Evaluating soil health benefits of temporary grassland in crop rotations

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Abstract

Temporary multi-species grasslands are an integral part of crop rotations in mixed livestock-cropping systems. They provide many ecosystem services to crop rotations, including enhancing soil health. The share of temporary grassland required in the rotation to optimise the multifunctionality of these benefits is of special interest. This study investigated the effects of the share and the duration of temporary grassland in the crop rotation on soil health at the field plot level, focusing on bulk density and earthworm populations. The effect was investigated on maize fields with varying shares of temporary grassland in the rotation ranging from 0 to 76% and with the duration of the temporary grassland as the precedent crop ranging from 0 to 5.75 years. Eighteen fields were sampled on farms with long-established crop rotations. No effect of the share nor the duration of temporary grassland as the precedent crop on total earthworm numbers or biomass was observed. However, the relative abundance of anecic earthworms increased with a longer duration of temporary grassland. A lower share and shorter duration of temporary grassland resulted in a higher bulk density of the topsoil (0–20 cm). This result suggests the importance of including temporary grassland in crop rotations to reduce soil compaction in arable soils.

Keywords: temporary grasslands, ecosystem services, crop rotation, soil health, soil compaction

Introduction

Temporary grasslands (TG) constitute a pivotal element of crop rotations within mixed livestock-cropping systems. In their review, Malisch *et al.* (2024) have observed that the beneficial impacts of TG on ecosystem services during the grassland phase of the rotation are well documented. The effects of TG on the following crop, however, remain to be investigated. In a recent paper, Guillaume *et al.* (2022) demonstrated a positive relationship between the share of TG and the soil organic carbon stock in the top- and subsoil. The present study aims to explore the relationship of (i) the share of TG in the crop rotation and (ii) the duration of TG as a precedent crop with the soil health in the follow-on crop maize, with the focus on soil structure conservation and soil activity at the field-level.

Materials and methods

The study was conducted in the canton of Fribourg, Switzerland on 18 farms with widely different shares of TG (grass-legume mixtures) in their crop rotation. On each farm one field planted with maize at the time of the study was examined. Soils were Cambisols, the fields were managed conventionally and were located within a radius of 11 km. Maize fields were selected that followed directly after the TG. The duration of TG as the precedent crop to maize was calculated from the period from sowing to ploughing of TGs. The duration of TG as the precedent crop ranged from 0 to 5.79 years, with an average of 2.58 years. The share of TG in the crop rotations was calculated by dividing the length of all TG periods (as some fields have additional TG periods, but not as a precedent to maize) by the duration of the whole rotation. This calculation gave a range of shares from 0 to 0.76, with the duration of the whole rotation varying from four to eight years. A sampling area of 100 m^2 was defined within each examined field after the harvest of maize. Soil core samples with a volume of 100 ml and a diameter of 5.1 cm were taken for bulk density measurement (five replicates per field and at two depths of 10 cm and 40 cm, corresponding to topsoil and subsoil, respectively). Bulk density was then determined by drying the samples at 105°C to constant weight, with stone volumes subtracted from the total cylinder volume. Extraction of earthworms was carried out in three replicates, firstly by the mustard method (using a commercially available fine and strong mustard, solution applied on 0.25 m^2) and then by hand sorting of a soil block extracted with a spade (surface 0.04 m^2 and depth 0.2 cm). Adult earthworms were then identified by ecological category and weighed. Statistical analyses were performed with R version 4.3.3 (R Core Team, 2025).

Results and discussion

A negative relationship was observed between the duration of TG as the precedent crop and the bulk density of the topsoil (Figure 1, $P = 0.004$, $R^2 = 0.41$). In the subsoil this relationship was also preset as a trend ($P = 0.061$). For the topsoil a similar relationship was found with the share of TG in the crop rotation ($P = 0.032$) but explaining less of the variability in the dependent variable ($R^2 = 0.26$). However, the relationships with share of TG in the crop rotation was not observed in the subsoil ($P = 0.506$). These findings suggest a positive effect of TG on reducing soil bulk density of arable soils in the topsoil, a benefit that persists even after the growing period of the follow-on maize crop. This effect was also manifested below the plough pan (subsoil), although much weaker. In line with this, earlier work has shown that TG improve soil structure by increasing organic matter and promoting root growth, resulting in a decrease in bulk density and an increase in soil porosity (Loiza *et al.*, 2018).

Both earthworm abundance (mean 11.05 individuals/m^2) and biomass (mean 4.59 g/m^2) sampled after the harvest of the follow-on maize crop were found not to be related to the share of TG in the crop rotation ($P = 0.799$ and $P = 0.305$, respectively), nor to the duration of TG as the precedent crop ($P = 0.910$ and $P = 0.506$, respectively). This is somewhat surprising, as TG has been shown to benefit

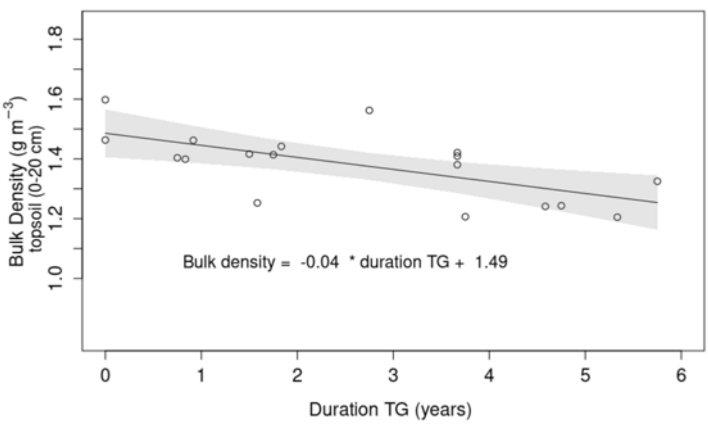

Figure 1. Linear regression analysis of the effect of the duration of temporary grassland (TG) in the crop rotation as a precedent crop to maize and the bulk density of the topsoil after the harvest of the follow-on crop maize. The solid line shows the linear regression fit. Shaded areas indicate 95% confidence intervals.

earthworm populations in arable soils (e.g. Prendergast-Miller *et al.*, 2021). The lack of detectable positive effects on earthworms may be attributed to either the rather short-term positive effect of TG on earthworm abundance (van Eekeren *et al.*, 2008) or the possibility that these benefits were overshadowed by the impact of other agricultural practices, such as tillage (Crotty *et al.*, 2016). Anecic and endogeic earthworms were found to be the most abundant ecological categories, while epigeic earthworms were observed in very few of the fields studied, which is consistent to the observation that they live in the litter (Blouin *et al.*, 2013). The percentage distribution of the ecological categories of earthworms was affected by TG: the relative abundance (percentage) of anecic earthworms increased significantly with a longer duration of TG (intercept 37.94, slope 0.58, $P = 0.043$, $R^2 = 0.23$) and showed a trend to increase with a higher share of TG ($P = 0.084$). This finding aligns with the results of Van Eekeren *et al.* (2008), who noted that anecic earthworms were more prevalent in arable crops compared to forage crops. The vertical biopores formed by anecic earthworms are known to be critical for soils capacity to infiltrate water (Blouin *et al.*, 2013), thereby contributing to the resilience of soils against extreme weather events anticipated under climate change.

Conclusion

A clear benefit of the TG gradient in the crop rotation was observed for the bulk density, indicating the capacity to improve soil structure and mitigate the risk of soil compaction in arable soils. Regarding the earthworm populations, as an indicator for soil biotic activity, some changes in the relative abundances of ecological groups were observed. Further investigation by including management variables within the models is expected to shed more light on the impact of TG on soil health in the mixed livestock-cropping systems.

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