

LegacyNet: introducing an international multi-site experiment investigating potential benefits of increasing the species diversity of grassland leys within crop rotations

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Abstract

LegacyNet is a voluntary network of 32 international sites, established to investigate the yield benefits of multispecies grassland leys and their legacy effects on a follow-on crop. Relatively few experiments have investigated the impact of manipulating species diversity in grassland leys within crop rotations, and fewer still have accounted for variability across environments and soil types. A common experiment is being conducted at all 32 LegacyNet sites, with 52 grassland plots of systematically varied combinations of six forage species from three functional groups (two grasses, two legumes and two herbs) being sown at each site. The plots are measured and harvested for a period of at least 18 months. After this time, grassland plots are terminated, and a follow-on crop established on each plot (retaining the same plot structure). Measurements taken during the grassland and follow-on crop stages include dry matter yield, forage quality, botanical composition, and legacy effects. In this paper, we introduce the LegacyNet international experiment, its design, and overall aims and objectives.

Keywords: crop rotation, grasses, grassland leys, herbs, legumes, multi-site experiment

Introduction

Agricultural systems have been subjected to ongoing simplification, leading to the widespread use of monocropping (single crop being used continuously) and monocultures (single species) that are only high yielding with high inputs of inorganic nitrogen fertiliser, herbicides and pesticides. This lack of diversity lowers the resilience of the agri-ecosystems and reduces environmental quality and the supply of ecosystem services. For grassland leys, a previous pan-European multi-site experiment (the 'Agrodiversity' study across 31 international sites) showed that increases from one to four species increased forage yield and reduced weeds in grassland communities, compared to monocultures (Connolly *et al.*, 2018; Finn *et al.*, 2013). Through grass-legume mixture effects, four-species grassland mixtures greatly enhanced nitrogen use efficiency (Nyfeler *et al.*, 2009; Suter *et al.*, 2015). However, the benefits of diverse leys in crop rotations remain under-investigated. Legume-based mixtures have great potential to contribute

legacy effects to subsequent follow-on crops within rotations; recent studies showed a significant legume-legacy induced increase in biomass yield of a follow-on model crop (Fox, 2020; Grange *et al.*, 2022). There is also evidence that including herb species (or forage forbs) in multi-species grasslands will provide additional benefits to those provided by legumes (Grange *et al.*, 2021; Jaramillo *et al.*, 2021).

LegacyNet, an international research network, tests whether this increase in diversity will also enhance the ley benefits in crop rotations, and whether these benefits are generally applicable across a gradient of soil and environmental conditions. The LegacyNet experiment is still ongoing at many sites; thus, in this paper, we introduce the experiment and discuss its research objectives and potential impact.

Methods

The LegacyNet experiment was established at 32 sites across 17 countries between 2018 and 2022 (LegacyNet 2022). The common experiment consists of two stages implemented over a three-year crop rotation, the grassland ley phase (~ two years) and the follow-on crop phase (one growing season). In the grassland stage, an innovative experimental design is implemented, consisting of forty systematically varying combinations of six forage species, including two species from each of the three functional groups: grasses, legumes, and herbs. The core design consists of 47 plots: 18 monoculture plots and 29 mixture plots consisting of either two, three, four, or six species. All 47 plots are managed at the same level of nitrogen (N) fertiliser (dictated by local practice). An additional five monoculture plots of one of the grasses are managed at a higher level of N (at least 100 kg N ha⁻¹ higher). The total of 52 plots are arranged in a completely randomised design at each site.

In the grassland stage, plots are sown, fertiliser applied, and harvested by mowing for at least 18 months. At each harvest during this period, dry matter yield is recorded per plot along with a measurement of the plot's botanical composition and forage quality. After a minimum of 18 months, the grassland ley is terminated, but the 52-plot structure is retained, and a follow-on crop is established on each plot, with no or low nitrogen application. The follow-on crop varies across the sites, either a grass monoculture 'model' crop, wheat, barley or maize is used. Yield, nitrogen yield and other quality variables are recorded on each plot in this phase.

The data from all sites in the experiment will be collated and analysed using the Diversity-Interactions modelling approach (Kirwan *et al.* 2009), embedded in a multi-site framework. The main research aims of LegacyNet are to assess and quantify: (1) the role of up to six species across three functional groups of grasses legumes and herbs, in grassland mixtures on yield, weed invasion and forage quality, (2) the effect of varying the species diversity of a grassland ley on the transfer of legacy benefits to a follow-on crop, (3) the resource use efficiency of the full crop rotation under varying ley manipulations. A major strength of LegacyNet will be the ability to test the robustness of the effects across wide geographic and climatic gradients; this is an important benefit of multi-site experiments.

Results and discussion

A small number of the 32 LegacyNet sites have already completed the experiment, however, the experiment is still ongoing at most sites; all experiments will be completed by the end of 2024. It is anticipated that the results from LegacyNet will help identify optimal designs of grassland leys within crop rotations (e.g. what is the recommended proportion of each functional group) and how (or if) the optimal design varies with climatic and other local conditions, and the extent to which the optimal grassland ley designs are an improvement over conventional 'low-diversity high-input' grassland leys in crop rotations.

Conclusions

The LegacyNet experiment is expected to provide important contributions to knowledge on the effects of species diversity in grassland leys and subsequent effects on follow-on crops, across a climatic gradient. Through a common 32-site experiment implemented across 17 countries, the results are expected to be internationally relevant to farm management practices and to contribute to reducing the environmental impact of crop rotation systems.

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