Modelling the environmental impacts of Swiss mixed agroforestry systems

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1. Introduction

Farming systems are under increasing environmental pressure due to the climate and biodiversity crisis. In this context mixed agroforestry systems are suggested as potential solutions to increase circularity of nutrient flows and productivity of the land used for agriculture, while at the same time storing carbon in biomass and soils to mitigate climate impacts. Few studies have assessed the environmental performance of mixed agroforestry systems within European farms and models for doing so are scarce. In this study, a life cycle assessment (LCA) model "FarmLCA" (De Baan et al., 2024) was further developed to include agroforestry and reflect the most recent methodologies for estimating carbon sequestration in soil and biomass. Here we present these developments and their applicability on Swiss agroforestry farms, co-producing fruits, milk, meat and other crops.

2. Methods

Two sub-models, quantifying changes in soil carbon and in woody biomass, were implemented in the FarmLCA model. For soil carbon, the IPCC Tier 2 methodology (IPCC, 2019) was used, assessing the dynamics of different soil carbon pools, such as active and passive C-pools. For C-storage in woody biomass, we chose the Tier 1 methodology proposed by Cardinael et al. (2018). As recommended by ISO 14044 for LCA we propose a biophysical allocation for tree-management impacts to the fruits and close-by grassland only. The area used by single fruit trees within the fields was calculated using the approach proposed by Hemery et al. (2005) as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. This approach should more accurately distribute impacts between crops, trees and livestock in mixed systems. Following development, FarmLCA was used to model seven real Swiss farms. They combine growing high-stem fruit trees within pasture- or cropland, mixed with dairy or beef cattle systems.

3. Results and discussion

The adapted model was able to analyse the very heterogeneous agroforestry farms (see

Table 1), both in terms of the degree of specialization (i.e., proportion of different income streams), input dependency (i.e. N self-sufficiency) as well as resource management (i.e. nitrogen use efficiency). Depending on the farm, 0.5-575% of a farm's greenhouse gas emissions were offset by carbon stored in soil or woody biomass. This range underlines the importance of transparent assumptions when dealing with biomass carbon as emission offset measure. To analyse the environmental performance of such multi-functional systems, selecting appropriate functional units (FU) and performance indicators is challenging. Allocating impacts is an additional challenge, where disentangling management inputs, as performed here, is recommended (Figure 1), but requires further testing and validation.

4. Conclusions

We tested a novel LCA approach to assess impacts within agroforestry systems. The soil carbon and biomass modules in the FarmLCA are useful add-ons to assess the carbon dynamics in various farming systems. Since carbon storage in agricultural systems can strongly impact carbon footprints, but is highly dynamic and potentially reversible, a discussion is needed on the temporal dimension of carbon storage and how it should be treated within LCAs.

5. Acknowledgements

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6. References

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Table 1. Overview of farm characteristics. Farms are sorted by livestock income proportion. LU: livestock units. NUE: nitrogen use efficiency.

Variable	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
Area (ha)	14.6	33.2	24.2	7.6	34.0	29.9	20.4
Arable land (%)	-	56%	-	-	68%	51%	39%
Permanent grassland (%)	94%	39%	98%	24%	30%	27%	56%
Agroforestry (%)	6%	6%	2%	76%	2%	22%	5%
Livestock density (LU/ha)	3.02	0.63	2.63	-	-	0.97	1.07
Crop revenue (% of total)	18%	72%	1%	100%	100%	75%	42%
Livestock revenue (% of total)	82%	28%	99%	-	-	25%	58%
N self-sufficiency fertilisers (%)	85%	94%	69%	0%	5%	83%	89%
NUE (kg N export/kg N import)	0.16	4.27	0.46	0.35	0.55	1.59	1.41
Climate change, short term, no carbon models (kg CO2 eq ha-1)	27216	8583	30265	1689	3643	8237	5972
Climate change, short term, with carbon models (kg CO2 eq ha-1)	26738	8538	29979	-8022*	3242	7647	5379

**Only valid for first 20 years after orchard establishment, and requires interpretation, depending on the long-term future of the orchard and the embedded carbon which can easily be lost back to the atmosphere.*

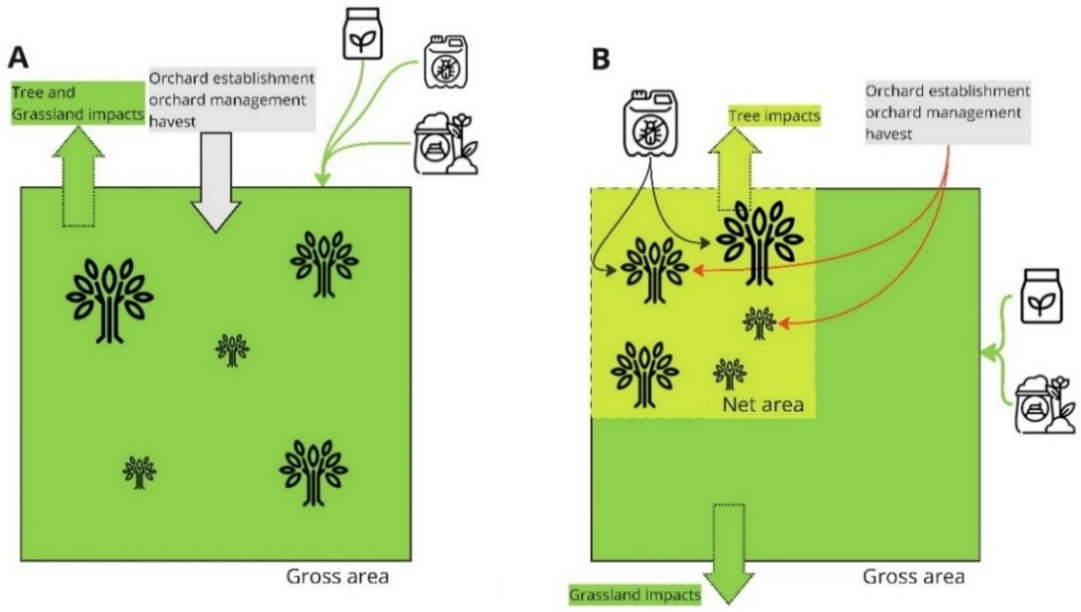

Figure 1. Allocation of environmental impacts of field management on mixed grassland and fruit trees: (A) per-plot approach: impacts are allocated to both outputs (tree and grassland); (B) approach proposed by Hemery et al. (2005): impacts of tree-management (e.g. pesticide application) are allocated to trees only, net area of trees is calculated.