Mulch layer dynamics in conservation agriculture and the mulch module in Daisy

Thesis project (45 ects)

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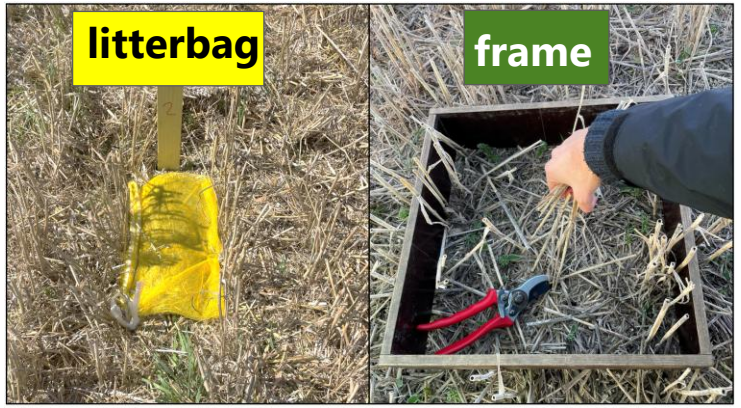
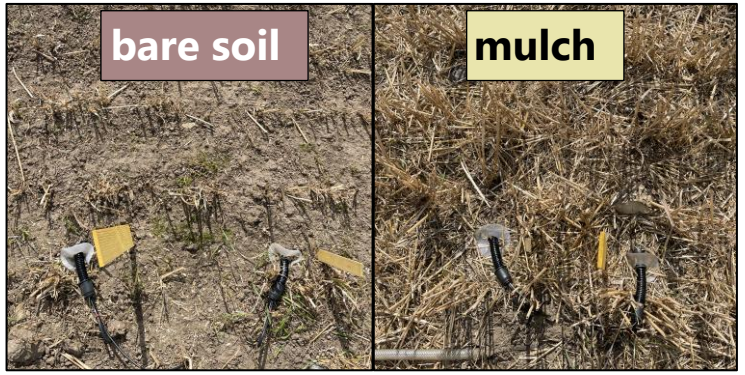
PHISHES PHysically-based Integrated Soil HEalth Simulation platform

Aim of the thesis

Improve understanding and modelling of mulch dynamics in CA

1. Temporal changes in mulch properties (biomass, height, density, cover and CN)
2. Decomposition in litterbags and unrestricted mulch
3. The effect of mulch on soil evaporation
4. Calibration of key mulch parameters in Daisy

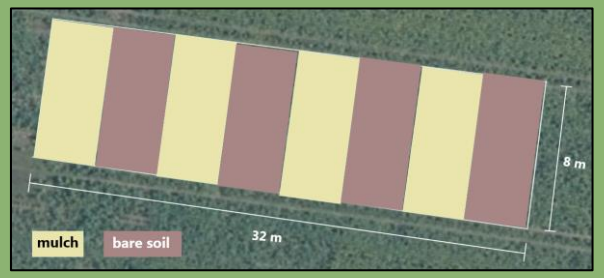




DAISY

Thesis workflow

Data collection



Data analysis in lab




Model setup, calibration & evaluation

DAISY

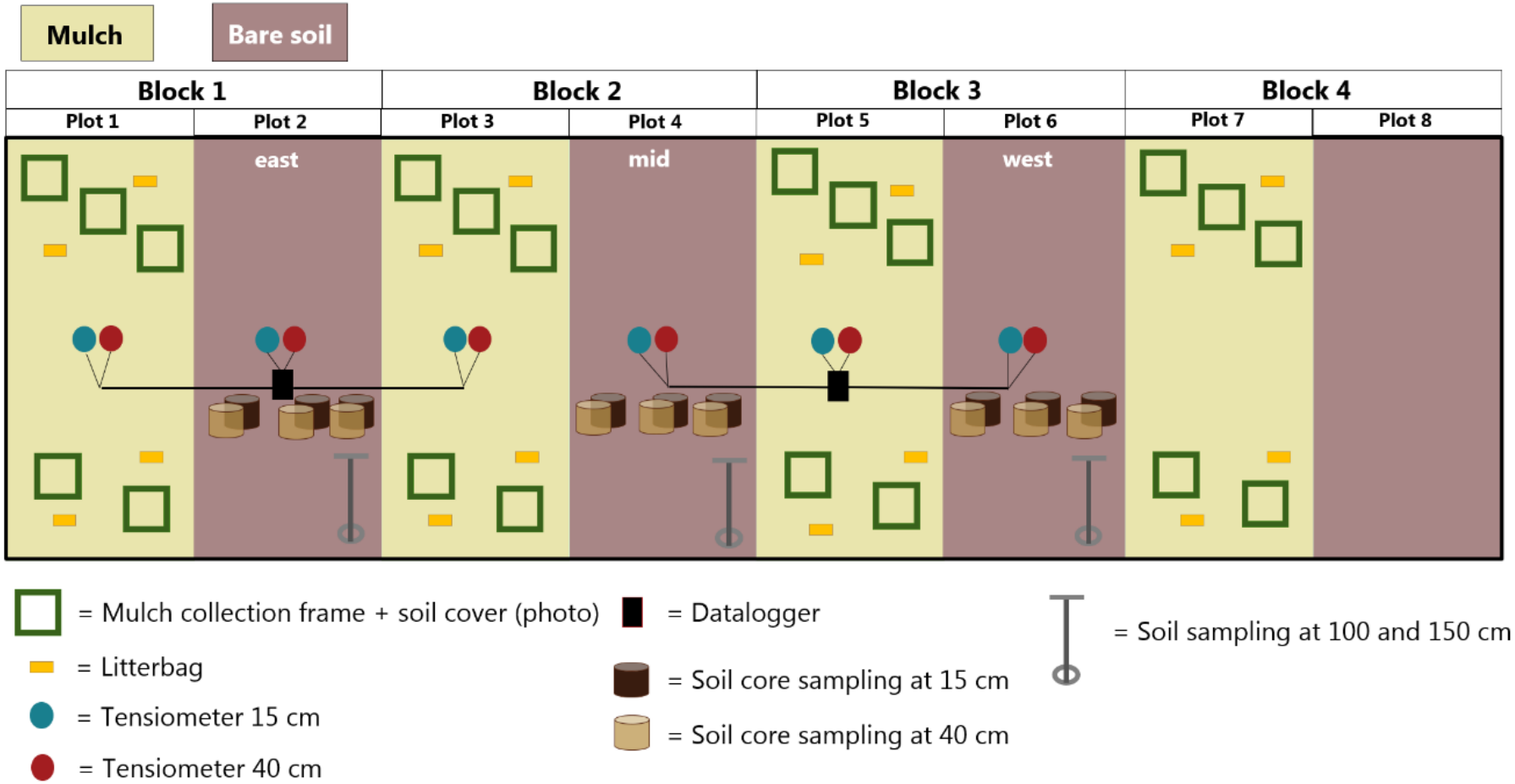
Calibration of Density and R_max, and removal of C_per_N_factor

Study site and design

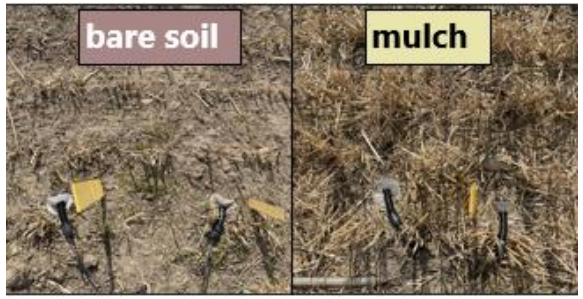
- Field experiment near Haslev, Zealand
- August - November 2025

Collected data:

- Collection frames: mulch biomass, height, cover, and CN ratio
- Litterbags to estimate decompostion with macrofauna excluded
- Tensiometers to monitor soil water tension in mulch and bare-soil plots
- Soil samples for texture and hydraulic properties

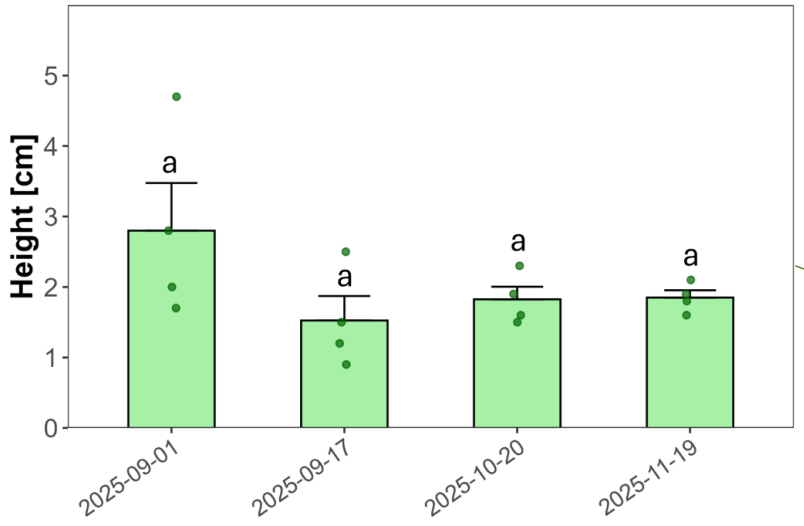


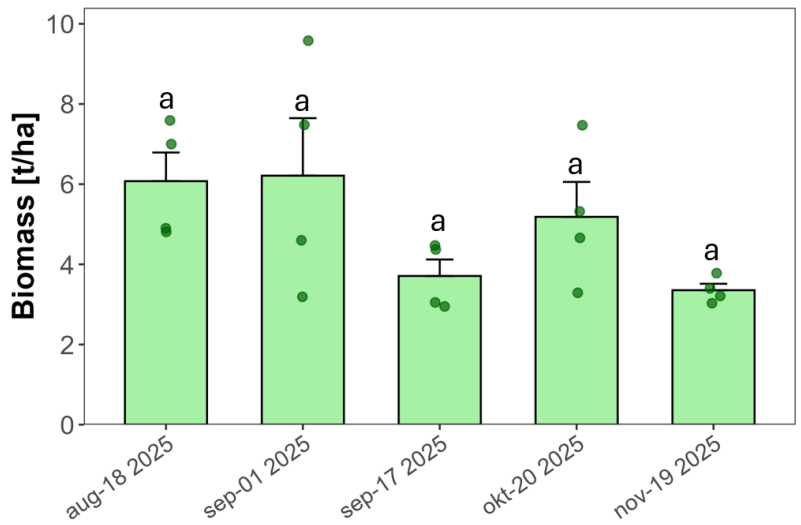
- Two treatments: mulch and bare soil



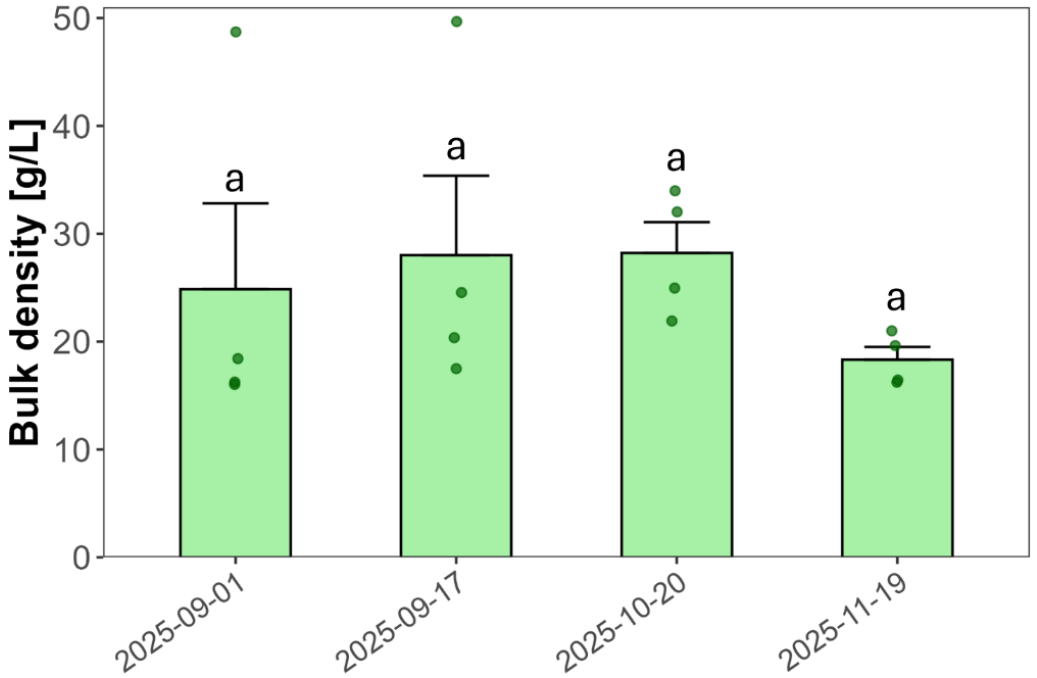
Height, biomass and density

Measurements from collection frame





$$height\ [cm] = \frac{biomass\ [\mathrm{g\ cm^{-2}}]}{density\ [\mathrm{g\ cm^{-3}}]}$$

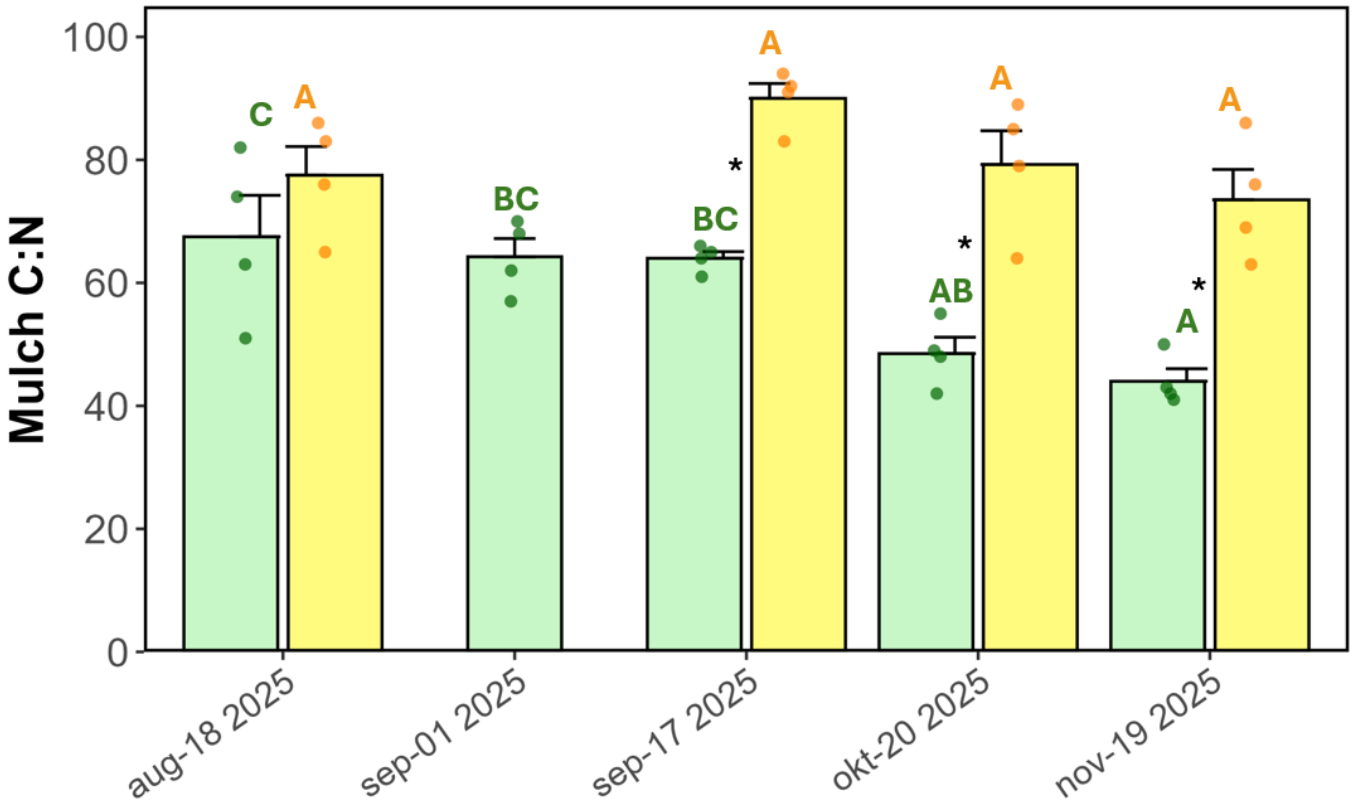


CN

Litterbag CN was relatively stable (around 80)

Collection frames showed decrease in CN ratio over time (68±7 to 44±2)

- Macrofauna-mediated removal or incorporation of high-CN material
- Contrasts with common view in literature, that earthworms grow better on low CN.



Modelling context: CN restriction on bio-incorporation (C_per_N_factor) was removed in the calibration

Relative mass loss

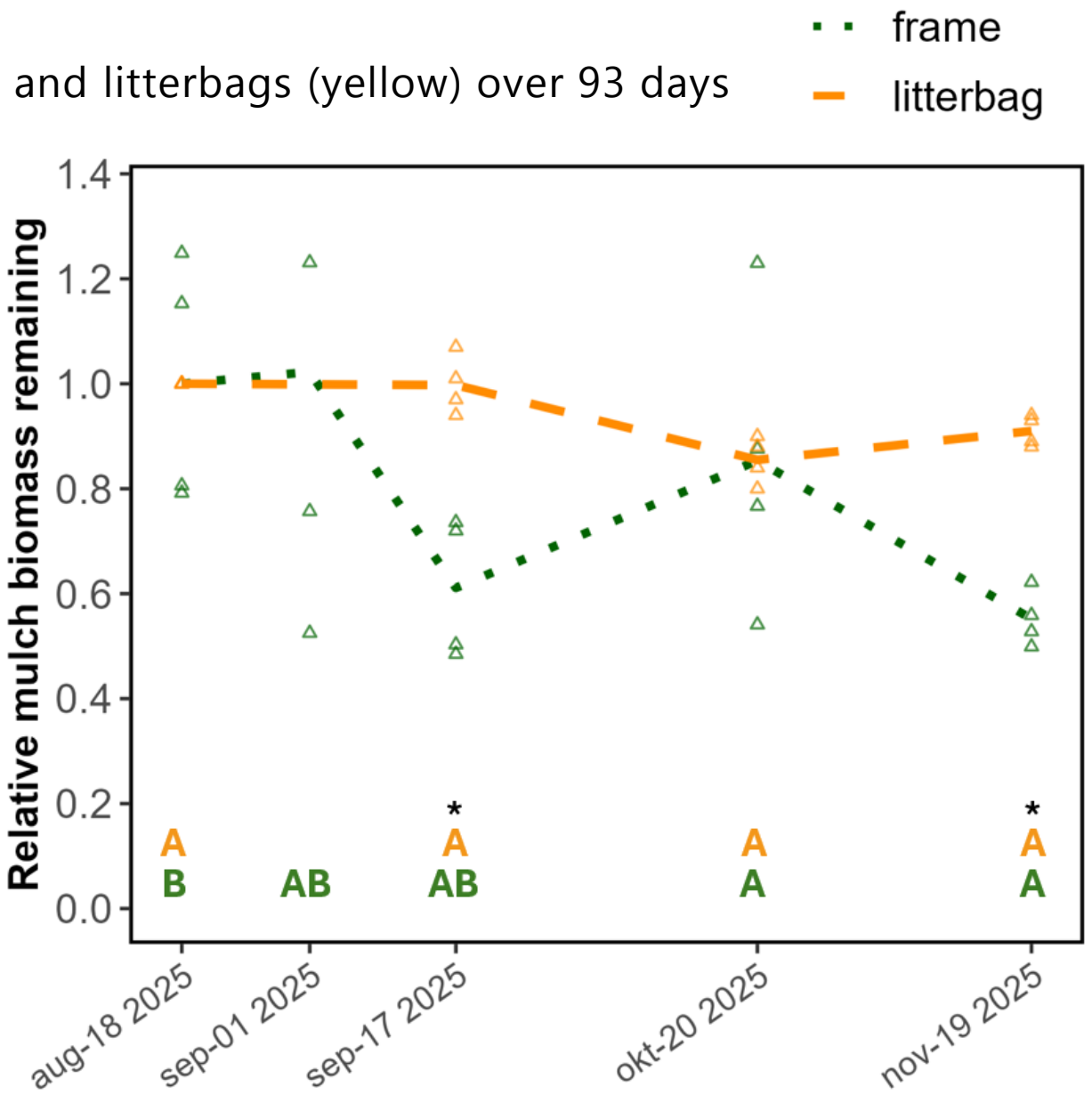
Relative remaining mass in collection frames (green) and litterbags (yellow) over 93 days

Unrestricted mulch lost substantially more mass than litterbags after 93 days:

Collection frames: 55% (45% loss)

Litterbags: 90% (10 loss, not significant)

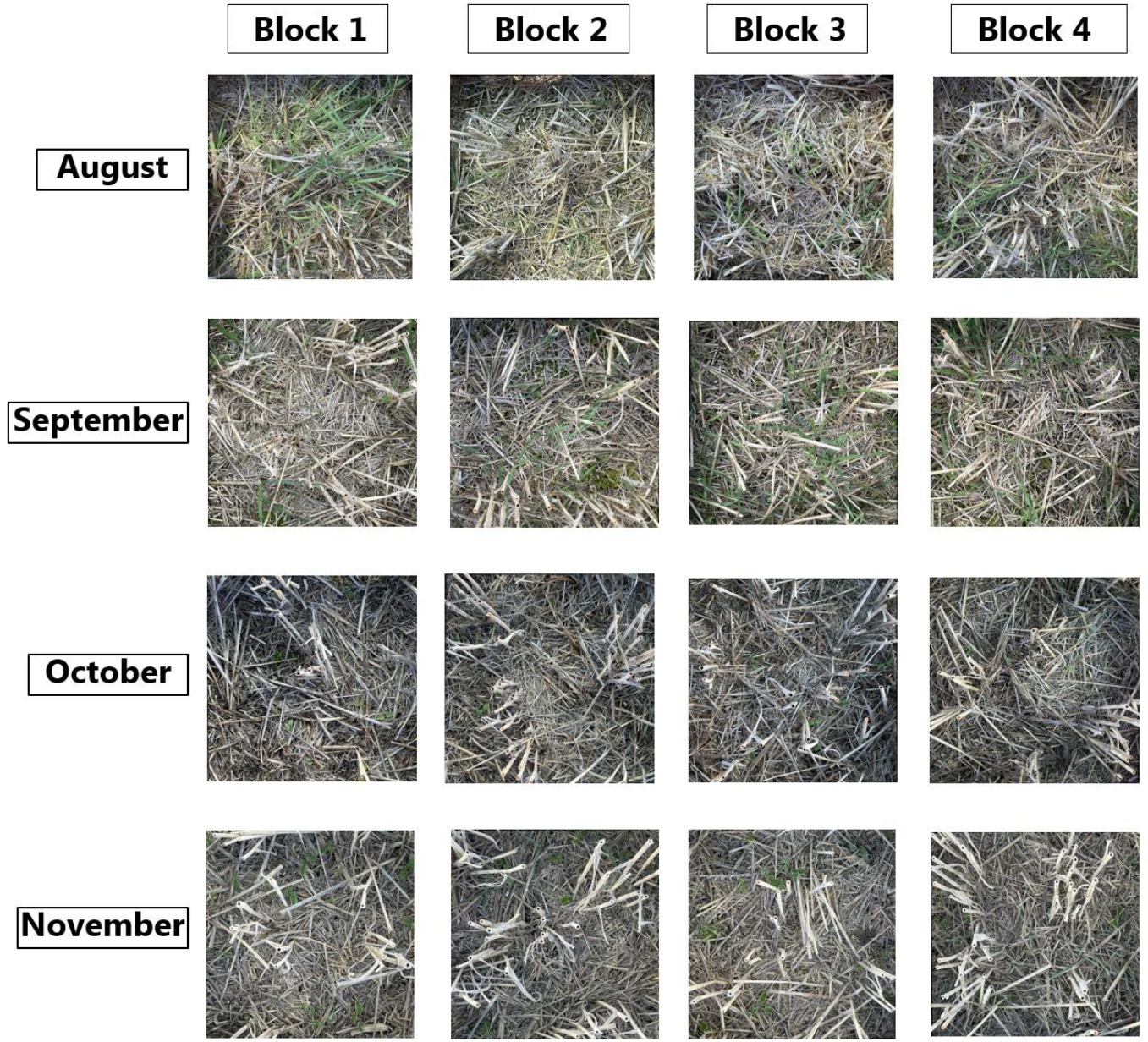
- Similar study found 60% loss after 100 days
  - Conducted in summer:
    - Seasonal component



Cover

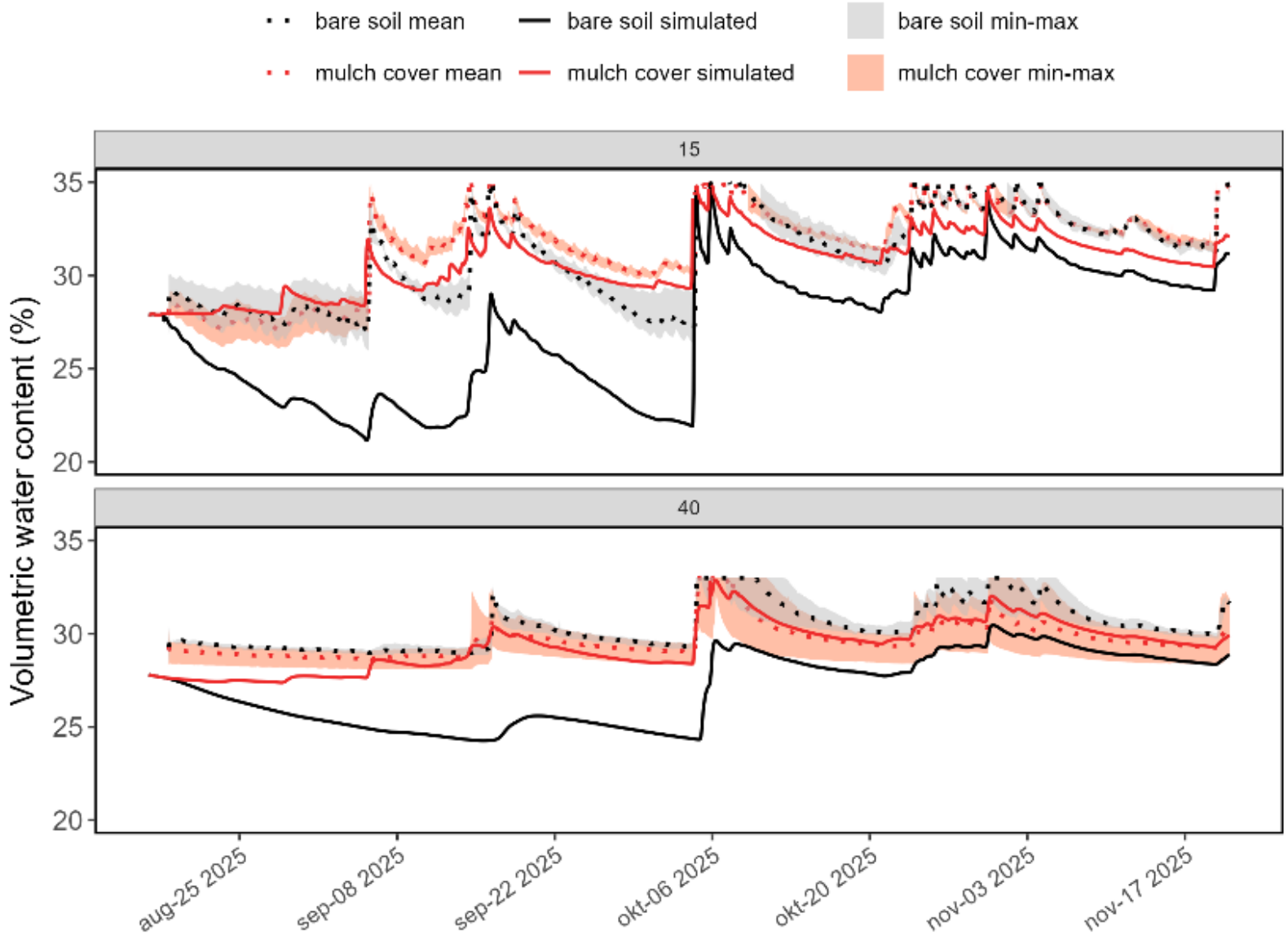
100 % coverage during experiment

Mulch had almost disapeared the previous season in June 2025:



Soil water response

Plot **with simulations** (now the solid lines are simulated, while dotted lines are measured)



Mulch plots generally retained more water than bare-soil plots.

Differences were most visible during drying events in September

- decrease of 4-5 % in VWC in bare-soil plots compared to mulch plots
- largest difference corresponded to 15 mm water loss in bare soil.

This supported the idea that mulch reduced evaporation under field conditions

Calibration strategy

Parameter selection was based on a small sensitivity analysis on 7 mulch-related parameters

Steps:

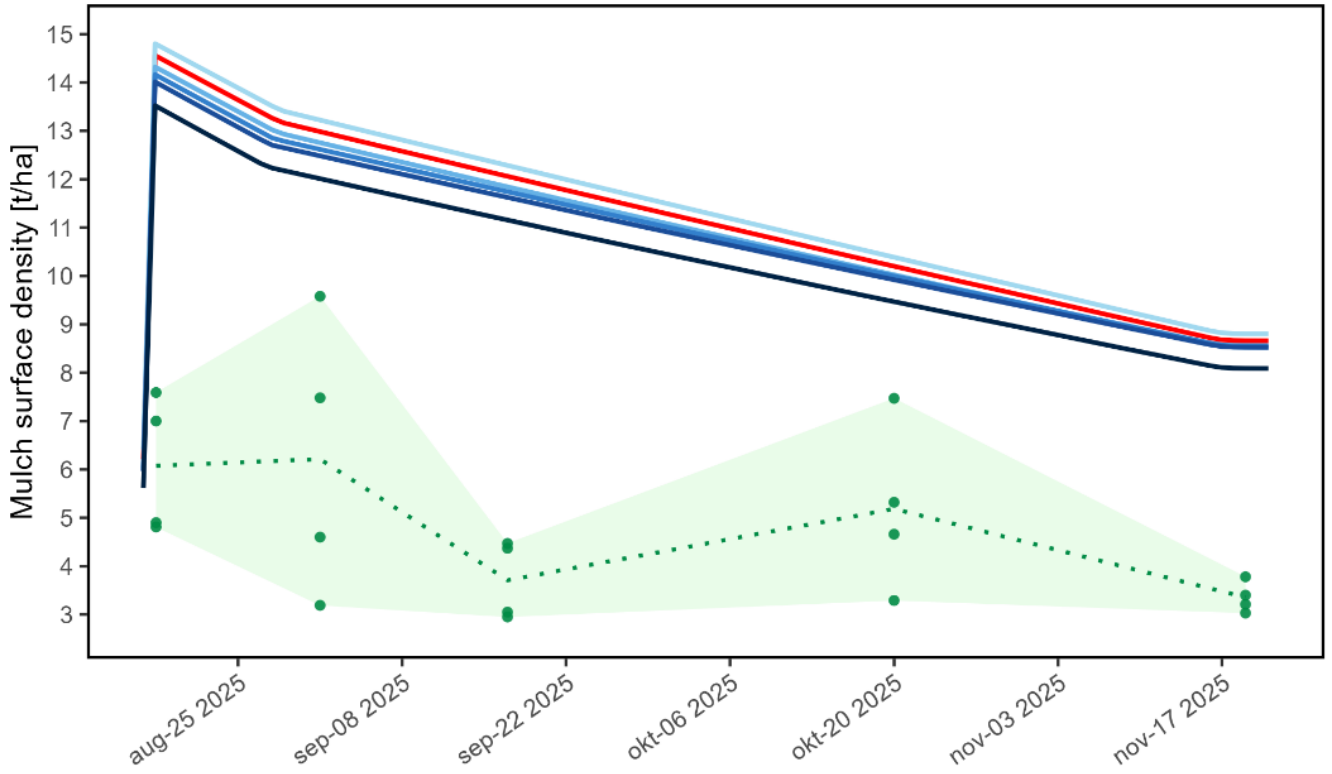
1. Calibrate mulch density.
2. Remove the CN restriction on bio-incorporation.
3. Calibrate the maximum bio-incorporation rate, R_max.

Calibration range for density and R_max:

Submodule	Parameter	Default value	Calibration range (mean±std. dev.)	Notes	Reference
Mulch	**density** [g/L]	15	23 ± 10.4	Field data (mean±std. dev., n =4) from August-November 2025.	See Figure 9
Organic matter	**R_max** [g DM/m^2/h]	0.5	0.146 ± 0.0885	Average based on litterature values of earthworm abundance [/m^2] and litter consumption [g litter/g earthworm/h].	See table 1 and 2

Calibration of density

- Increasing mulch density from 15 g/L to 33.4 g/L improved biomass simulation slightly.

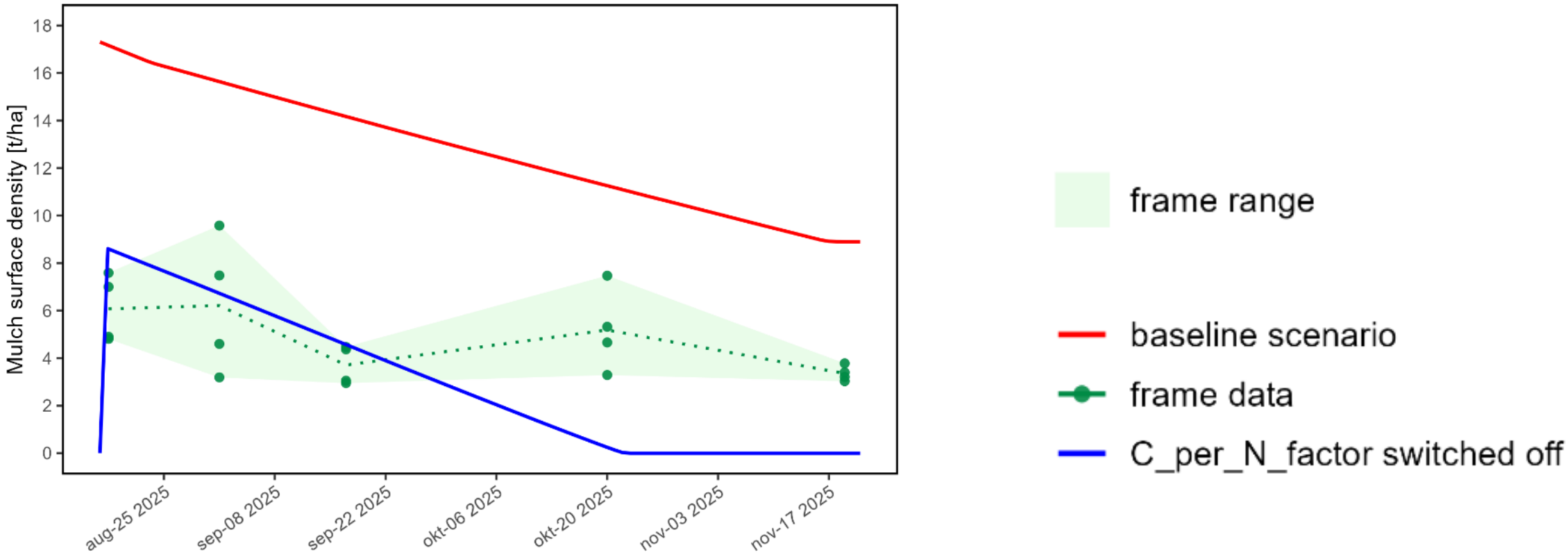


baseline scenario =15 g/L
bulk density = 12.5 g/L
bulk density = 16 g/L
bulk density = 22.5 g/L
bulk density = 28 g/L
bulk density = 33.4 g/L
frame data

Bulk density (g/L)				
date	**mean**	**SE**	**max**	**min**
18-08-2025	15.4	0.5	16.3	14.0
18-09-2025	24.8	8.0	48.7	16.0
30-09-2025	28.0	7.4	49.7	17.5
20-10-2025	28.2	2.9	34.0	21.9
19-11-2025	18.3	1.2	21.0	16.2
mean	**23.0**			
std. dev.	**10.4**			

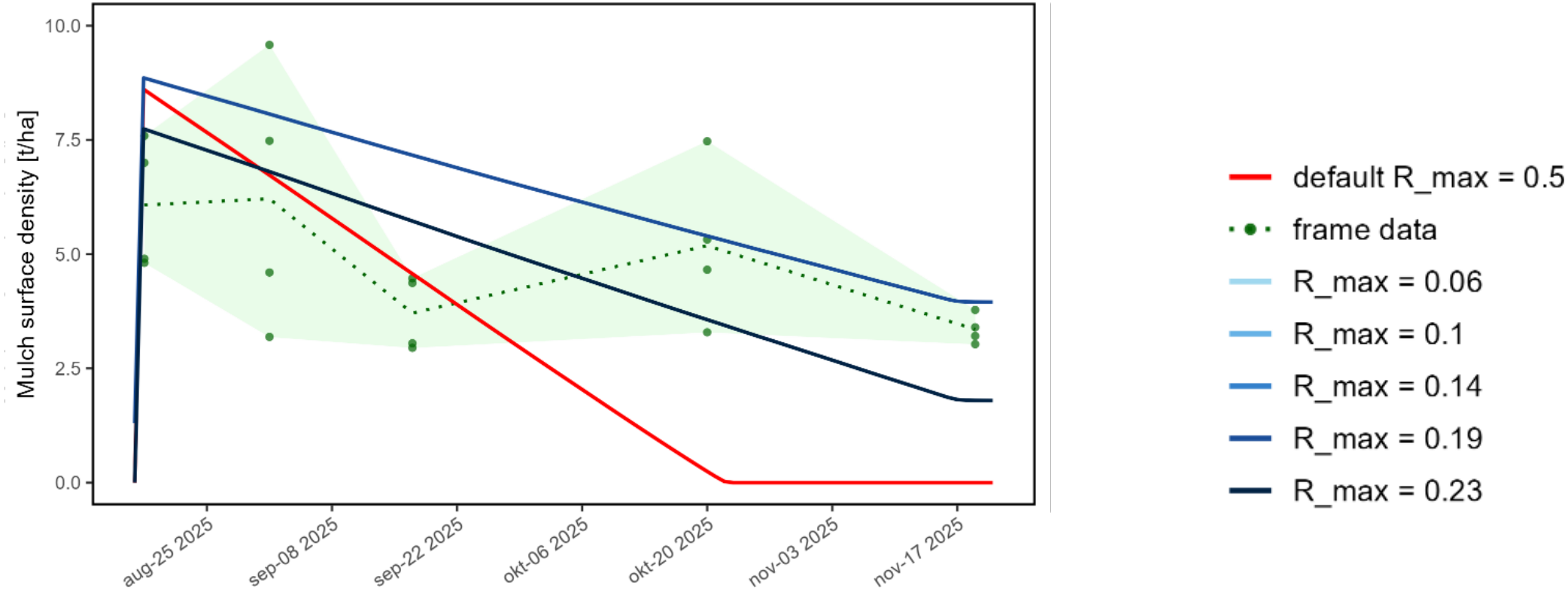
Removing CN restriction (C_per_N_factor)

- The CN restriction on bio-incorporation was removed.
- This allowed stronger bio-incorporation
- Biomass predictions improved substantially after this change.



Calibration of R_max

- R_max was calibrated to fit the biomass observations.
- Best fit was obtained with R_max = 0.19



Evaluation of the calibrated model

Daisy submodule	Parameter name	Default value	Calibrated value	Notes
Mulch	**density** [g/L]	15	33.4	range determined from measured data
Organic matter	**R_max** [g DM/m^2/h]	0.5	0.19	range determined from litterature data

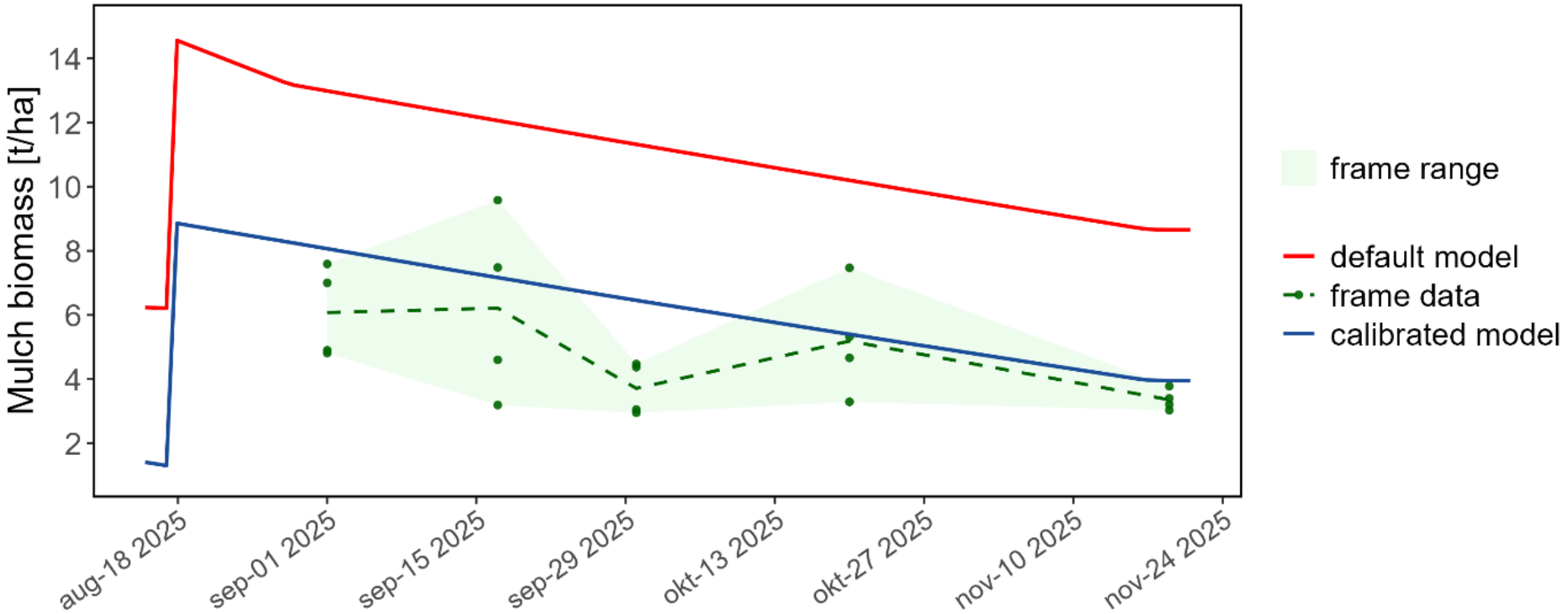
- The calibrated model is compared to the default model.
  Models were evaluated based on RMSE of predicted versus measured values.

- Following outputs were investigated:
  - Biomass
  - Height
  - Volumetric water content
  - CN
  - cover

Biomass evaluation

- Calibration lowered RMSE of estimated biomass from 6.2 t ha^{-1} in the default model to 1.6 t ha^{-1} in the calibrated model

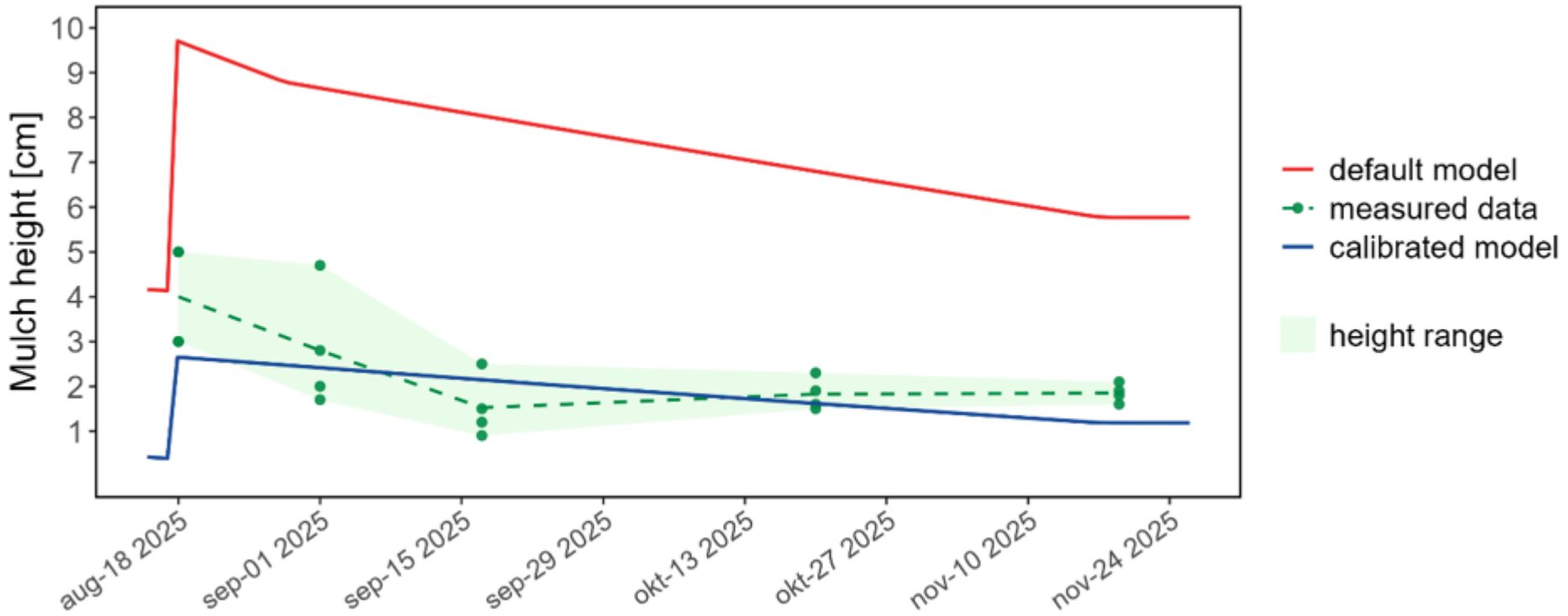
→ **Model improvement**



Height evaluation

- RMSE for the estimated height decreased from 5.0 cm for the default model to 0.9 cm for the calibrated model

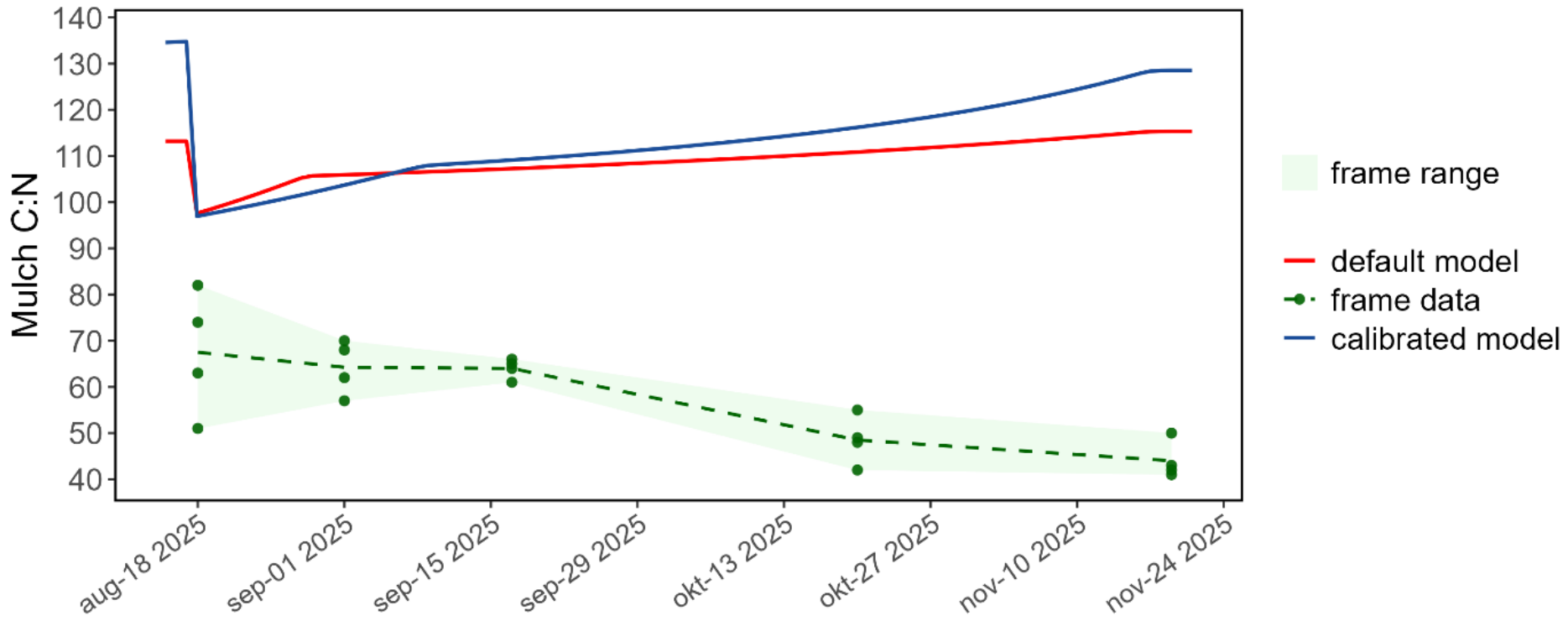
→ Model improvement



CN evaluation

- RMSE for the estimated CN increased from 53 for the default model to 59 for the calibrated model

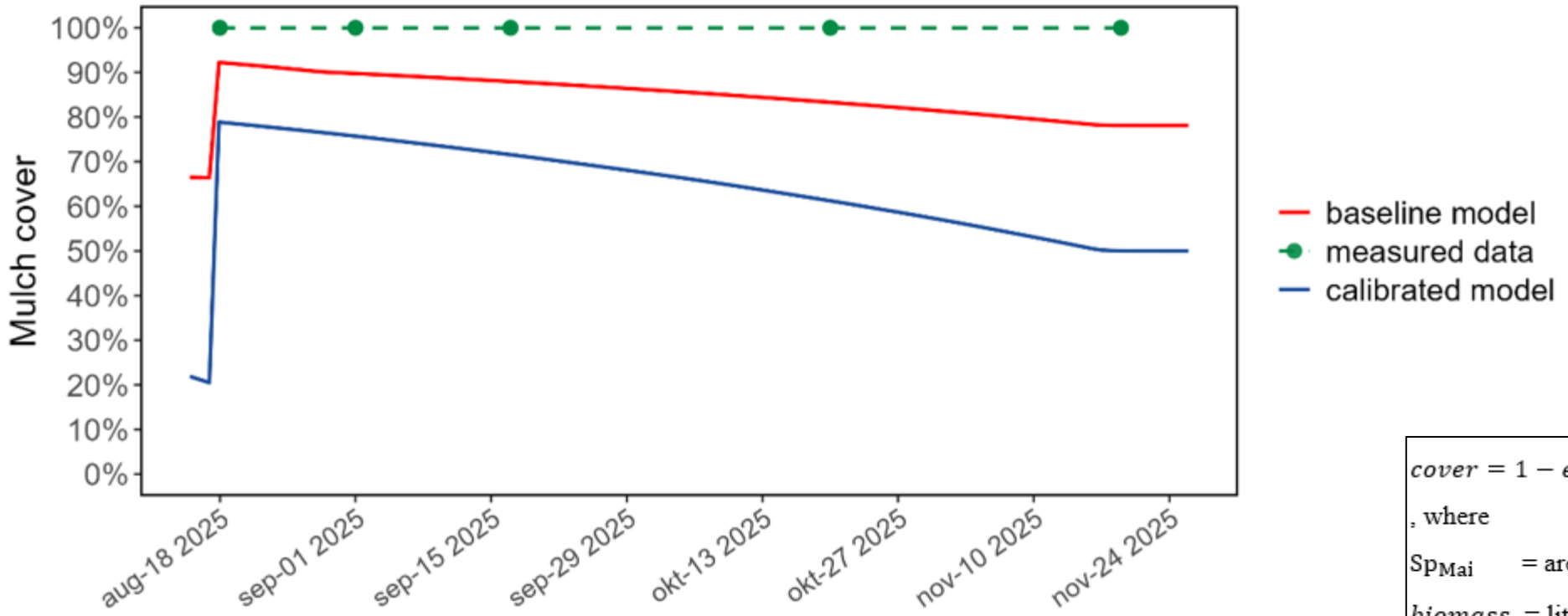
→ Trade-off



Cover evaluation

- RMSE of the estimated cover increased from 16% to 36% after calibrating the model

→ Trade-off



$$cover = 1 - e^{\gamma \, Sp_{Mai} \, biomass}$$

, where

Sp_{Mai} = area covered per kg litter [m^2 cover kg^{-1} DM]

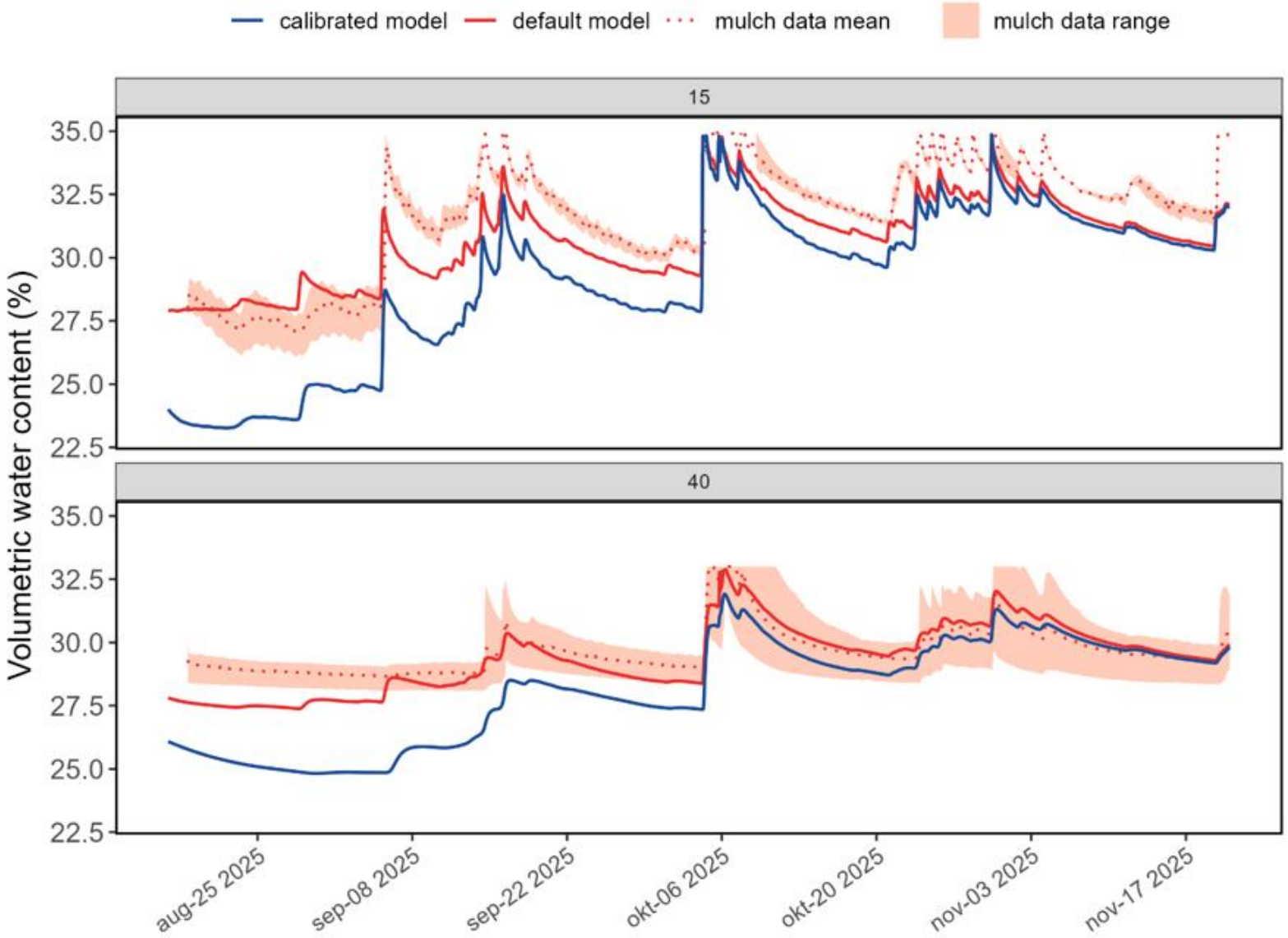
$biomass$ = litter biomass per surface area [kg DM m^{-2}]

γ = extinction coefficient [–]

Soil water evaluation

- Model performance on soil water predictions under mulch conditions **decreased** after calibration, with RMSE of VWC increasing from 1.3 to 2.8 %

→ **Trade-off**



Main conclusions

- Mulch is highly dynamic; however, longer experiment duration or a larger setup is needed to capture temporal effects of biomass, height, density, and cover

- Field data showed clear differences in CN and mass loss between unrestricted mulch and litterbags

- Improvements and trade-offs from calibration of mulch-related parameters
  - improved simulated biomass and height
  - weakened CN, cover and soil water predictions

Future work

Explore whether biomass, cover, and soil water can be balanced simultaneously.

Explore parameters linked to cover dynamics and microbial decompostion

parameters related to cover:
- specific_AI
- extinction_coefficient

Parameters related to deomposition:
- Decompose_SMB_KM
- decompose_height

A selection of parameters from the mulch model:

Name	Name in Daisy reference manual	Explanation	Value for the modelling setup	Daisy default value	Unit
ρ_M	density	Bulk density of the mulch layer	15	user specified	[g/L]
$f_{M,w\text{-}ext}$	factor_exch	Limiting factor when calculating Darcy exchange between mulch and soil.	0.15	user specified	[ ]
Θ_{res}	Theta_res	residual water content mulch [%], referred to as the sheltered storage	0.044	user specified	[ ]
K_M	decompose_SMB_KM	Michaelis-Menten parameter for AOM-turnover	0.000364	0	[g C/cm^3]
	T_ref	Reference temperature for deacy. heat factor = 1 at this temperature	25	10	[ ]
α	alpha	Interception parameter	1.86	0	[ ]
	water_capacity	Water holding capacity of surface residues	2.44	user specified	[L/kg]
	decompose_height	Height of mulch considered in contact with the soil. Only this will decompose	0.6	user specified	[cm]
ΔZM	soil_height	Height of soil layer (a negative number) contributing to decay	-5	0	[cm]
Sp_{MAi}	specific_AI	area covered per kg litter	3.9	depends on model (Maize, Millet, mulch)	[m^2/kg DM]
y	extinction_coefficient	Beer's law extinction coefficient for litter	0.45	depends on model (Maize, Millet, mulch)	[ ]

Thank you for listening!

Questions?

Daisy's mulch module – a litter model

- The mulch is a decomposing surface layer
  - Mulch fate is determined by bio-incorporation and tillage, but also microbial processes
- The mulch layer is hydraulically connected
  - Has its own retention curve and can exchange water with the soil