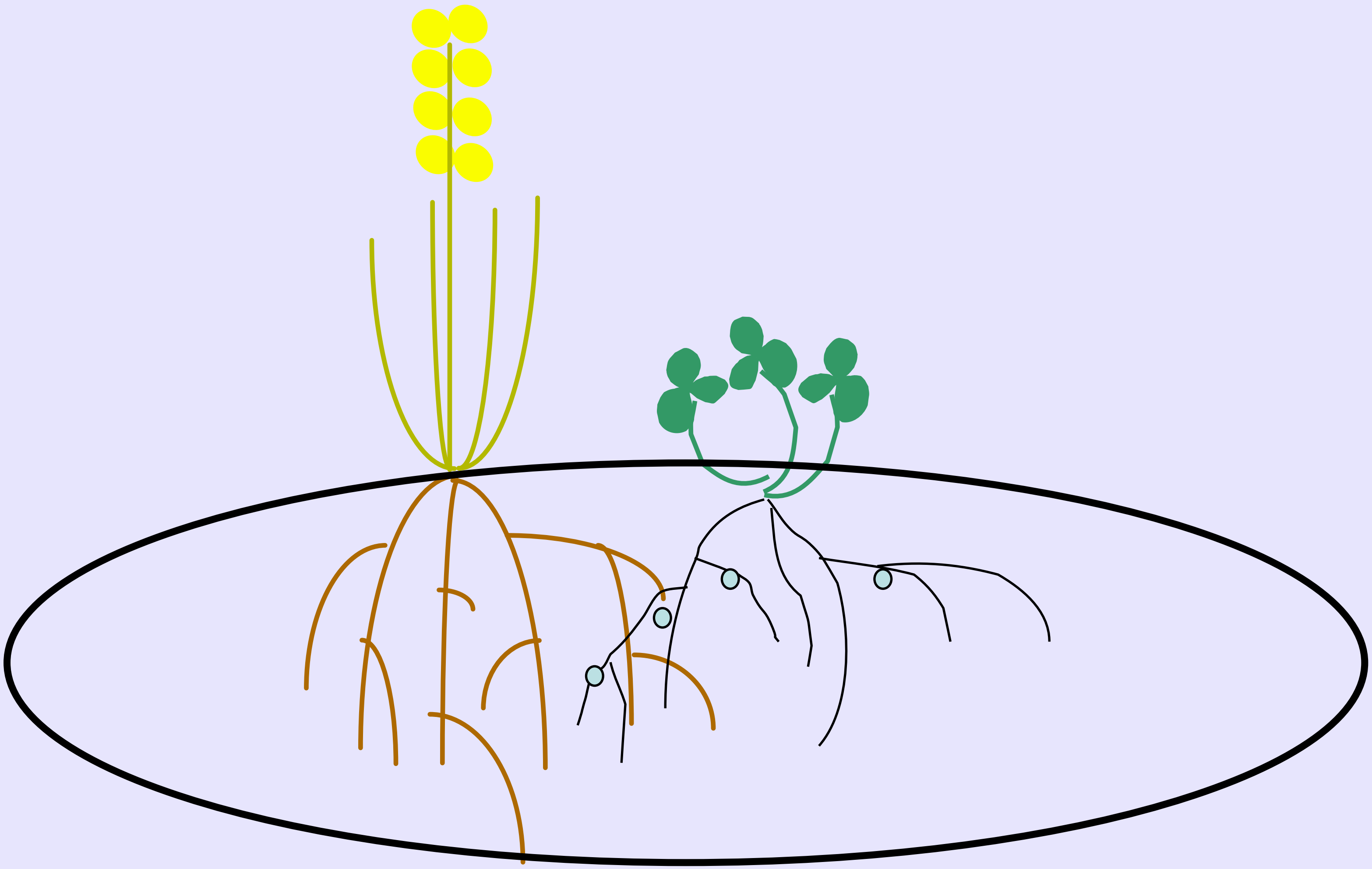
Examine N leaching in sole and intercropping systems

Appropriate root architecture improves resource capture & avoids N pollution



Dunbabin et al. (2003)

Can intercropping with complementary root systems help to reduce leaching loss?



CONFIGURATION OF SIMULATIONS

SITE: Aberdeen, Scotland (57^{o}12”N)

MODEL CROPS:

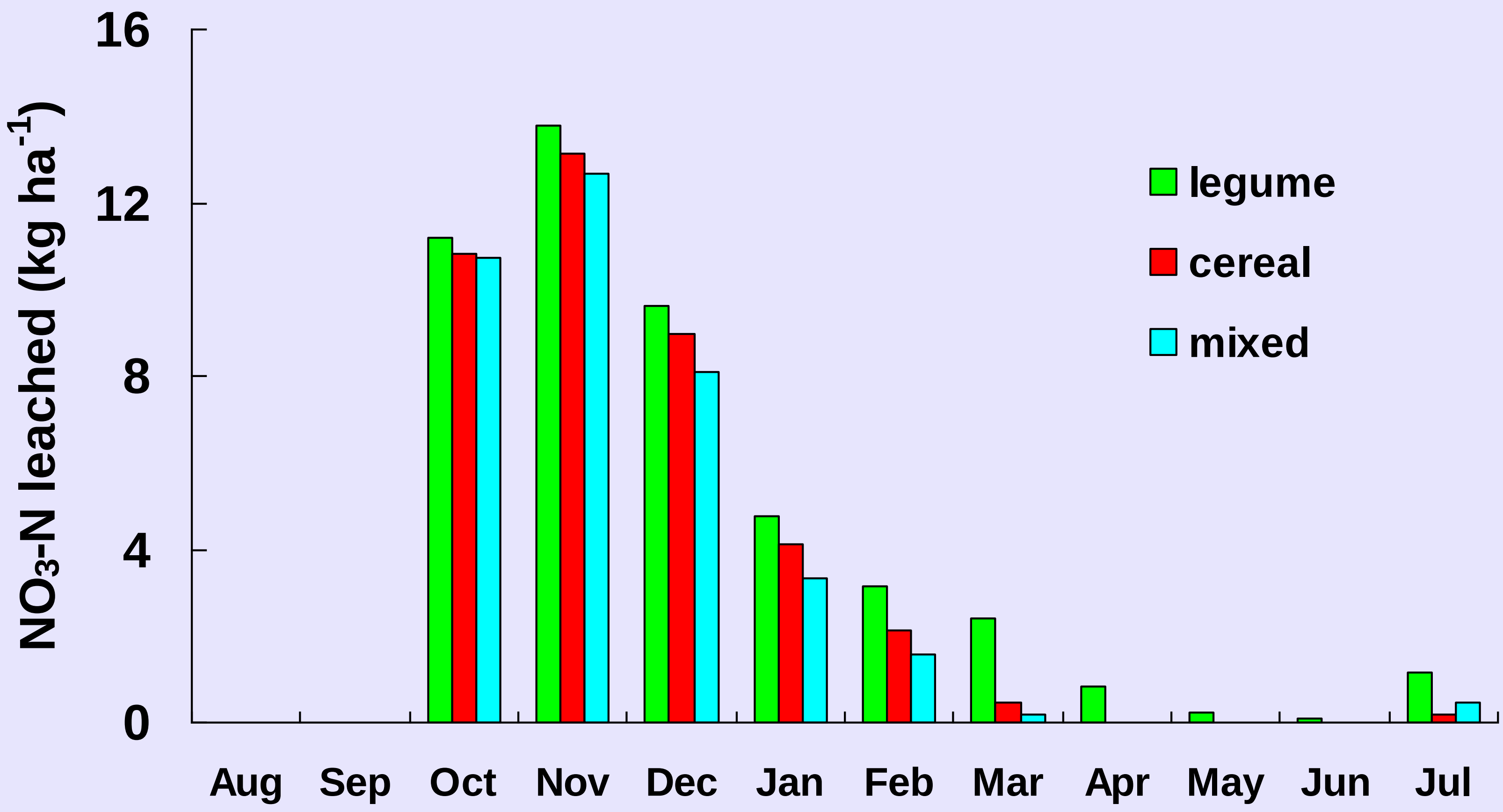
- **cereal**
- **grain legume**
- **50:50 intercropped mixture**

RUNNING YEARS:

- **Aug.1994 - July, 1995**
- **Aug. 2000 - July, 2001**

FERTILISER APPLICATION: No

Simulated monthly NO_3-N leaching in 2000/01



Simulated annual nitrate leaching from different crop designs in two years with contrasting rainfall

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	1994/95	2000/01
Precipitation (mm)	695	1217
Annual Nitrate Leaching (kg N ha^{-1})		
Cereal	38.2	39.9
Grain legume	38.8	47.3
Intercrop	24.7	37.1

Simulated annual N input & plant uptake (kgN ha^{-1}) from sole crops in 1994/95

	Deposition	fixation	mineralisation	Plant uptake
Grain legume	**24.2**	**9.5**	**115.5**	**85.2**
Cereal	**24.2**	**-**	**119.3**	**92.8**

Conclusions

- Cultivation of grain legumes can lead to increased nitrate leaching
- Leaching losses following incorporation of grain legumes are generally higher than from cereal crops, in part due to the lower C:N ratio of grain legume residues.
- Growing grain legumes in mixtures with cereals has the potential to reduce leaching losses, either by changing residue quality or through improved nutrient capture by roots.
- Varietal selection, especially with regard to belowground characteristics of both the grain legume and the cereal, have the potential to improve the nutrient capture of intercropped systems.

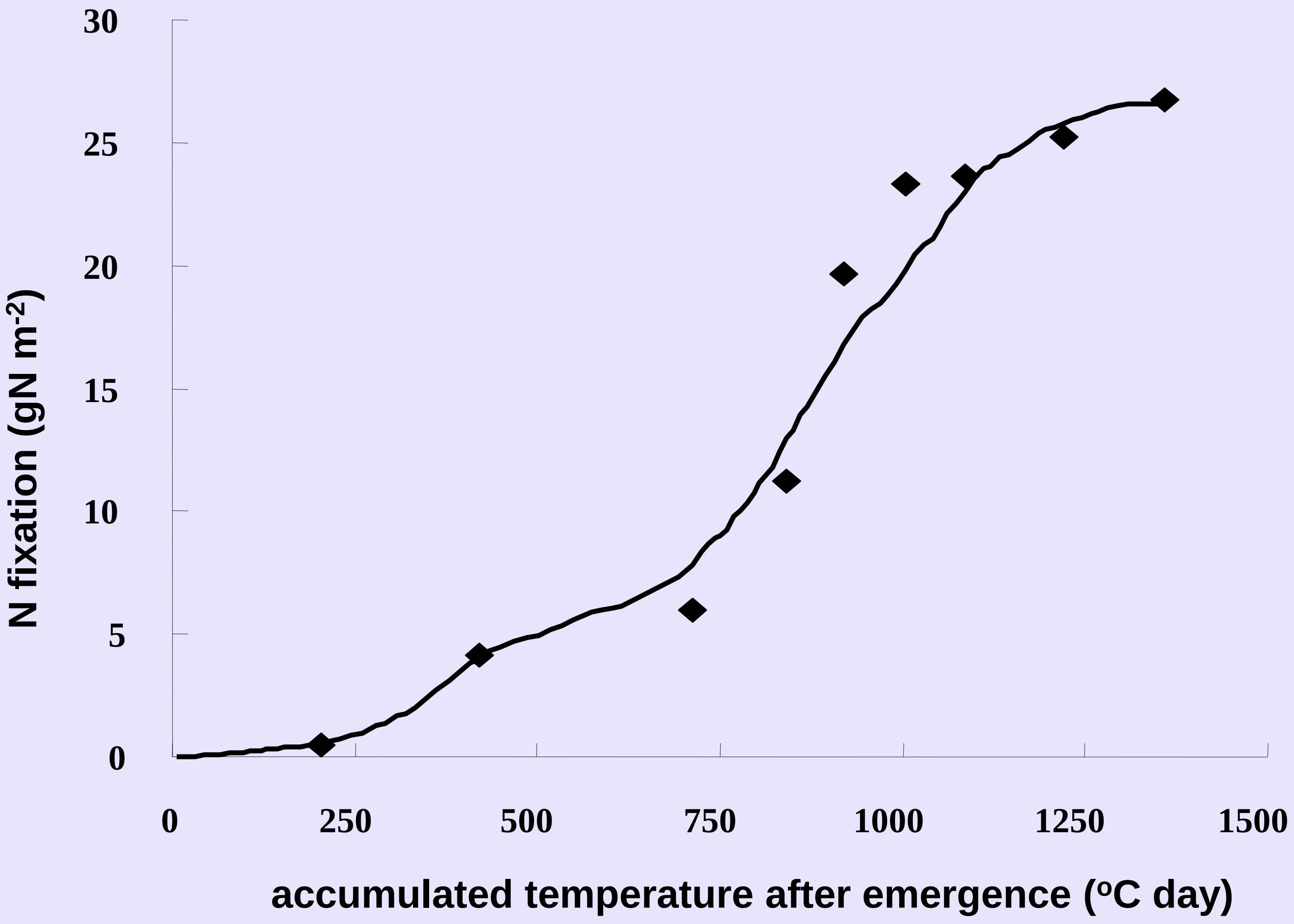
Simulate N fixation with above-ground biomass

Revisit an N fixation experiment in Risø, Denmark (1984)

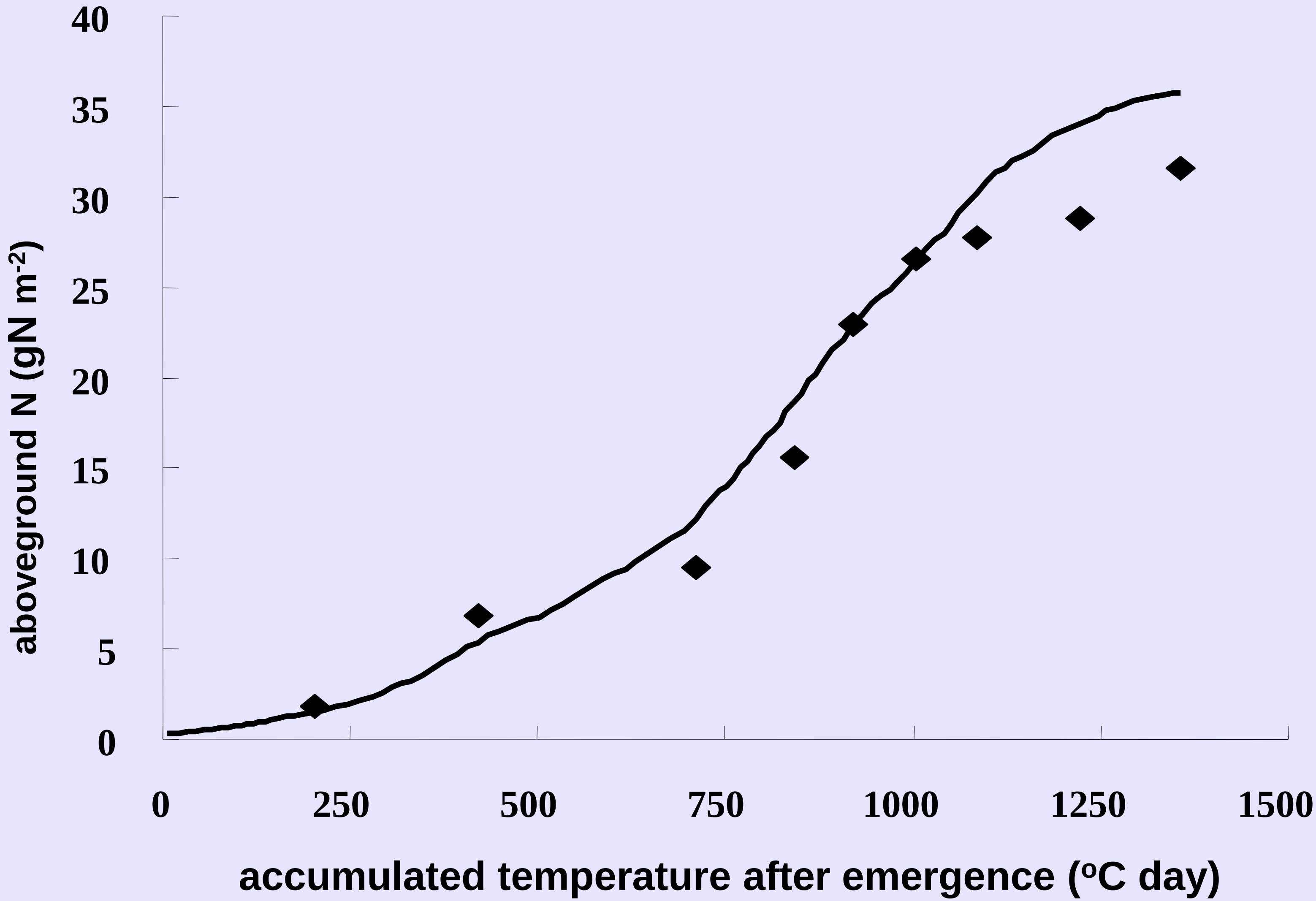
Field pea cultivar		Bodil
Soil type		sandy loam
Soil mineral N in top soil layer before sowing		30 kg ha^{-1}
Weather conditions during growing season	Total precipitation	311mm
	Average min. T	12.1°C
	Average max. T	20.3°C
N application	Fertilizer type	NO_3^-
	Amount	25kg N ha^{-1}

Jensen, 1987; 1996

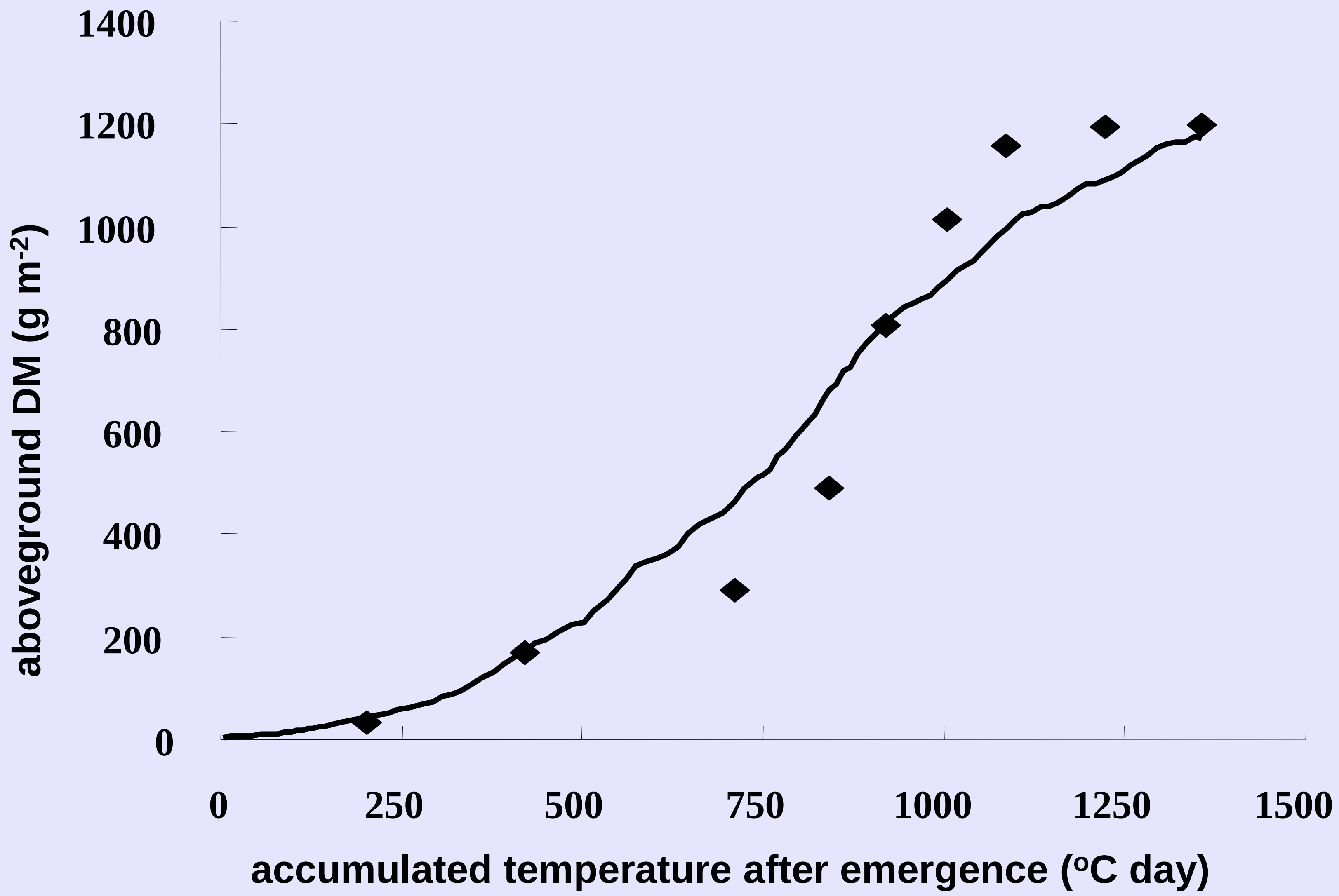
Comparison between measured and simulated accumulated N fixation



Comparison between measured and simulated accumulated above-ground N



Comparison between measured and simulated accumulated above-ground DM



Which parameters is N fixation sensitive to?

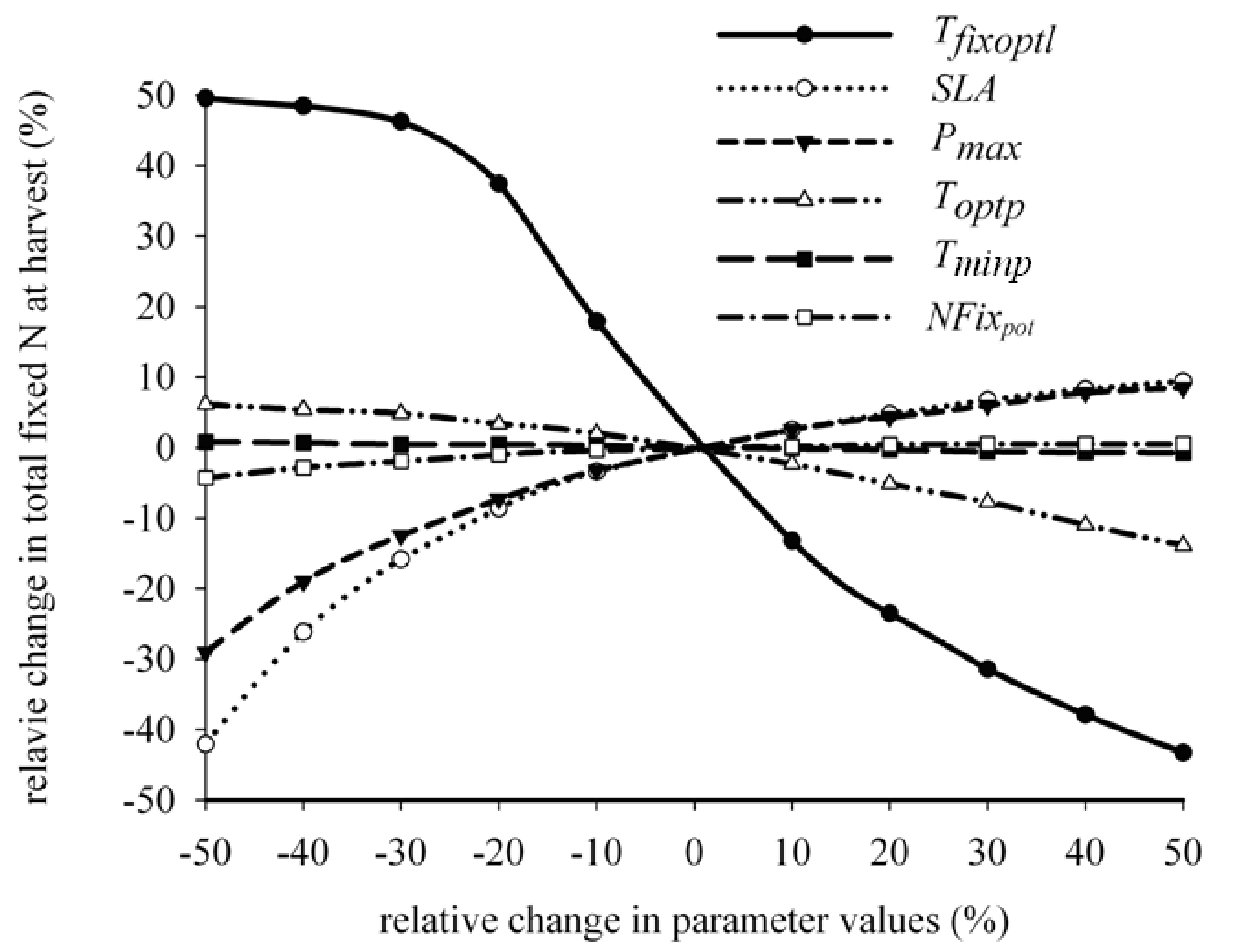
Single parameters

- Optimal T for fixation ($T_{fixoptl}$)
- Specific leaf area (*SLA*)
- Potential leaf photosyn. Rate (P_{max})
- Optimal T for photosyn. (T_{optp})
- Min. T for photosyn. (T_{minp})
- Potential fixation rate ($NFix_{pot}$)

Multiple parameters

- Identified four parameters: *SLA*, $T_{fixoptl}$, P_{max} and T_{optp}
- 8 combinations in pair

Relative changes of N fixation at harvest with different parameter values



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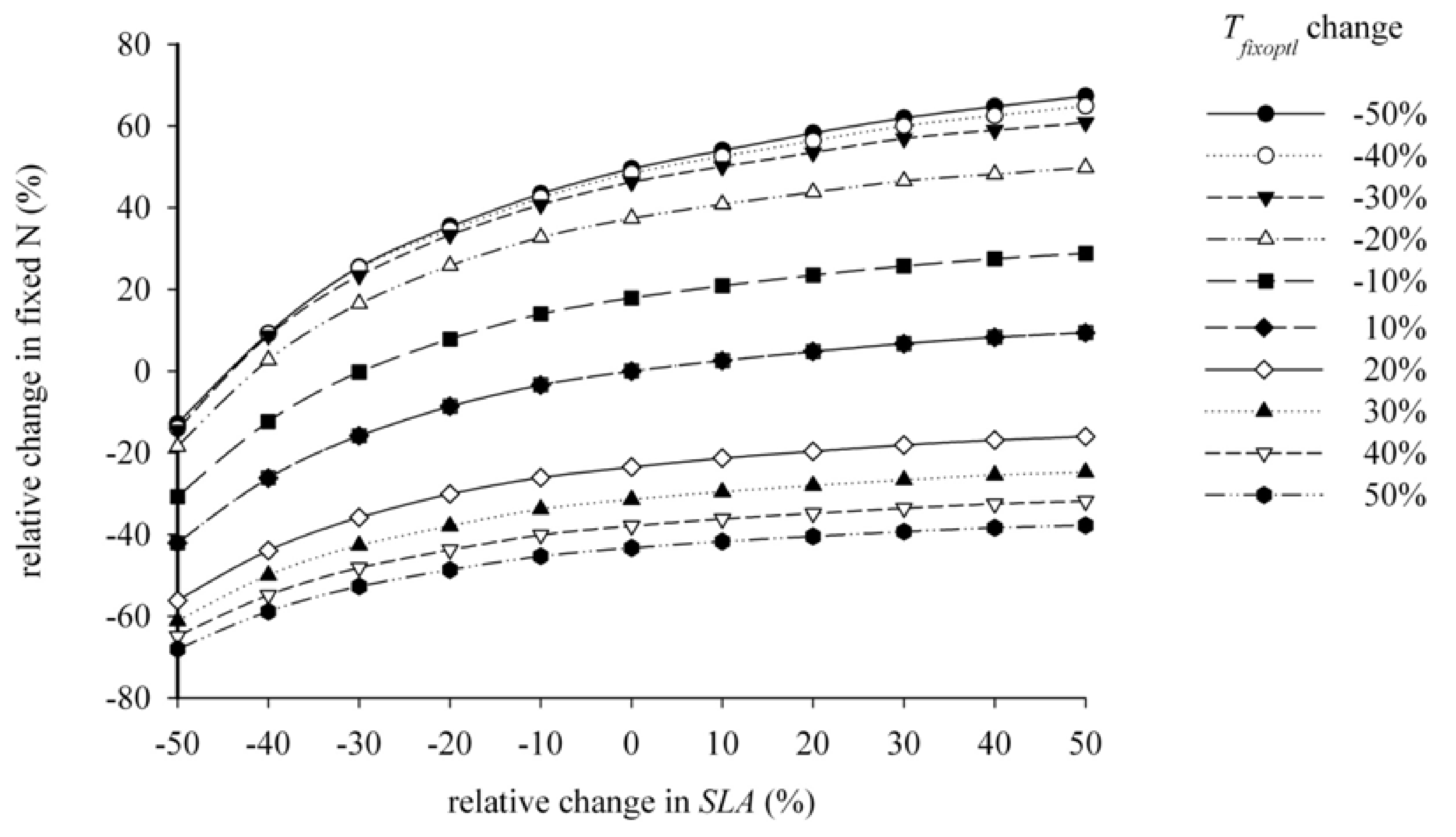
Changes of simulated N fixation with *SLA* in different $T_{fixoptl}$ levels



In prep.

Conclusions

- The algorithm with aboveground DM is able to simulate dynamics of accumulated N in aboveground reasonably
- Potential fixation rate is one of the most important parameters in estimating actual rate accurately
- N fixation in Risø is very sensitive to low temperature and photosynthetic rate
- Greater green leaf cover and faster establishment in young plants and high photosynthesis would enhance N fixation

General discussions to simulate biological N fixation by legume

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Difficulty of simulating legume biological N fixation

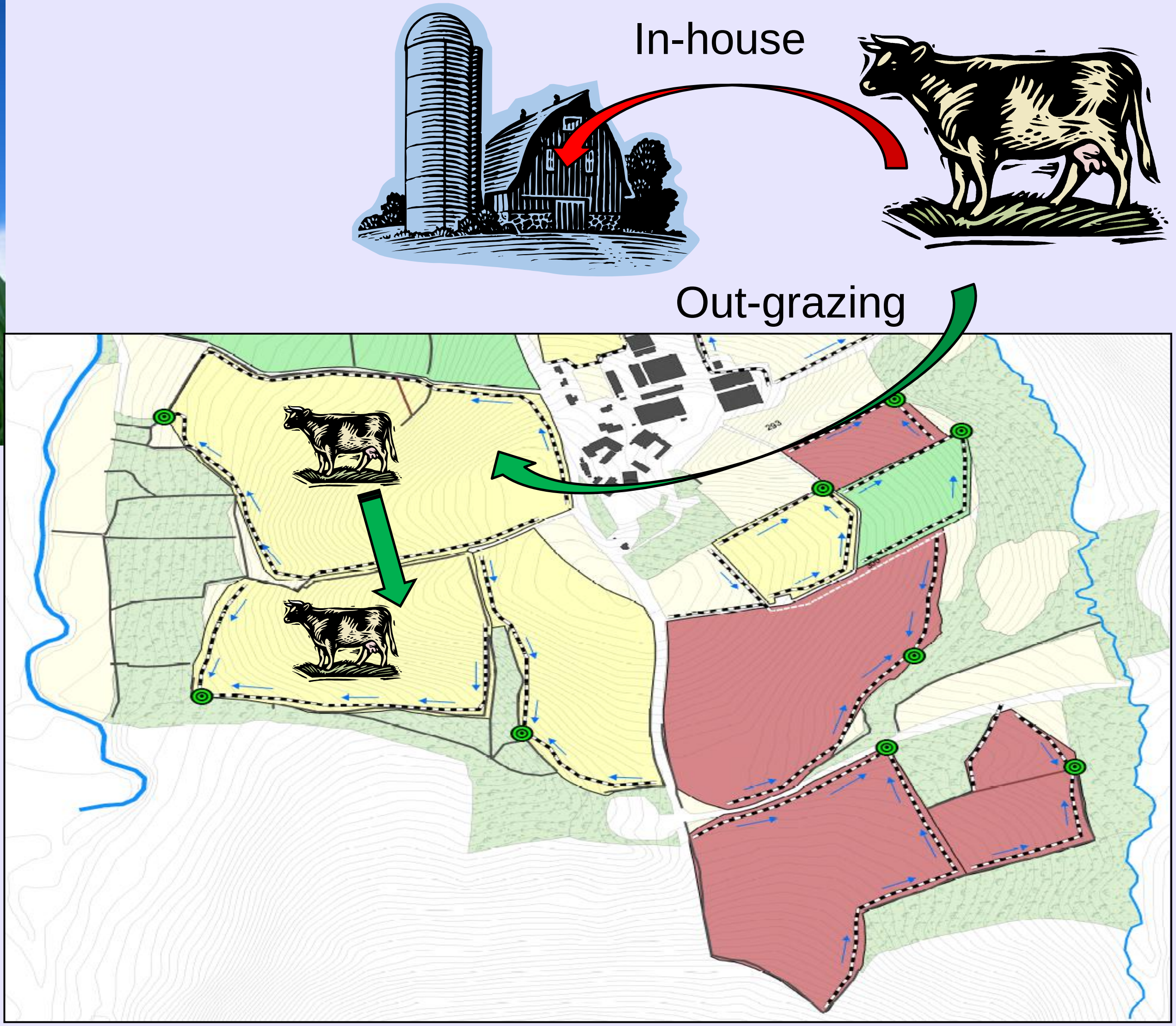
- large variance in N fixation between sites and species, and over time
- a highly complex process:

  integrate plant and soil processes in macro- with micro-environmental processes of *rhizobial* bacteria in nodules

In further development, it is desirable:

- define the key parameter of potential N fixation rate based on nodule mass
- distinguish the different inhibitory effects of soil nitrate and ammonium in the rhizosphere

Farming systems



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