Effects of temperate alley-cropping agroforestry on nitrate leaching losses

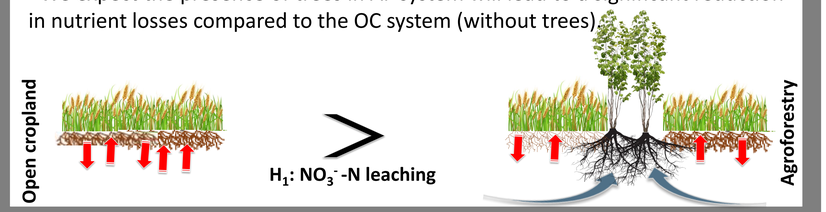
Raphael Manu[1]*, Marife D. Corre[1], Marcus Schmidt[1], Fasil Mequanint[2], and Edzo Veldkamp[1]

[1]Soil Science of Tropical and Subtropical Ecosystems, Georg-August University of Goettingen, Germany

[2]University of Hohenheim, Institute of Soil Science and Land Evaluation (Biogeophysics), Stuttgart, Germany

Introduction

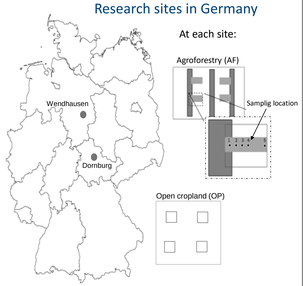
- Nitrate (NO_3^-) leaching from agroecosystems can represent a primary source of groundwater pollution[1] and can lead to downstream eutrophication in freshwater ecosystems.
- Relative to open croplands (OC), alley-cropping agroforestry (AF) systems can substantially reduce leaching losses through deep soil nutrient uptake by the extensive roots of its constituent tree strips.
- The EU's soil strategy 2030 aims to cut nutrient losses by 50%, how this goal is achieved remains an open question.
- Here, we assess the effect of AF on nutrient leaching losses specifically nitrate
- We expect the presence of trees in AF system will lead to a significant reduction in nutrient losses compared to the OC system (without trees).

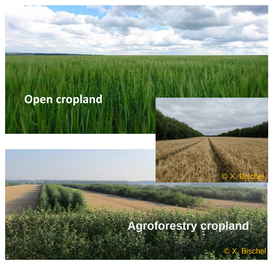


Materials & methods

- Two sites across Germany, with each site having 4 replicate plots in the AF system and 4 plots in adjacent open cropland (as reference). Site management, and fertilization regimes in the systems at each site are identical
- Using suction-cupped lysimeters, we measured soil water concentration (at 60 cm depth) in the tree row, 1m, 4m, & 7m from the tree row to represent each 30 × 30m plot of the AF system
- In the OC system, we measured from the center of each plot
- Soil water drainage fluxes were modeled using Expert N with soil & vegetation properties, & climate (temperature, precipitation, solar radiation, rel. humidity & wind speed)
- Leaching flux (mg/m^2) = nitrate concentration (mg/L) x water drainage (mm)
- N fertilization (kg/ha/year) for 2016/17; 2017/18: 45N (Barley); 105N (Rapeseed) in Dornburg, 220N (rapeseed); 165N (wheat) in Wendhausen

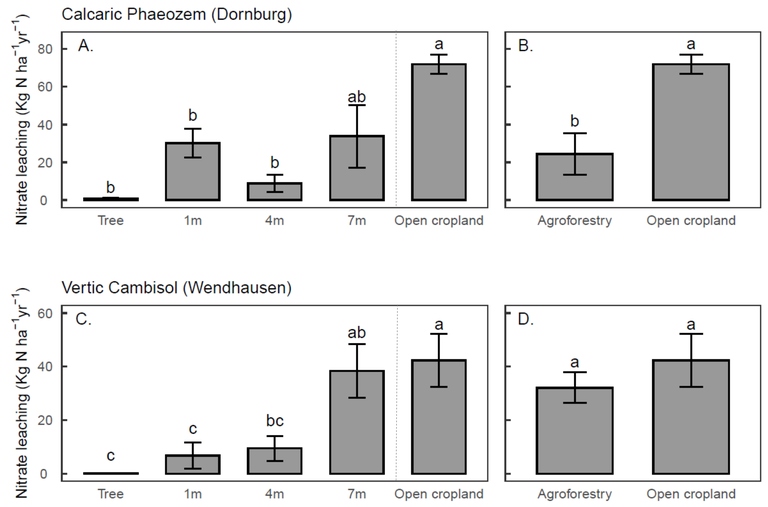
Research sites in Germany



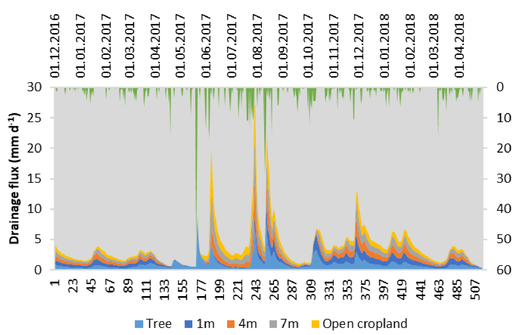


Results

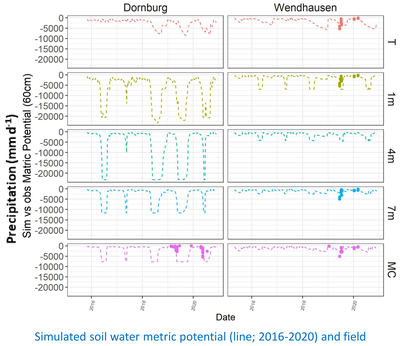
- Nitrate represented ≥ 90% of total dissolved N leached at the observed sites.
- Nitrate leaching losses was 66% lesser (Fig. B) in the agroforestry system than in the open cropland on Calcaric Phaeozem, but showed comparable leaching losses at the Vertic Cambisol site.
- These leaching losses tended to increase with increasing distance from the tree strip highlighting the key complementary role of trees in nutrient capture and redistribution.



Mean (±SE, n = 4 plots) on different soil types, measured from Dec. 2016 to April 2018 (A, B) and from May 2016 to Dec. 2018 (C, D). Means representing agroforestry (in B and D) have been area-weighted



Drainage flux (stacked plot) at different sampling locations at the Calcaric Phaeozem site



Simulated soil water metric potential (line; 2016-2020) and field measured metric potential (points; 2019-2020) on our study period at 60cm depth. Measurement unit is **mm.**

- Lesser nitrate leaching losses and dissolved N concentrations observed in the tree row (occupy 20% of farm area) likely because the tree strips are unfertilized.
- While this unfertilized tree strip did not reduce N_2O emissions in AF compared to OC system, they explain the reduced leaching losses observed in the AF system.

Dissolved nitrogen and organic carbon concentrations (mean ± SE, n = 4 plots)

Site	Management	Dissolved nitrogen concentration (mg N L^{-1})			Dissolved organic carbon (mg C L^{-1})
		NO_3^-	NH_4^+	Total N	
Calcaric Phaeozem (Dornburg)	AF_Tree	0.4 ± 0.2	0.12 ± 0.07	0.9 ± 0.2	30.6 ± 4.1
	AF_1m	15.9 ± 7.5	0.11 ± 0.05	22.1 ± 11.3	45.4 ± 5.1
	AF_4m	3.6 ± 1.9	0.10 ± 0.05	4.7 ± 2.1	66.8 ± 5.8
	AF_7m	8.8 ± 3.5	0.12 ± 0.04	9.7 ± 3.4	50.8 ± 5.9
	Open cropland	22.2 ± 2.6	0.08 ± 0.02	26.1 ± 2.7	26.4 ± 3.5
Vertic Cambisol (Wendhausen)	AF_Tree	3.8 ± 3.7	0.08 ± 0.01	4.1 ± 3.8	35.5 ± 6.8
	AF_1m	3.6 ± 2.4	0.11 ± 0.03	4.2 ± 2.4	55.0 ± 12.5
	AF_4m	7.9 ± 4.0	0.07 ± 0.02	8.2 ± 3.9	58.4 ± 9.8
	AF_7m	15.8 ± 3.4	0.11 ± 0.03	16.5 ± 3.3	52.8 ± 12.7
	Open cropland	16.4 ± 3.0	0.13 ± 0.03	16.9 ± 3.0	48.5 ± 4.0

- Although the high leaching losses in our open croplands (A-B) are not unusual in temperate agroecosystem with high fertilization rates[3], they are surprising at the Dornburg site considering the N fertilzation rate of the study period. However, present leaching flux may reflect the legacy effect of previous fertilizations[1]
- Precipitation averaged 545 mm yr^{-1} (Dornburg), 625 mm yr^{-1} (Wendhausen) over the study periods, the soil order may have mediated the effect of trees in the AF-system in reducing nitrate leaching losses eg. in Wendhausen.

Summary

- Our results, though preliminary, support our hypothesis and show that trees in the agroforestry system have a positive reduction effect on nitrate leaching losses and therefore holds a potential to contribute to the broader EU objective of cutting down nutrient losses by half by 2030 .
- The reduced nitrate leaching losses in agroforestry indicates an improved soil function of water filtration compared to the open cropland management system

References

1. Di & Cameron (2002). Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutrient Cycling in Agroecosystems 46: 237–256, 2002
2. Formaglio et al. (2020). Herbicide weed control increases nutrient leaching compared to mechanical weeding in a large-scale oil palm plantation. Biogeosciences, 17, 5243–5262, https://doi.org/10.5194/bg-17-5243-2020
3. Luo, et al. (2022). Reduced soil gross N2O emission driven by substrates rather than denitrification gene abundance in cropland agroforestry and monoculture. Journal of Geophysical Research: Biogeosciences, 127, e2021JG006629. https://doi.org/10.1029/2021JG006629
4. Schmidt et al. (2021). Nutrient saturation of crop monocultures and agroforestry indicated by nutrient response efficiency. Nutr Cycl Agroecosyst. 119:69–82
5. Veldkamp et al. (2023) Multifunctionality of temperate alley-cropping agroforestry outperforms open cropland and grassland. Communications earth & environment. https://doi.org/10.1038/s43247-023-00680-1

*Email: raphael.manu@uni-goettingen.de