UNIVERSITY OF HOHENHEIM

Institute of Agricultural Sciences in the Tropics
(Hans-Ruthenberg-Institute)

Implementing ecological functions in a land use change model to assess impacts of crop expansion and overstocking in a Kenyan savanna

Benjamin Warth

Carsten Marohn, Folkard Asch

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Knowledge gaps

Awakening the sleeping giant (Morris et al., 2009)
Does large-scale conversion of African savannahs to cropland generate negative ecological impacts?

Vegetation effects
→ cultivation effects on erosion
→ enhanced SOM turnover and decreasing SOC stocks
→ overgrazing of remaining rangelands
→ reduced grass competition → bush encroachment

Effects on animals
→ altered feed composition → livestock nutrition and productivity

Management strategies
→ herd composition, herd mobility, fodder supply and residue management

Land use change (LUC) is difficult to be tested in the field for a landscape
→ application of **process-based modelling**

Socio-ecological model coupling

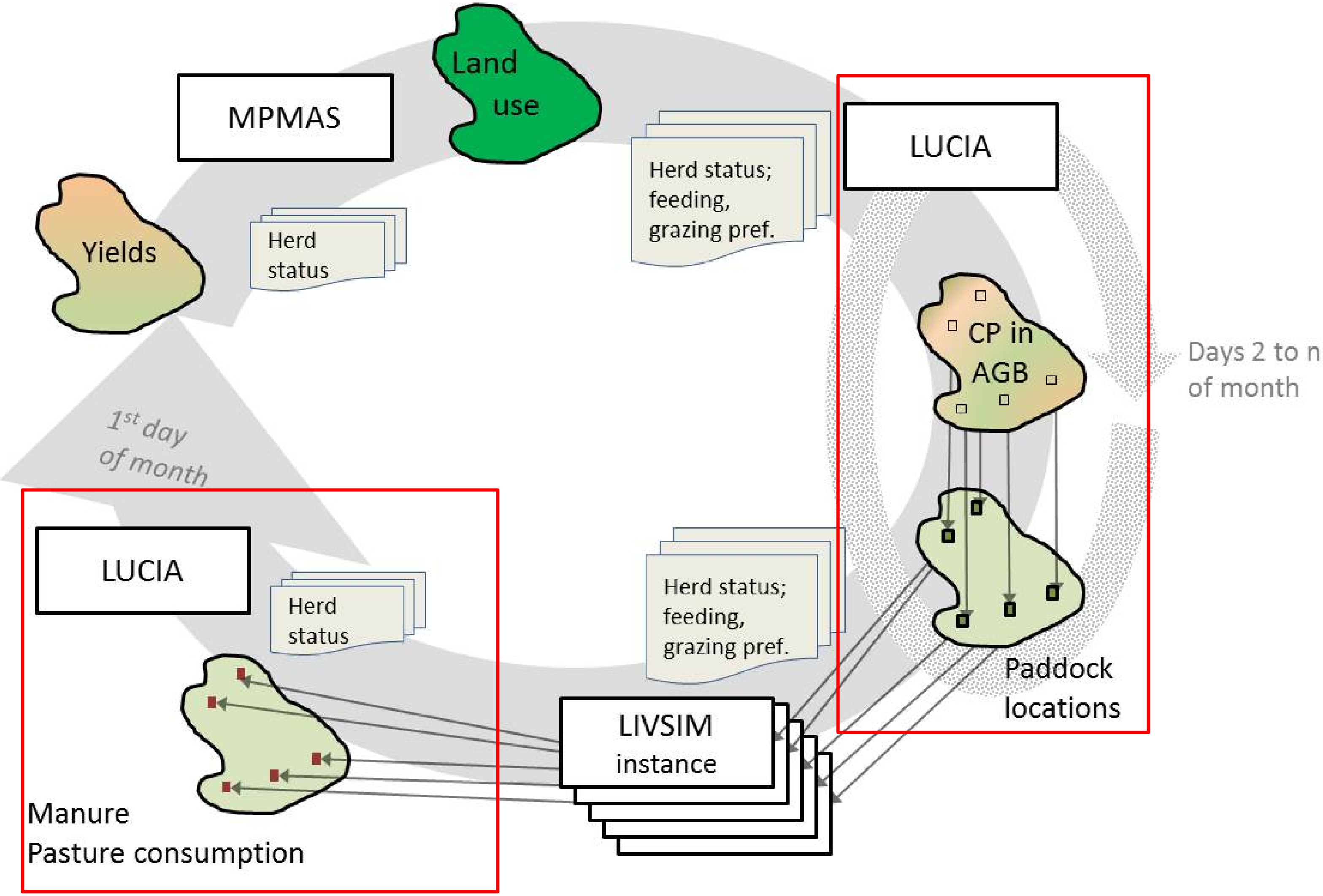
Coupled models

Crop-Economic
LUCIA-MPMAS
(Marohn et al., 2013; Berger et al., 2017)

Animals
LIVSIM
(Rufino et al., 2011)

LUCIA-LIVSIM

Need for plant-animal interaction functions in **LUCIA**



LUCIA model

Land Use Change Impact Assessment tool
(**LUCIA**, lucia.uni-hohenheim.de)

LUCIA

- Spatially distributed landscape model

Model development idea

Integrate crop model and ecological model concepts

LUCIA model development

WOFOST concept

- Annual crops
- Leaves drive plant growth

Trees

- Perennial woody vegetation
- Tree architecture

Plant competition

- For light, water, NPK
- Individual plant dimensions & overlaps

Perennial herbaceous plants such as grasses are needed
- React to grazing

Research question

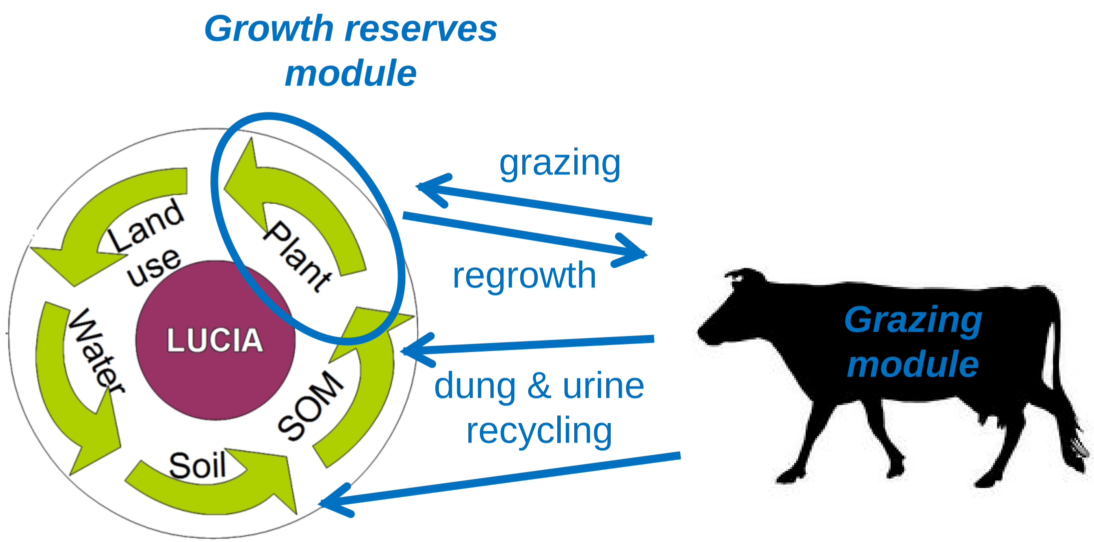
Assess impacts of crop expansion into rangeland on ecosystem functions over 10 years

Specific objectives

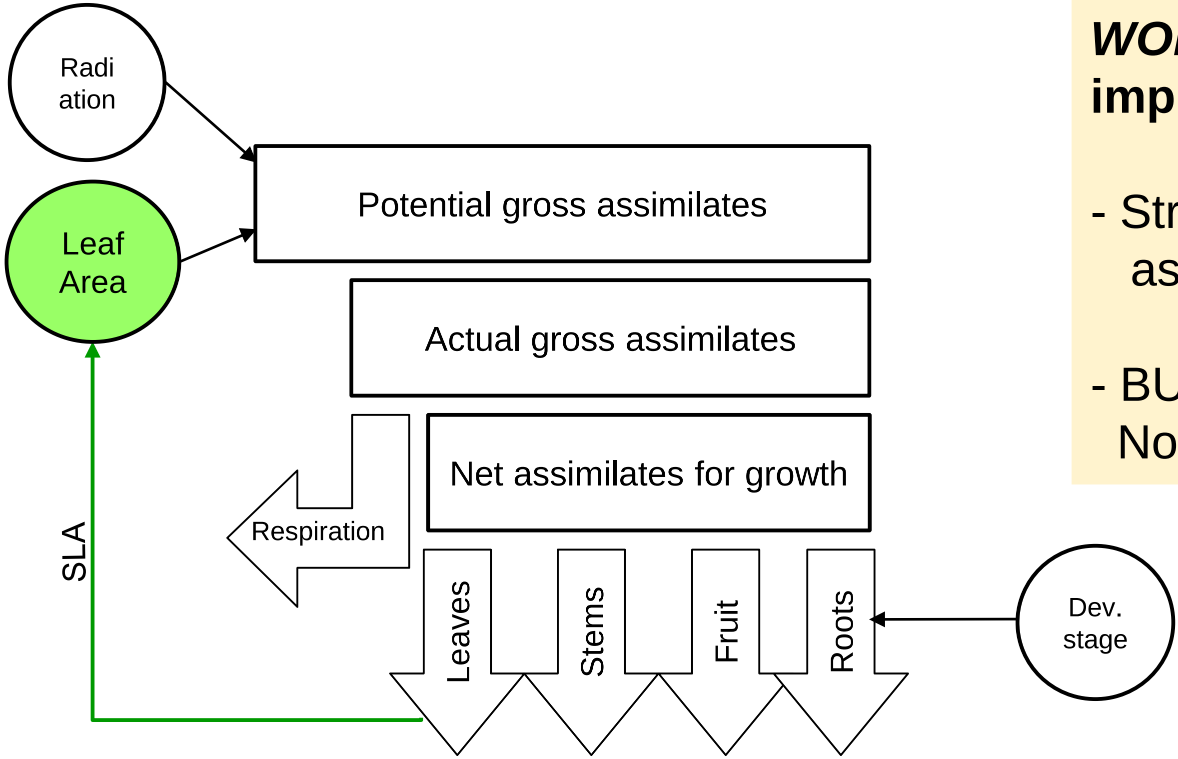
1.) Integrate and test a **(1) grazing module** and **(2) growth reserves module** to simulate pasture-based land use systems where plants react to defoliation

2.) Simulate LUC patterns by running scenarios

3.) Test plausibility of the grassland modules under crop expansion and overstocking at landscape scale: grass AGB, soil organic carbon (SOC)



Growth reserves concept

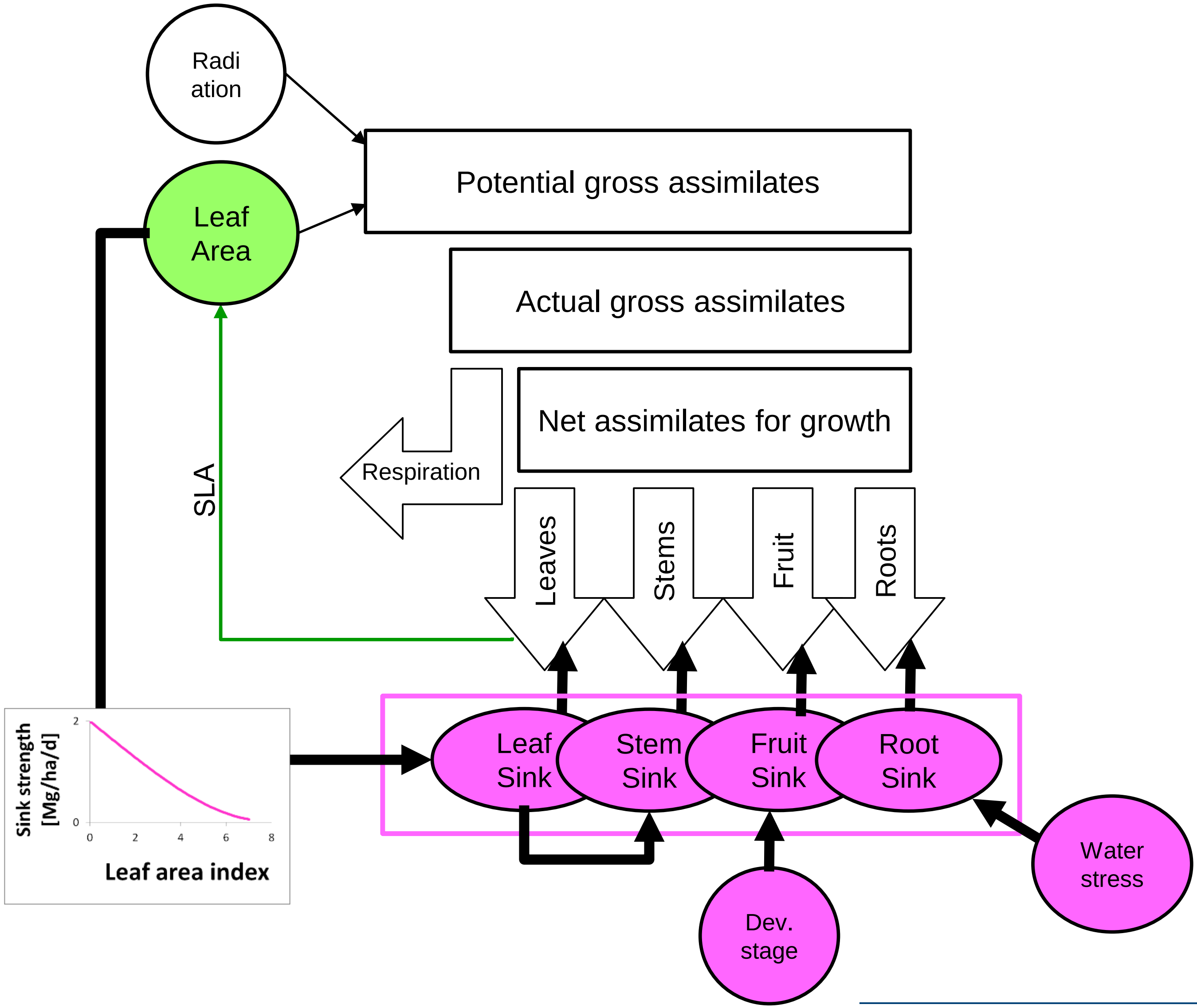


***WOFOST* concept currently implemented**

- Strong feed-back of leaf growth to assimilation, producing more leaves

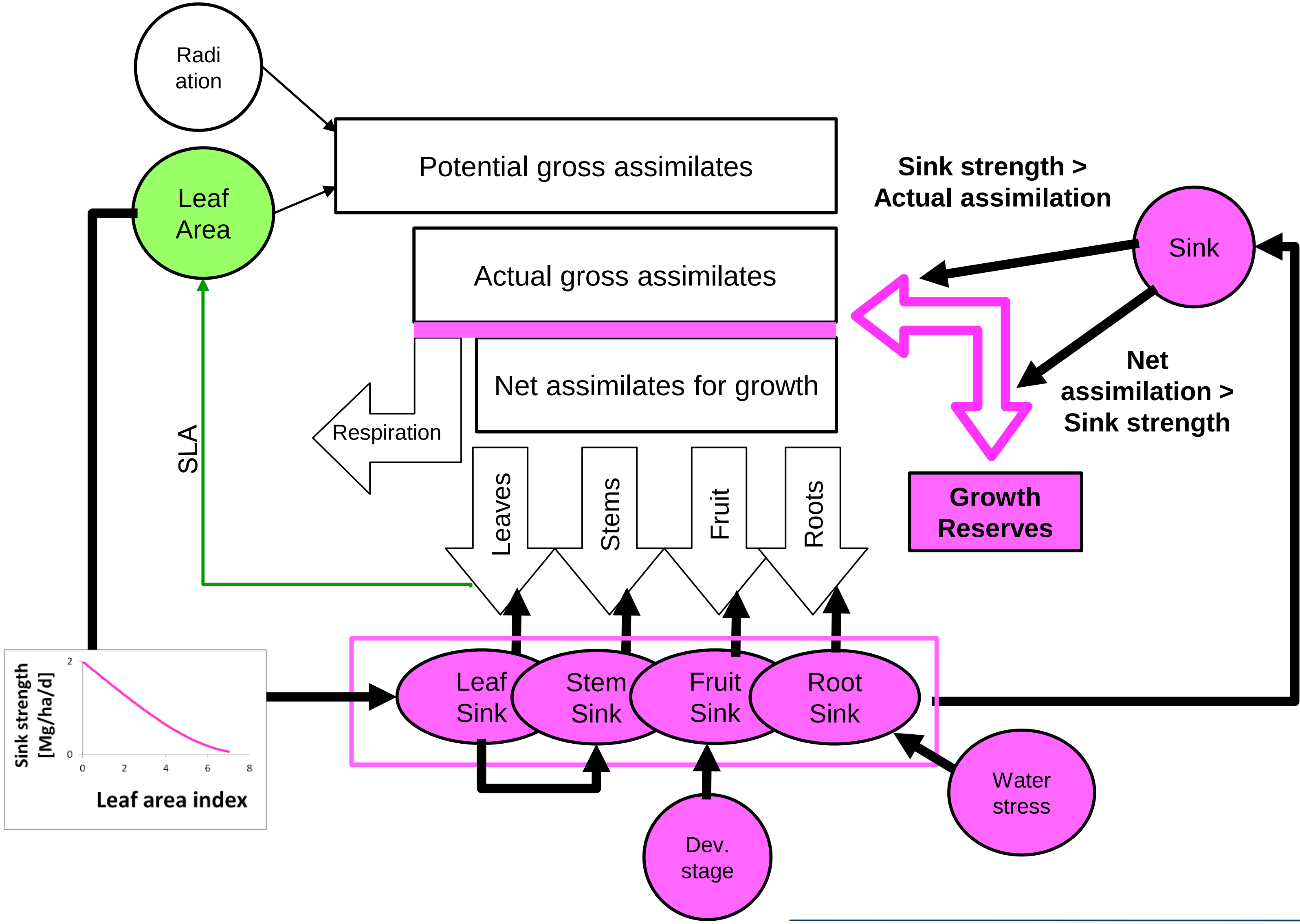
- BUT:
  No leaf area, no growth

Growth reserves concept



Sink-source concept:
- active sinks regulate growth
- leaf sink strength decreases with increasing leaf area
- root sink increases under water stress

Growth reserves concept

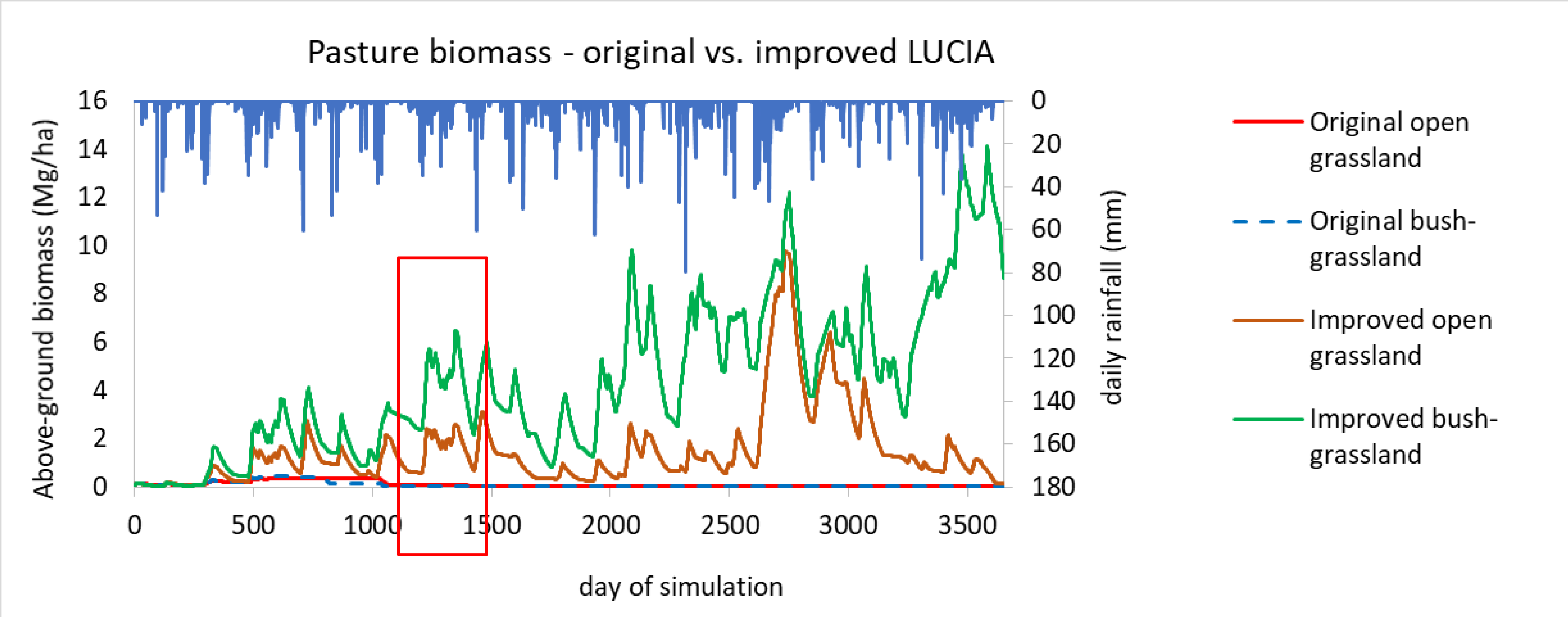


Sink-source concept:
- active sinks regulate growth
- leaf sink strength decreases with increasing leaf area
- root sink increases under water stress

Sink dormancy under low water availability

Plant death when leaf area & reserves = 0

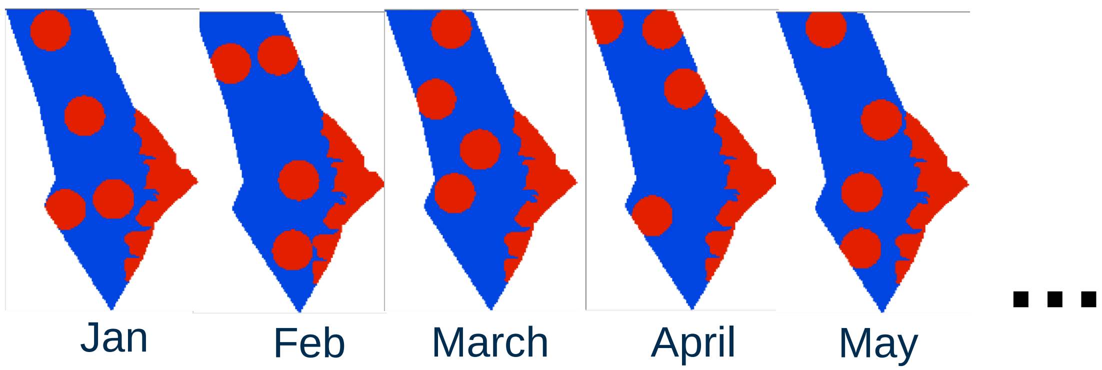
Growth reserves implementation



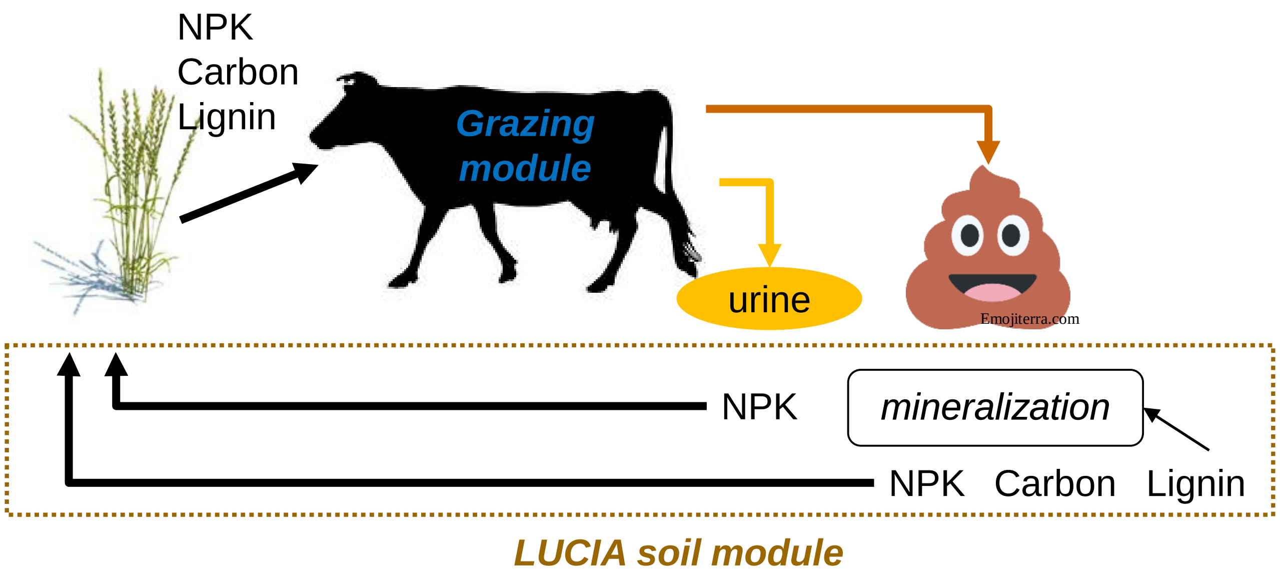
Reserve pool allows pasture regrowth after drought and grazing

Grazing concept

Herd rotation maps



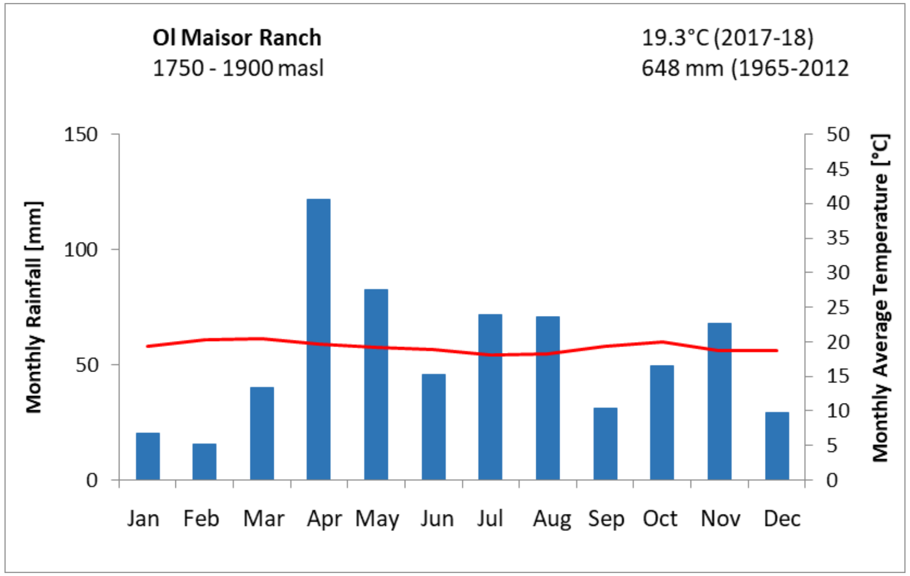
- Monthly shifting grazing locations, according to farmers management practice
- Considering dry and wet season water sources and grazing areas



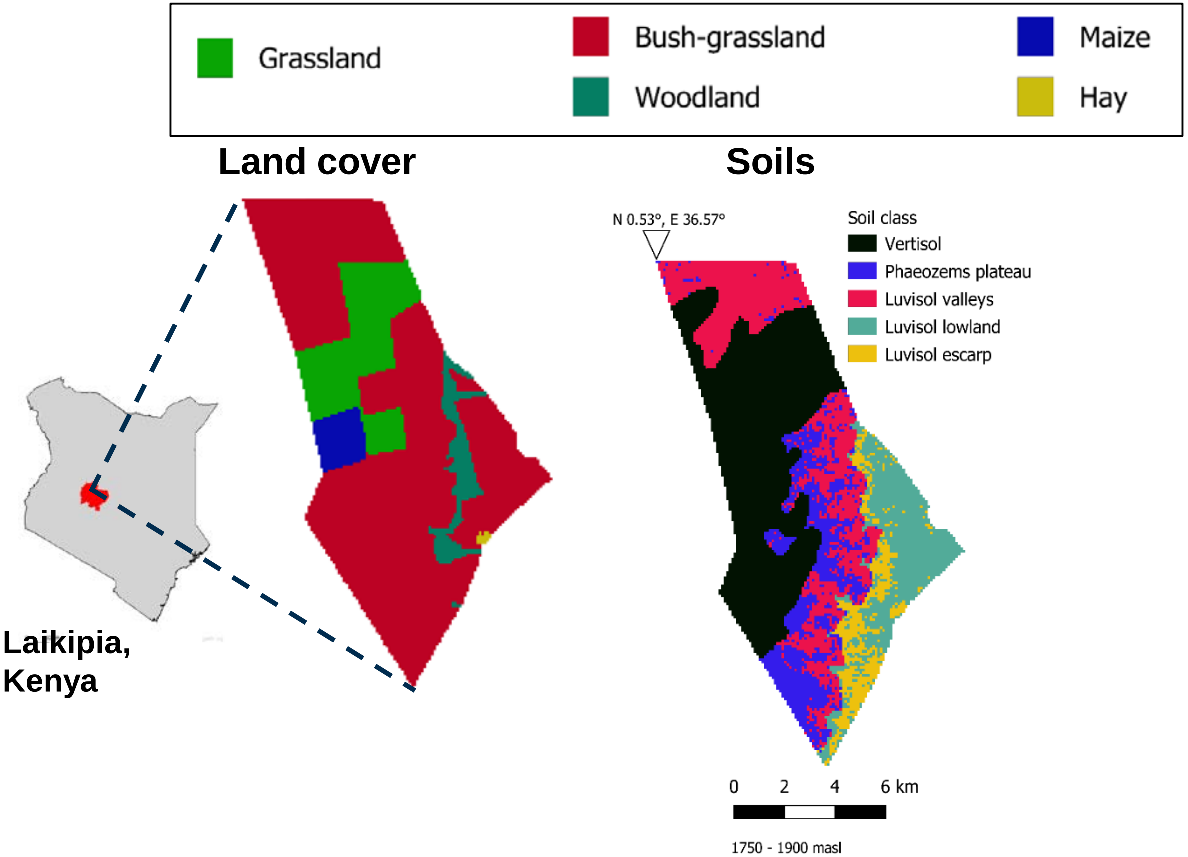
- Constant herd size, weight and max herbage offtake (3% body weight)
- Dynamic plant nutrient contents
- Constant fractions of intake excreted

Case study

- 11,500 ha semi-arid savannah in Laikipia, Kenya (N 0.53°, E 36.57°)
- Natural vegetation from open grassland to dense bush- and woodland
- Soils: 'black cotton soil' (60% clay) & 'red loam soils' (30-60% clay)



Evans, Ol Maisor Ranch



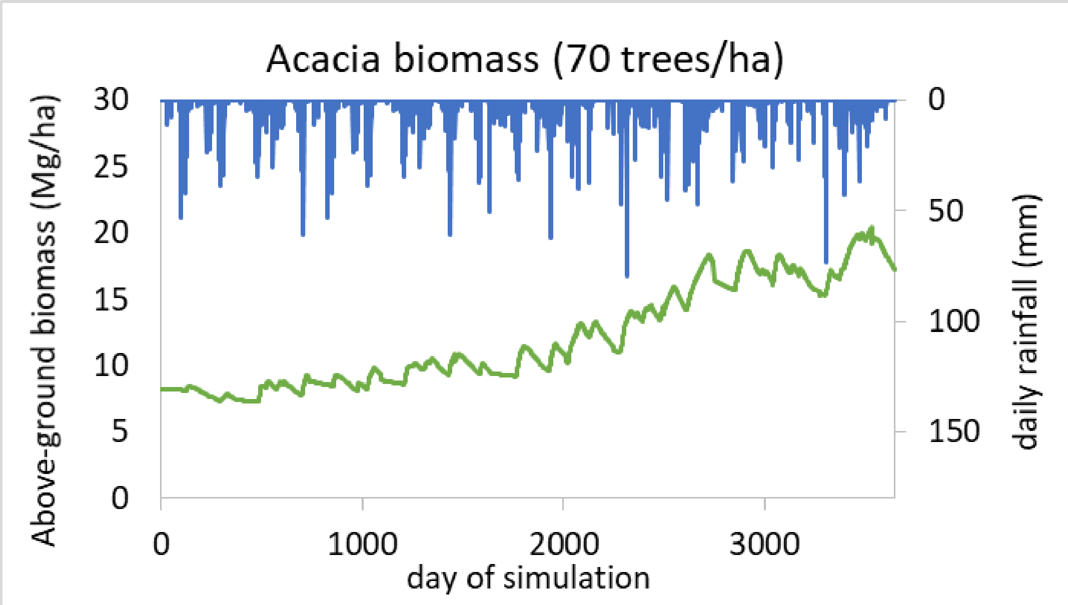
Soil map - own data: texture, SOC, N
Land cover map: Evans, Ol Maisor Ranch

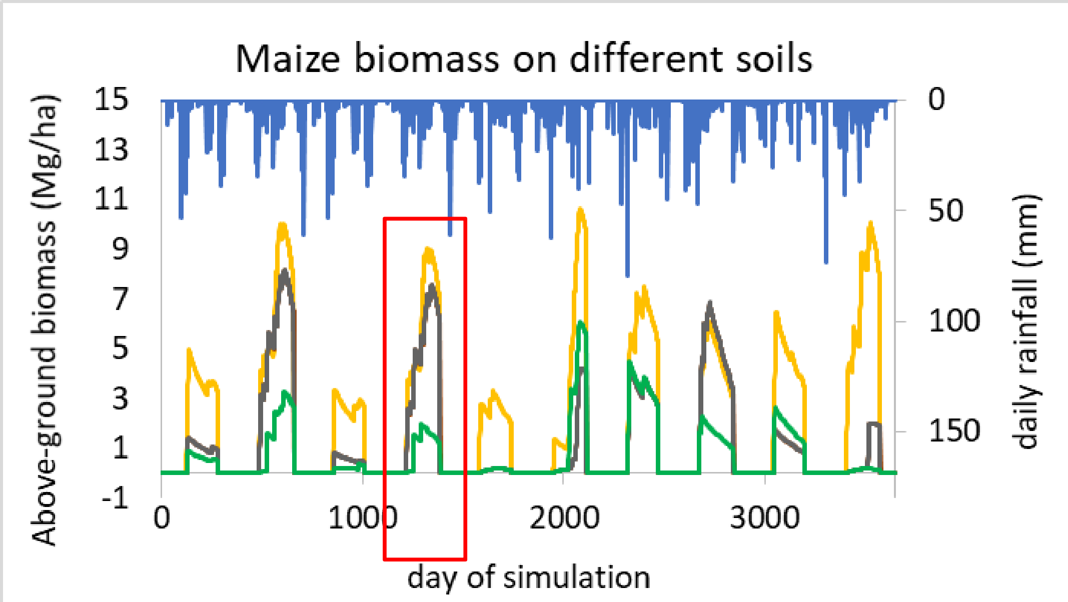
Model validation

- Pasture grass growth was overpredicted
- Hay grass growth was underpredicted
- Grass AGB shows realistic seasonal dynamic and responds to rainfall variability and grazing

Year 2018	observed	predicted
Peak grass AGB Mg/ha	2.0	4.1
Maize AGB harvest Mg/ha	19.1	6.4
Hay cut Mg/ha	8.0	6.6

Field data
- Pasture AGB around 2 corral sites
- Maize biomass & yield
- Hay cut (Evans, Ol Maisor Ranch)
- tree size and stand densities





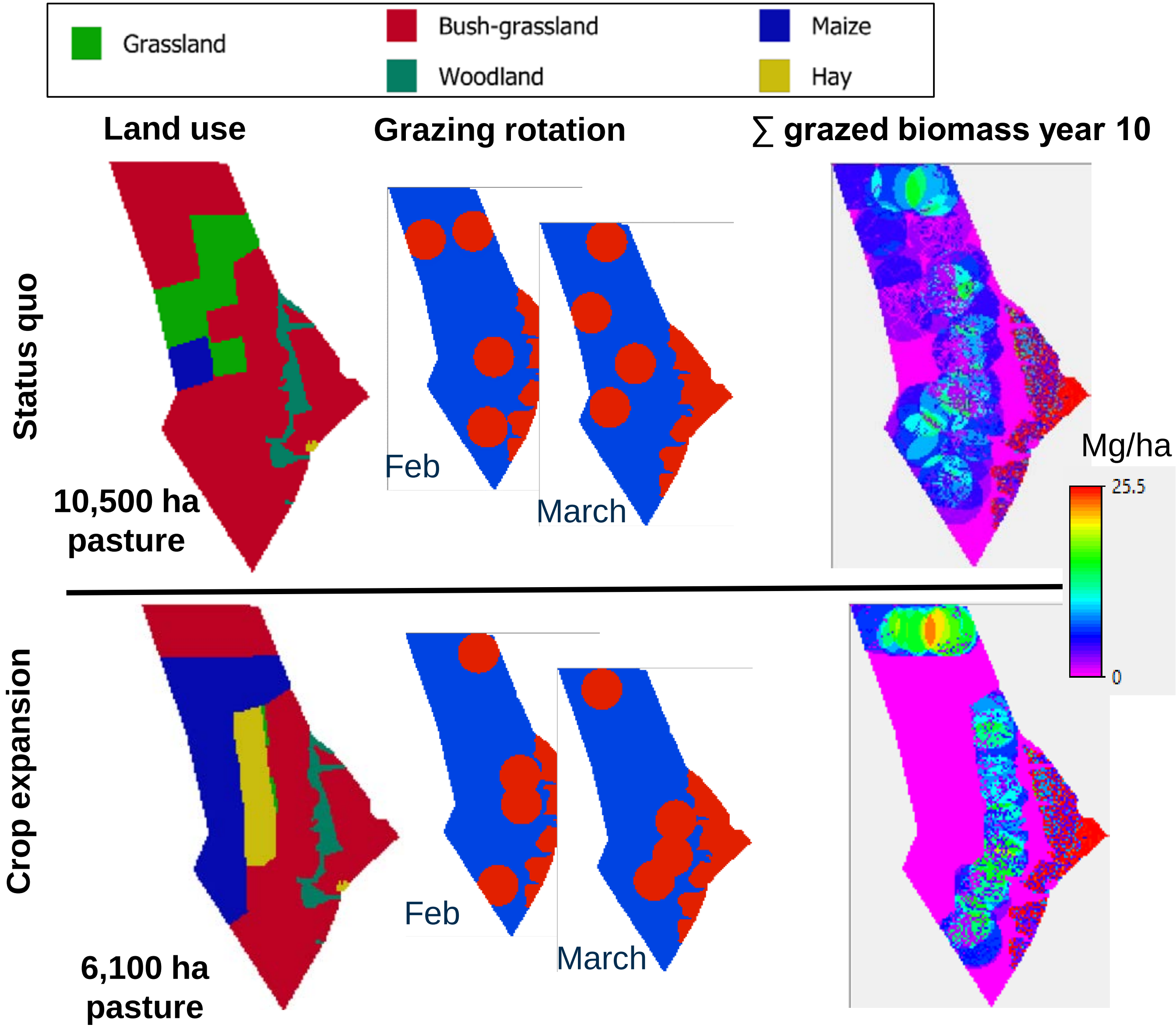
Model scenarios

- **daily** time step
- **100m** grid resolution

- **10 year** model runs
- 4 corrals with 600 cattle each
- Monthly shifting corral locations
&
- 1800 cattle continuously grazing
- excrement N: 5-10 kg/ha
- Maize N fertilizer: 100 kg/ha

Crop expansion vs. Status quo

→enhanced herbage offtake



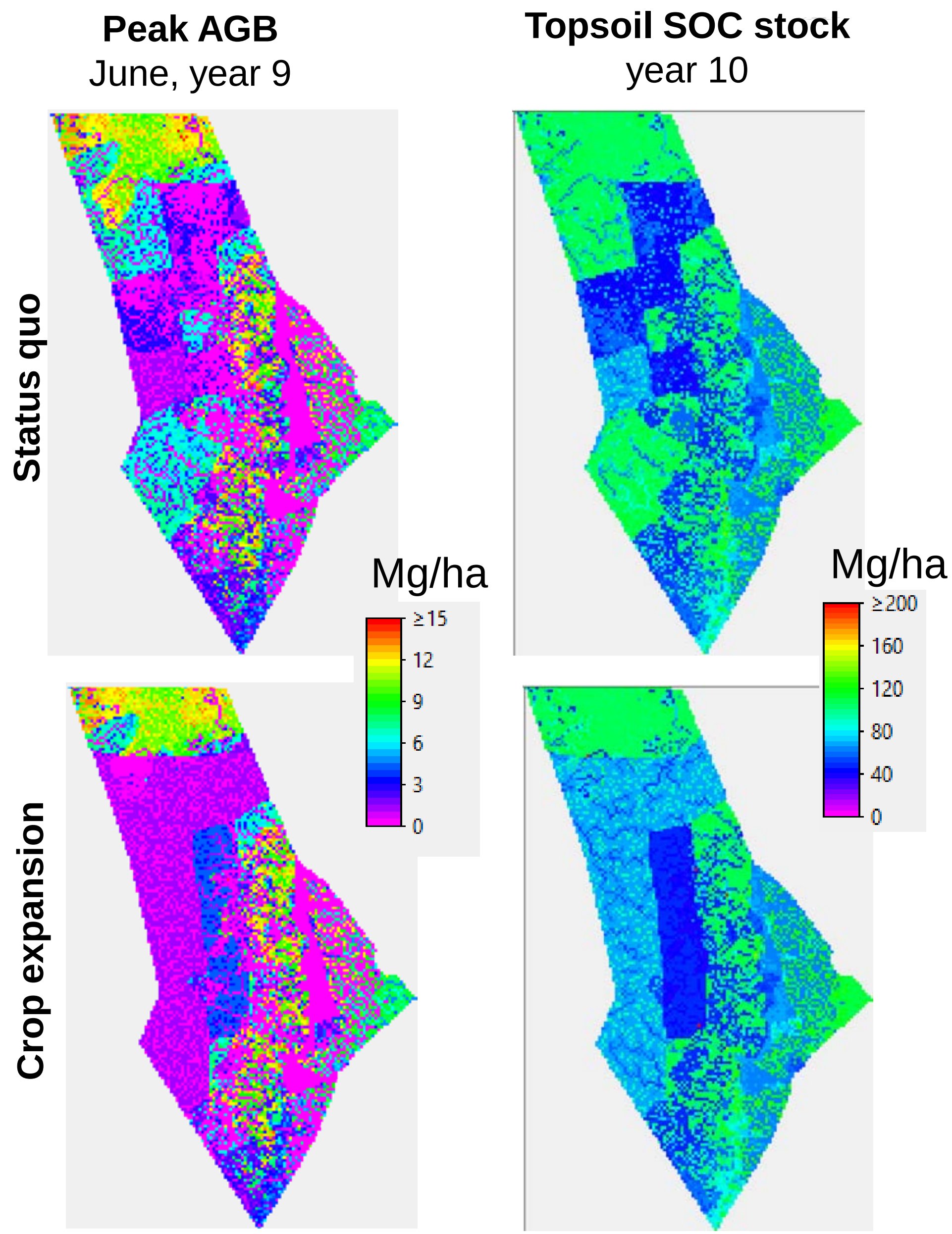
Results

In **crop expansion scenario**…

- higher herbage offtake/ha from pasture…
→ no additional pasture degradation and topsoil SOC decline

- SOC increases under maize after conversion of open grassland
- But is lower compared to bush-grassland
→ because:
- Maize residues left on fields
- bush-grassland > Maize > open grassland biomass productivity

- Erosion is low (< 0.01 cm), despite increase in erodibility under maize due to tillage and low cover

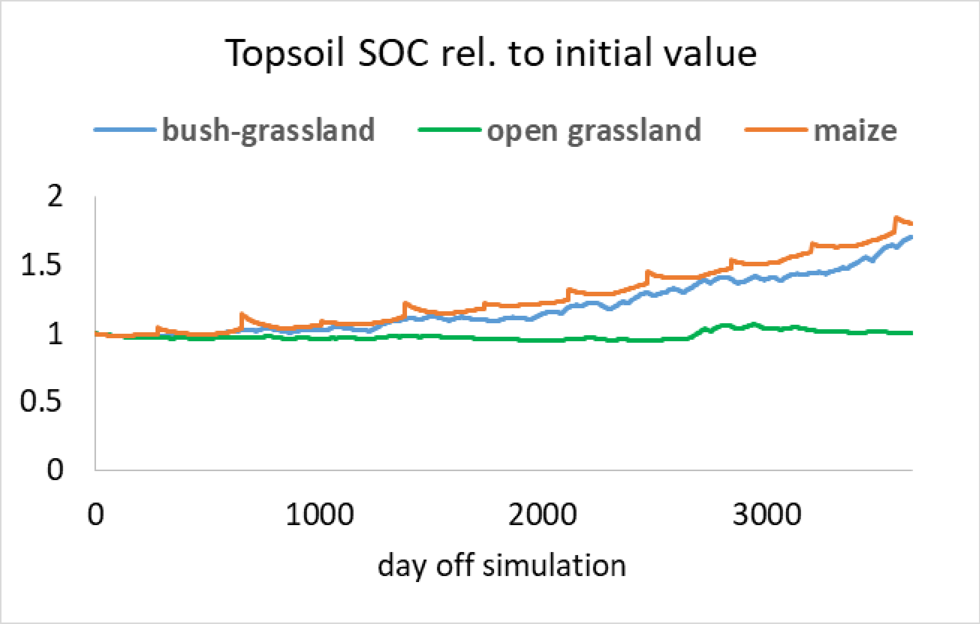


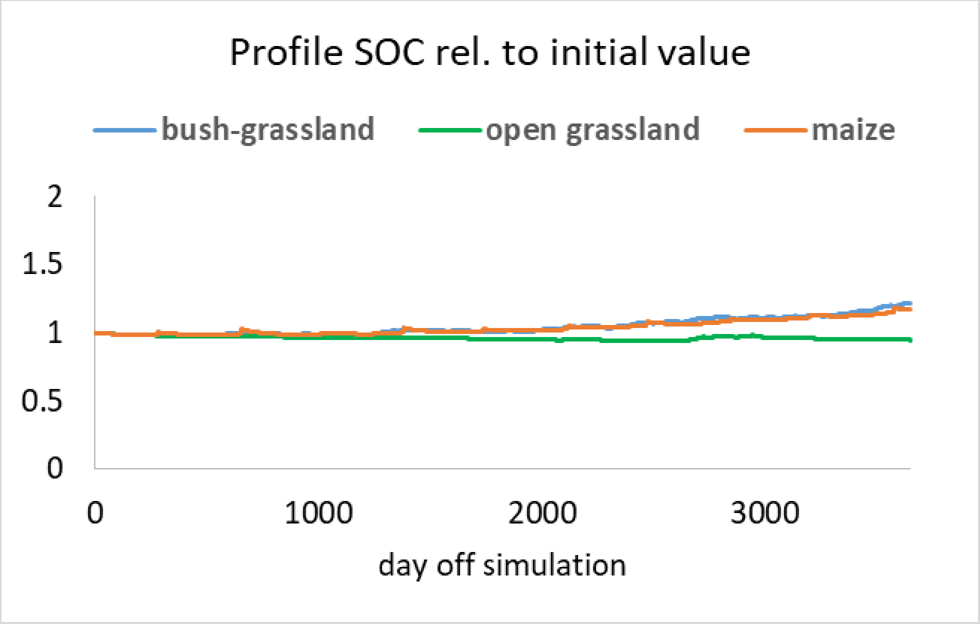
Discussion

- Converting open grassland to maize
→ enhances biomass productivity and topsoil SOC

- but only if crop residues are left on fields
- Intensive maize cultivation, mineral fertilizer
- Different for small-holders without fertilizer and residue feeding
- Smaller difference for whole soil profile SOC

- LUC effects on ESS such as wildlife, biodiversity, water balance etc. not yet evaluated





Conclusions

Model improvement

- Herd rotation across landscape pre-determined (to be delivered by coupled MPMAS)
- Grazing and recovery periods for grassland
- Reserves allow regrowth after drought and grazing
- Dormancy during dry season triggered by plant available water

Model application

- High spatial variability of plant growth, due to lateral water flows on clay soils

→ Pasture degradation where water limitation and overgrazing coincided

- Pasture growth and resilience: bush-grassland > open grassland (facilitation?)

- Maize still water limited despite high fertilizer inputs

Outlook

Socio-ecological model coupling
- Currently tested dynamic modelling framework of LUCIA + LIVSIM + MPMAS
→ dynamic herd composition & management, herd mobility (daily by CP/ha, monthly by agents), grazing pressure/rhythm and animal nutrition

Integrated crop-livestock systems
- Crop residues, cut & carry system, manure storage

Implement more ecological functions
- simulate tree recruitment and bush encroachment pattern, influenced by landscape management

→ Combine tree seed production depending on growth conditions (LUCIA), with seed dispersal

→ Combine mechanistic plant competition (LUCIA) with tree cohorts that interact

→ Combine herd routes and fruit ingestion/dung excretion (LUCIA) with seedling establishment probability

Acknowledgements

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UNDERUTILIZED OR UNPROTECTED? NEW METHODS FOR ANALYZING DIVERGING PERSPECTIVES ON THE LARGE-SCALE CONVERSION OFTROPICAL GRASSLAND ECO-SYSTEMS
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