

Positive effects of plant diversity on dry matter yield while maintaining a high level of forage digestibility in intensively managed grasslands across two contrasting environments

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Funding information

EC FP7-KBBE Specific Programme "Cooperation": Food, Agriculture and Biotechnology, Grant/Award Number: 244983; Science Foundation Ireland Frontiers for the Future Programme, Grant/Award Number: 19/FFP/6888

Abstract

The local abiotic and environmental conditions of a grass-based farming system may influence the agricultural benefits of mixtures in comparison to pure stands. We investigated the effects of species identities and interactions between grass, legume, and herb species on dry matter yield and sward digestibility and explored how contrasting environments may affect these relationships. We established experimental plots across 11 mixtures and 4 monocultures of perennial ryegrass (*Lolium perenne* L.), chicory (*Cichorium intybus* L.), white clover (*Trifolium repens* L.), and red clover (*Trifolium pratense* L.) established at two seeding densities in two sites Brody and Szelejewo (Poland) and managed them over a 3-year period. The two sites were close geographically and had similar climates, but differed in soil types (Luvisols and Cambisols, respectively). We confirmed that the annual DM yields were generally higher on Cambisols soil as compared to Luvisols soil; both individual species effects and species interaction strengths differed across the two contrasting environments. The predicted annual DM yield for the 4-species mixtures in general gave comparable or higher yields compared to monocultures across the 3 years, with the mixtures giving around 10%–30% higher yields than the weighted average of the monocultures of the constituent species. Analysing the transgressive overyielding it turned out that there was no significant difference between the 4-species mixtures and best performing monoculture. The benefits of species diversity in our study was greater on less productive site because we found larger overyielding of the 4-species sward on the Luvisols soil than on the Cambisols soil. Additionally, the effect of mixtures composed by 4-species increased the yield stability compared to monocultures in the 3-year period of our study, particularly on Cambisols soil. Sward digestibility applied to average values did not differ much between sites with mixtures performing similarly to monocultures. The reason for that could have been the dynamics of sward botanical composition during study years shifted towards increased perennial ryegrass and decreased proportions of chicory in the sward as well as the observed phenomenon that the species in mixed swards progressed to successive growth stages more slowly than in pure sowing.

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KEYWORDS

contrasting environments, digestibility, dry matter yield, multi-species sward, overyielding, temporary grassland

1 | INTRODUCTION

The production of forage from intensively managed agricultural grasslands has largely been based on grass monocultures when using high doses of inorganic nitrogen (N) fertilizers. This system secured high productivity, but at the same time, large amounts of energy and nutrients were lost, negatively affecting many ecosystem services. Therefore, over the past two-three decades, extensive research has been conducted on the potential of multi-species mixtures for intensive grassland cultivation to determine if a positive biodiversity and ecosystem function (BEF) relationship can be identified for these systems. Among the many studies (Finger & Buchmann, 2015; Hector et al., 1999; Hooper et al., 2005; Hooper & Dukes, 2003; Roscher et al., 2005; Tilman et al., 1996; Tilman et al., 2014), an important pan-European experiment (Kirwan et al., 2014), tested whether higher yields, compared with monocultures, can be achieved under typical agricultural conditions with grass-legume mixtures containing four species (Kirwan et al., 2007). These studies have shown that species diversity is a major determinant across a variety of ecosystem functions like productivity, stability, weed invasion resistance, nutrient dynamics, etc. (Brophy et al., 2017; Finn et al., 2013; Heshmati et al., 2020; Kirwan et al., 2007). Proulx et al. (2010) have also shown that highly diverse species mixtures are temporally stable, in that they exhibit a lower variance over time, across a range of ecosystem functions compared to species mixtures with low diversity. This results in providing the farmer with an 'insurance' against extreme weather conditions (Yachi & Loreau, 1999). Schaub, Buchmann, et al. (2020) have also reported that in intensively managed grasslands with higher plant species diversity production risks decreased and constituted a significant insurance value for farmers.

In recent research on multi-species swards (MSS) using intensively managed grasslands, it has been observed that mixtures of species with contrasting plant characteristics frequently produce higher yields than the weighted average of the monocultures of the component species. This effect was usually confirmed in grass-legume mixtures (Finn et al., 2013; Husse et al., 2016; Šidlauskaitė et al., 2022; Sturludóttir et al., 2014), but including selected forbs in productive grass-clover mixtures is promising for further enhancing productivity, meanwhile effectively suppressing short-term weed growth in intensively managed grasslands (Cong et al., 2018; Grange et al., 2021; Jing et al., 2017; Pirhofer-Walzl et al., 2011). These increased yields which are caused by the interactions between the different species in the grassland mixture can be explained by the process of niche differentiation and facilitation in resource utilization (Hooper et al., 2005). Nyfeler et al. (2009) have shown that even under moderate N fertilization, grass-legume mixtures can produce comparable performances to grass monocultures receiving high N fertilization. Also, Sturludóttir et al. (2014) have confirmed that

positive diversity effects lead to higher herbage dry matter yield (DMY) in grass-legume mixtures than expected from species sown in monocultures; additionally, this positive effect was not accompanied by a reduction in herbage dry matter digestibility (DMD) and crude protein (CP) concentration that is usually observed with increased DMY. This typical relationship was confirmed by Ergon et al. (2017), who found a significant species diversity effect on the chemical composition of forage harvested from mixed swards, leading to a 10% increase in acid detergent fibre (ADF) concentration, a 20%–22% reduction in water-soluble carbohydrate (WSC) concentration and a 4% reduction in net energy of lactation (NEL) concentration averaged across the two-first years, which would probably lead to reduced digestibility. The inclusion of forbs in ryegrass-clover mixtures can affect forage quality both positively, for example by providing sufficient dietary mineral supply to ruminants (Pirhofer-Walzl et al., 2011), and negatively, for example by decreasing the digestibility of organic matter and CP concentration (Jing et al., 2017). As suggested by Sanderson (2010), differences in nutritive value appear to be more closely related to differences in the relative proportions of the functional groups (grasses, legumes, forbs) than to mixture complexity.

Besides these above-ground interactions, the productivity and forage quality in intensively managed grassland are likely to also be affected by the environmental factors, for example soil type, climatic variables, pest and disease burden. Soil type can be particularly influential because the growth of forage plants can depend on the physical, chemical, and biological properties of the soil, from which the soil N and water availability are most important (Hofer et al., 2017). The soil conditions may also favour the vegetation of individual functional groups of plants or the species themselves. Legumes do not depend solely on soil N (due to their benefit from symbiotic dinitrogen fixation), and they may increasingly rely on N₂ fixation as soil N availability in upper soil layers decreases. Similarly, deep-rooting herbs as chicory can extract water from greater depths than shallow-rooted plants, and therefore they have a competitive advantage and an adaptation option to drought (Skinner et al., 2004). Alongside soil properties, climatic variables can also be influential. For instance, air temperatures, and amount and pattern of precipitation can affect soil water balance, as well as the physiological status of plants and competition dynamics of mixtures (Huyghe et al., 2014). There could also be an impact of environmental factors on the plant diversity relationships in intensively managed grasslands. Experiments across two (or more) contrasting environments could aid in better understanding the BEF relationship and help inform on good management practices for local conditions.

An intensively managed multi-sward grassland experiment was carried out in Poland at two sites Brody and Szelejewo; the primary difference between the two sites was soil type (Luvisols and Cambisols, respectively) from August 2010 to 2013 to investigate the effects of monocultures and a range of mixtures of grasses, legumes, and herbs on

the productivity and nutritive value of the herbage across two contrasting environments. We address the following objectives:

1. Were there annual DMY benefits (overyielding) from mixtures and, if so, did the benefits persist over 3 years and across two contrasting environments?
2. Were there species mixing effects on digestibility of herbage over the 3 years and two contrasting environments?
3. Were any such diversity effects affected by seeding density?
4. Did the relationships of yield and digestibility with plant diversity differ over the two contrasting environments?

2 | MATERIALS AND METHODS

2.1 | Field experiment

A variety of grassland communities consisting of various combinations of four key forage species: perennial ryegrass (*Lolium perenne* L.) cv. 'Akwamaryn' – G1, chicory (*Cichorium intybus* L.) cv. 'Polanowicka' – H1, white clover (*Trifolium repens* L.) cv. 'Romana' – L1, and red clover (*Trifolium pratense* L.) cv. 'Nike' – L2, were established at two sites in Poland. White clover and red clover are nitrogen fixing legume species, while perennial ryegrass and chicory are a grass and herb respectively and are both non-nitrogen fixing species. Perennial ryegrass and white clover are both shallow-rooted species, while red clover and chicory are both deep-rooted species.

A simplex design (Cornell, 2011; Kirwan et al., 2007) was used to establish the experiment. The design consisted of four monocultures (one for each species), one centroid mixture with equal sown proportions of each species (G1–25%, H1–25%, L1–25%, L2–25%), four mixtures with each species dominant in turn, for example (67%, 11%, 11%, 11%), and six mixtures containing each pair of species in turn, for example (50%, 50%, 0%, 0%). These 15 communities were each sown at a low and high density giving a total of 30 communities for each site. The high seeding density was the locally recommended monoculture seeding density (35, 5, 19, and 22 kg ha⁻¹, respectively for the four species) and low was 60% of the high seeding density. At each site, each community was sown on a 10 m² plot following a completely randomized design. The plot seeder Wintersteiger was used.

The sites were located at Brody (52°26' N, 16°18' E; 94 m a.s.l.) in the Experimental Station of Department of Grassland and Natural Landscape Sciences of PULS and Szelejewo (51°51' N, 17°09' E; 127 m a.s.l.) in Division of Plant Breeding Danko Ltd. in Poland and were mainly characterized by differing soil types with Brody having Luvisols soil (sandy-loamy soil; classified as IVa in the Polish system of soil classification; pH_{KCl} – 6.2, P – 0.294, K – 0.179, Mg – 0.058 mg g⁻¹; B – 1.03, Mn – 148.0, Cu – 2.6, Zn – 9.8, Fe – 794.0 mg kg⁻¹) and Szelejewo having Cambisols soil (loamy soil; classified as IIIa; pH_{KCl} – 5.9, P – 0.220, K – 0.102, Mg – 0.067 mg g⁻¹; B – 0.75, Mn – 62.0, Cu – 2.5, Zn – 9.2, Fe – 844.0 mg kg⁻¹). The contents of total nitrogen (N_t: N in all organic and inorganic forms) and mineral nitrogen (N_{min}: plant-available forms of N as a sum of nitrate N-NO₃⁻ and ammonium N-NH₄⁺) in the 0–20 cm

soil layer before the start of experiments in Brody and Szelejewo reached the level of N_t – 0.126% and N_{min} – 30.5 kg ha⁻¹ and N_t – 0.098% and N_{min} – 53.0 kg ha⁻¹, respectively. The level of fertilization was typical for low-input farming system. Fertilizer was applied each year at the rate of: N from 90 kg ha⁻¹ (Brody year one) to 120 kg ha⁻¹ (all other years in both sites) (30 kg ha⁻¹ before each regrowth), P₂O₅ – 60 kg ha⁻¹, K₂O – 90 kg ha⁻¹ applied before vegetation start in each year. Weather data were collected using meteorological stations located at both sites. The yearly mean temperature and total precipitation for 2011, 2012, and 2013 (calculated for each production season from October previous year to September in harvest year) in Brody were 8.5, 9.2, 8.2°C and 688, 757, 563 mm and in Szelejewo were 9.1, 9.7, 8.6°C and 593, 643, 593 mm, respectively. Air temperature and precipitation data for both sites for the years 2010–2013 are presented in the Appendix (Figure A1). The start of the growing season was similar in both sites but was different in the study years, on 22–23 March, 12–13 March and 11–13 April, in 2011, 2012, and 2013, respectively. The cumulative growing degree days differed also during each growing season (at base temperature 5°C) and between study sites reached in 2011, 2012 and 2013 for Brody 3343°, 3267°, and 3172°C and for Szelejewo 3429°, 3402°, and 3174°C, respectively. During the experiments, two periodical droughts were noted, based on the Vinczeff (1984) climatic index, in both sites in 2011 from April to May and from August to September. Thus, the sites differed considerably in soil type and slightly in weather variables.

The experiment reported here was a part of a larger biodiversity experiment, the 'Common Experiment within FP.7 Multisward project' which was carried out in five countries, namely France, Switzerland, United Kingdom, Norway, and Poland. The experiment was established in August 2010 and was carried out for 3 years. Plots were harvested to a height of 5 cm with a Haldrup plot harvester and measured four times in each year and site, except for year one in Brody where only three harvests were carried out. The reason for this exception being that periodic droughts in the region have a higher negative impact on the Luvisols soil in Brody than on the Cambisols soil in Szelejewo and there was insufficient yield for four harvests. The reference in determining the date of all harvests was the achievement by perennial ryegrass growing on monoculture plots the growth stage from beginning of heading to 30% ears emerged (BBCH 51–53 acc. Meier, 2001). Biomass proportions were determined throughout the experimental period by manual separation of plant samples from permanent sub-plots (50 × 50 cm) into the four sown species and the pooled unsown species portion, then dried and weighed. There was a high proportion of weeds in the first re-growth in both sites. It was a reason that the quality analysis of harvested forage was conducted from the second re-growth of 2011.

The response variables considered for this analysis were the annual DM yield and the average digestibility (defined below) of the forage. The DM yield was estimated by harvesting each whole plot area (10 m²) four times each year (three times for the first year in Brody) over the 3 years following the establishment of the experiment (2011, 2012, and 2013). After each harvest, the biomass from each plot was mixed, the representative subsamples were taken and cut

into smaller pieces. A sample of ~1 kg was oven-dried at 60°C for 60–72 h for estimation of dry matter content. Then, the samples were milled with a 1-mm sieve and prepared for chemical analyses. The annual DM yield was calculated by summing the DM yields over each harvest and was used as the response variable for the analysis.

$$\text{Annual DM yield} = \sum \text{DM yield over each harvest in year}$$

The nutritive values of the harvested forage (including any weeds) were calculated at each of the first two re-growths in each year and each site, except for the first year in Brody where the second and third re-growths were considered as there was a very high proportion of weeds in the first re-growth. Using the standard analytical methods of Kjeldahl (1883) and van Soest et al. (1991) the content of nitrogen, cellulose, hemicelluloses, and lignins was determined. These were then used to calculate the crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL) using the equations:

$$\text{Crude Protein} = 6.25 * \text{Nitrogen Content}$$

$$\text{Acid Detergent Fibre} = \text{Lignins} + \text{Cellulose}$$

$$\text{Neutral Detergent Fibre} = \text{Lignins} + \text{Cellulose} + \text{Hemicellulose}$$

$$\text{Acid Detergent Lignins} = \text{Lignins}$$

ADF was then used to calculate the dry-matter digestibility (DMD) as a percentage of the forage for each harvest using the following equation (Di Marco, 2011):

$$\text{Dry Matter Digestibility} = 88.9 - 0.779 * \text{ADF}$$

An average of the DMD value for each harvest weighted by the yield in the respective harvest was calculated and used as the response to assess the digestibility of the forage.

$$\text{Average Weighted Dry Matter Digestibility} = \frac{\sum_{i=1}^2 y_i * \text{DMD}_i}{\sum_{i=1}^2 y_i}$$

where DMD_i and y_i were the DMD value and yields for harvest $i = 1, 2$.

2.2 | Statistical analysis

The annual DM yield and the (average) DMD were modelled using Diversity-Interactions models (DI; Kirwan et al., 2007, 2009; Moral et al., 2023) which is a regression-based approach that models the community level response as a linear combination of the species identity and interaction effects scaled by the sown proportions of the species in each plot. The standard equation for a DI model is:

$$y = \sum_{i=1}^s \beta_i P_i + \sum_{\substack{i,j=1 \\ i < j}}^s \delta_{ij} P_i P_j + \alpha A + \epsilon$$

where y is the response, s is the number of species, P_i is the sown proportion of species i , β_i is the identity effect of species i (i.e., a measure of the impact of changing the sown proportion of species i), δ_{ij} 's are the interactions effects between species i and j , A is a vector of control variables or experimental structures such as seeding density or treatments etc., α is a vector containing the effects of the control variables and ϵ is the normally distributed error term with mean 0 and variance σ^2 , $\epsilon \sim N(0, \sigma^2)$. The identity effect (β_i) of a species scaled by its proportion (P_i) represents the inherent contribution (excluding any interactions) of the species towards the community response. This is a multiple regression model (with the predictors summing to 1) and can be fit using ordinary least squares estimation for single site and single year experiments. For our two-site and three-year experiment, species identities and interactions were crossed with site and year and repeated measures accounted for:

$$y = \left[\sum_{i=1}^4 \beta_i P_i + \sum_{\substack{i,j=1 \\ i < j}}^4 \delta_{ij} P_i P_j \right] * \text{site} * \text{year} + \alpha A + \epsilon$$

where y is the response variable (yield or digestibility), site is a factor with two levels (Brody and Szelejewo), year is a factor with three levels (2011, 2012 and 2013) and A is a dummy variable with two levels for seeding density (high and low). This is a multiple regression model where the error term included plot level covariances for the repeated measures on each individual plot in a block diagonal structure. This model was the starting point of our model selection process and a range of fixed effect models were tested during the model selection process to identify if a more parsimonious model could be fitted (Kirwan et al., 2009), for example, different structures of the interaction terms were tested (each testing a separate biological hypothesis) and whether all terms need to be crossed with site and year was tested; details of this are in Appendix Table A1. Model selection was carried out using the corrected Akaike Information Criterion (AICc) (Burnham & Anderson, 2002) and the final model was fitted using Restricted Maximum Likelihood (REML) estimation. The models were fit using the MIXED procedure in SAS/STAT software version 9.4 (SAS Institute Inc., Copyright © 2002–2012).

3 | RESULTS

3.1 | Annual DMY and average DMD empirical data

The distributions of the annual DM yields and the average weighted dry matter digestibility over the 3 years and two seeding densities for

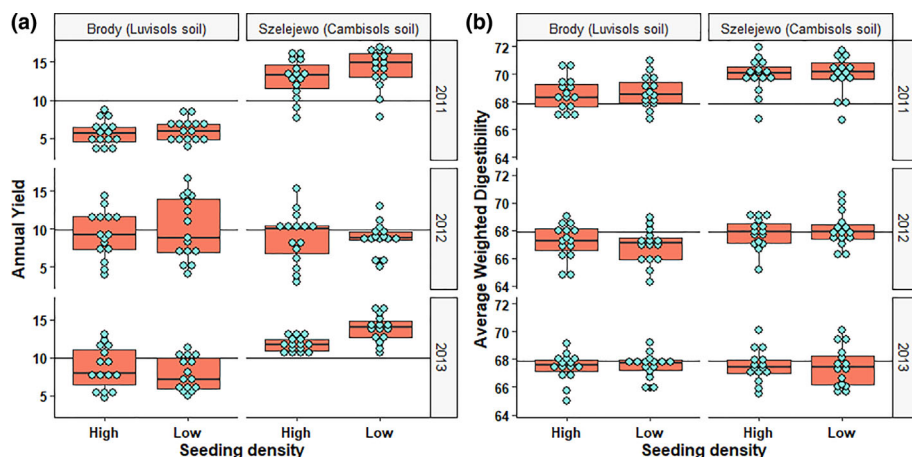


FIGURE 1 The distribution of annual DM yield and average weighted DM digestibility: The variation in (a) the annual DM yield (kg ha^{-1}) and (b) average weighted DM digestibility (%) is shown for the two seeding densities for each unique year-site combination. The horizontal lines show the mean annual DM yield (kg ha^{-1}) (a) and mean average weighted DM digestibility (%) (b) across both sites and all 3 years. The dots represent the individual plot level values for a particular year and site at a given level of seeding density.

TABLE 1 Regression coefficients for the selected linear mixed model using annual DM yield as response along with their associated standard errors for the two sites and 3 years (2011–2013).

Parameter	Brody (Luvisols soil)			Szelejewo (Cambisols soil)		
	Year			Year		
	2011	2012	2013	2011	2012	2013
β_{G1}	6.30 ± 0.721	3.48 ± 1.076	6.35 ± 0.929	14.98 ± 0.721	5.87 ± 1.076	15.14 ± 0.929
β_{H1}	5.32 ± 0.721	10.94 ± 1.076	6.06 ± 0.929	14.73 ± 0.721	11.37 ± 1.076	12.06 ± 0.929
β_{L1}	5.30 ± 0.721	6.94 ± 1.076	4.76 ± 0.929	8.52 ± 0.721	7.24 ± 1.076	12.28 ± 0.929
β_{L2}	5.07 ± 0.721	12.66 ± 1.076	11.15 ± 0.929	10.50 ± 0.721	7.63 ± 1.076	13.33 ± 0.929
δ_{AVG}	1.38 ± 2.118	5.10 ± 2.994	5.48 ± 2.627	6.45 ± 2.118	3.57 ± 2.994	-2.71 ± 2.627
$\delta_{G1:L1}$	5.33 ± 2.544					
$\delta_{G1:L2}$	6.30 ± 2.544					
$\delta_{H1:L1}$	7.43 ± 2.544					
$\delta_{H1:L2}$	6.57 ± 2.544					
α	-0.70 ± 0.249					

Note: Coefficients highlighted in bold are significant at the $\alpha = 0.05$ significance level.

Brody (Luvisols soil) and Szelejewo (Cambisols soil) are shown in Figure 1. Year-on-year variation was observed in both responses and there was a significant difference in both responses between the two sites ($p = .0000$ for DM yield and $p = .0015$ for DMD). There was no effect of seeding density on either response ($p = .2647$ for DM yield and $p = .8926$ for DMD). A scatterplot showing the variation in the two responses across different levels of richness between the two sites over the 3 years is presented in Figures A2 and A3 for annual DMY and average DMD respectively, in the appendix.

3.2 | Modelling of annual dry-matter yield and average dry-matter digestibility

Following the model selection process, the parameter estimates of our final models are in Tables 1 and 2. The final model for each response was of the form:

$$\text{DM yield} = \left[\beta_{G1}P_{G1} + \beta_{H1}P_{H1} + \beta_{L1}P_{L1} + \beta_{L2}P_{L2} + \delta_{AVG} \sum_{\substack{i,j=1 \\ i < j}}^s P_i P_j \right] * \text{Site} \\ * \text{Year} + \delta_{G1:L1}P_{G1}P_{L1} + \delta_{G1:L2}P_{G1}P_{L2} + \delta_{H1:L1}P_{H1}P_{L1} \\ + \delta_{H1:L2}P_{H1}P_{L2} + \alpha A + \epsilon$$

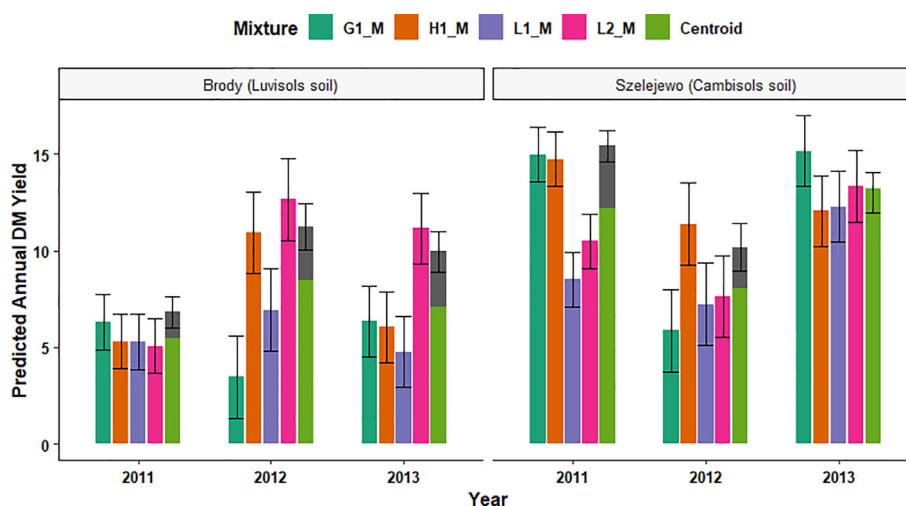
$$\text{Avg DMD} = \left[\beta_{G1}P_{G1} + \beta_{H1}P_{H1} + \beta_{L1}P_{L1} + \beta_{L2}P_{L2} + \delta_{AVG} \sum_{\substack{i,j=1 \\ i < j}}^s P_i P_j \right] * \text{Site} \\ * \text{Year} + \delta_{G1:L1}P_{G1}P_{L1} + \delta_{G1:H1}P_{G1}P_{H1} + \delta_{L1:L2}P_{L1}P_{L2} + \epsilon$$

A constant interaction term crossed with site and year was included for each response, and specific pairwise species interactions to capture deviations from this, not crossed with site and year were also included. The density term (A) was not crossed with site and year.

TABLE 2 Regression coefficient estimates for the model with average DMD (%) as the response with their standard errors for the two sites and 3 years (2011–2013).

Parameter	Brody – Luvisols soil			Szelejewo – Cambisols soil		
	Year			Year		
	2011	2012	2013	2011	2012	2013
β_{G1}	67.42 ± 0.31	68.65 ± 0.31	67.96 ± 0.31	70.59 ± 0.478	66.85 ± 0.478	66.49 ± 0.478
β_{H1}	68.37 ± 0.31	64.96 ± 0.31	65.69 ± 0.31	67.26 ± 0.478	68.02 ± 0.478	67.52 ± 0.478
β_{L1}	70.42 ± 0.31	67.39 ± 0.31	68.73 ± 0.31	70.16 ± 0.478	69.83 ± 0.478	70.3 ± 0.478
β_{L2}	69.59 ± 0.31	64.84 ± 0.31	67.38 ± 0.31	69.74 ± 0.478	68.65 ± 0.478	67.86 ± 0.478
δ_{AVG}	−1.96 ± 0.846	2.62 ± 0.846	0 ± 0.846	2.05 ± 1.284	−2.49 ± 1.284	−3.26 ± 1.284
$\delta_{G1:L1}$	−2.34 ± 0.75					
$\delta_{G1:H1}$	1.39 ± 0.726					
$\delta_{L1:L2}$	2.71 ± 0.726					

Note: Coefficients highlighted in bold are significant at the $\alpha = 0.05$ significance level.

FIGURE 2 Predicted annual DM yield for communities. The predicted annual DM yield (kg ha^{-1}) with the 95% CI for the monocultures and the centroid mixture at low seeding density for the each of two sites over the 3 years are shown. Predictions for each monoculture are shown (G1_M, H1_M, L1_M, and L2_M) and for the centroid equi-proportional community. The centroid mixture is split into two where the green region represents the average of the identity effects of the species in the mixture and the grey region is the net overyielding in the mixture due to the species mixing (interaction) effects.

The two models had different structures for the variance–covariance matrix. The model for DM yield had a unique variance for each year and a unique covariance between each pair of years while the model for avg DMD had a constant variance and a constant covariance for each year. The two models also had different additional pairwise interaction terms. Finally, the seeding density term was not significant and was omitted in the avg DMD model.

3.2.1 | Annual dry-matter yield

We confirmed that except for red clover in 2012, all the four species generally have significantly higher identity effects in Szelejewo (Cambisols soil) as compared to Brody (Luvisols soil) over the 3 years (Table 1). This may be explained by better soil quality in terms of moisture and nutrient content in Szelejewo compared to Brody. As shown in Figure 2, the predicted annual DM yield for the centroid mixture consistently gave comparable or higher yields than the average of the components in monoculture across the 3 years with high

overyielding (the increase in DM yield relative to what would be expected from weighted average monoculture stand yields – shown in grey). The monocultures yielded high in certain years, but they were not consistent across years or sites, that is, the best performing monoculture differed across years and sites. The overyielding for the centroid mixture was high in the first and second years in Szelejewo with no overyielding in the final year, while in Brody there was consistent overyielding across the 3 years with the mixture performing much better in the second and third years. In general, during the 3-year period the monocultures and centroid mixture yielded better on Cambisols soil in Szelejewo than Luvisols soil in Brody. We also confirmed a consistent overyielding of around 10%–30% for each of the 4-species mixture in the experiment. The overyielding was significant in each year, except for the year 2013 in Szelejewo, where there was not any overyielding (Appendix Figure A4(a)). There was no evidence of transgressive overyielding at either site in any year (shown in Figure 2 for the centroid mixture – there was no significant difference between the centroid and best performing monoculture).

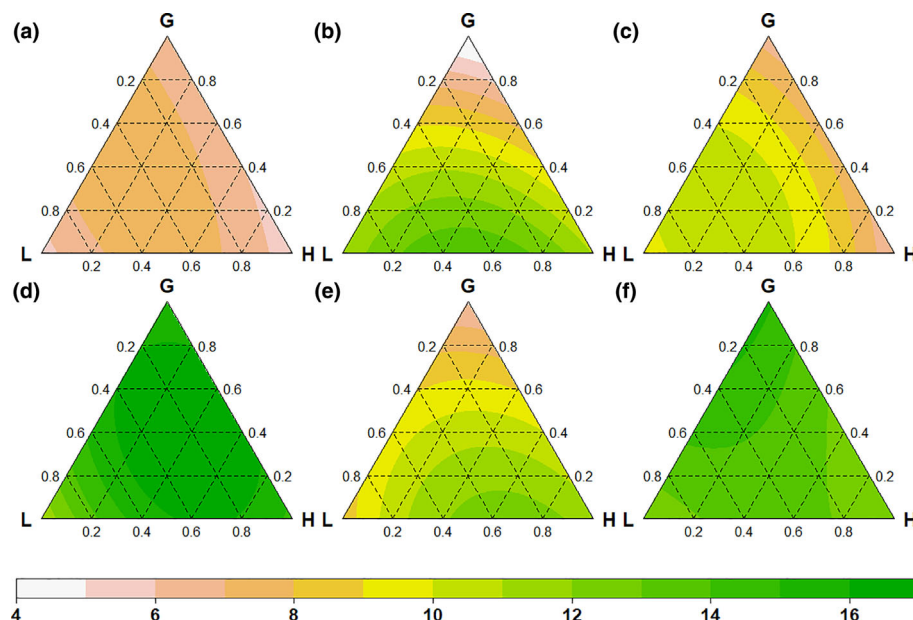


FIGURE 3 Variation in predicted annual DM yield vs initial species proportions: The predicted annual DM yield (kg ha^{-1}) across the three-dimensional simplex space including grass (G), herb (H), and legume (L) proportions is shown for Brody – Luvisols soil (a–c) and Szelejewo – Cambisols soil (d–f) over the 3 years (2011, 2012 and 2013) respectively. The proportion of legume in the mixture was obtained by summing the proportions of red and white clover in the mixture while the proportion of grass and herb were the proportions of ryegrass and chicory respectively. At every point in the ternary diagrams, the legume proportion is split equally between red and white clover. For example, a prediction for 100% legume would be 50% red clover and 50% white clover, a prediction for 30% grass, 30% herb, and 40% legume would be 30% ryegrass, 30% chicory, and 20% each of red and white clover, etc. Predictions shown are for ryegrass and chicory monocultures (shown at the respective G and H vertices), 50%–50% red and white clover mixture (shown at the L vertex), grass-legume, grass-herb, or legume-herb mixtures (shown on the sides of each ternary diagram) and for four species mixtures (all points in the interior of the ternary diagram; e.g., the centre point predicts for 1/3 ryegrass, 1/3 chicory, 1/6 red clover, 1/6 white clover).

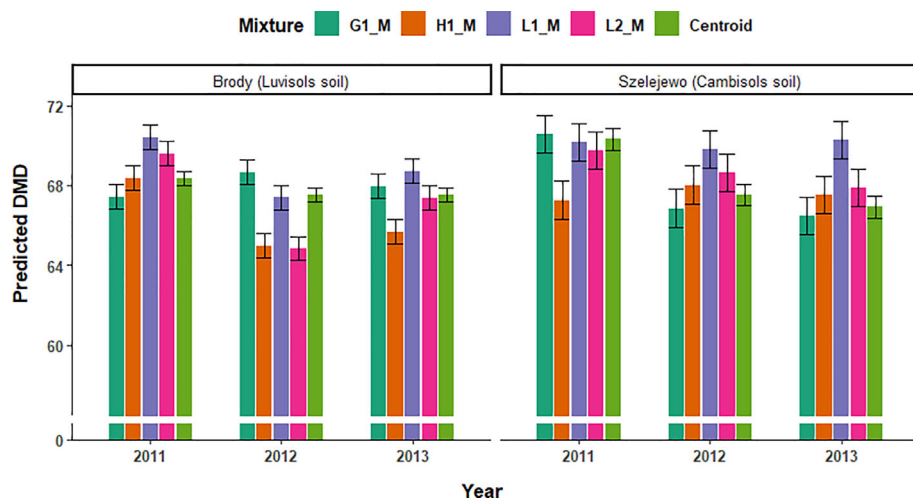


FIGURE 4 Predicted average DMD (%) for communities: The predicted average DMD (%) along with the 95% CI for the monocultures (G1_M, H1_M, L1_M, and L2_M) and the equi-proportional centroid mixture at low seeding density for both sites over the 3 years are shown. The y-axis was zoomed to be between 60 and 72, so differences between the predicted digestibility of the different communities are better visible.

Figure 3 shows the variation in the predicted annual DM yield across the different species mixtures for the two sites over the 3 years as the proportion of grass, legume, and herb changes. The high drop in annual DMY for both the sites in the second year with increasing proportions of perennial ryegrass can be attributed to the undesirable conditions of growth and development of this species in the second year. Figure 3 also shows that the high yields were evident across a wide range of grass, legume, and herb proportions, but robustness depended on site and year.

3.2.2 | Average dry-matter digestibility

The individual species identity effects for the average dry matter digestibility model did not differ much across the species, nor across the two sites (Table 2). Although several interaction terms were significant, their magnitude was small compared to the identity effects, thus their net impact was small and mixtures performed similarly to monocultures (shown for the centroid mixture in Figure 4).

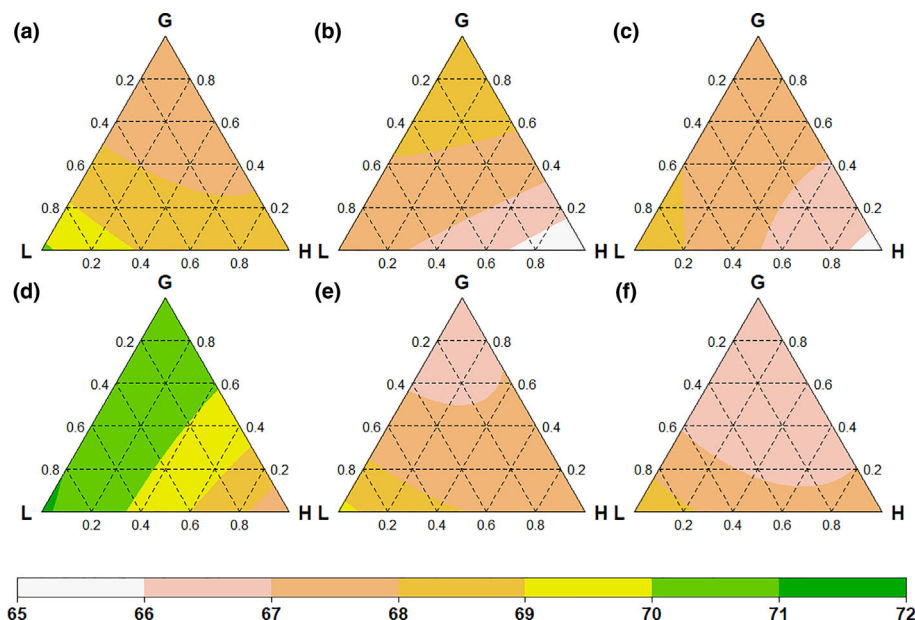


FIGURE 5 Variation in predicted average DMD (%) vs species proportions: The predicted average DMD (%) across the three-dimensional simplex space including grass (G), herb (H), and legume (L) proportions is shown for Brody – Luvisols soil (a–c) and Szelejewo – Cambisols soil (d–f) over the 3 years (2011, 2012 and 2013) respectively. The proportion of legume in the mixture was obtained by summing the proportions of red and white clover in the mixture while the proportion of grass and herb were the proportions of ryegrass and chicory respectively. At every point in the ternary diagrams, the legume proportion is split equally between red and white clover. For example, a prediction for 100% legume would be 50% red clover and 50% white clover, a prediction for 30% grass, 30% herb, and 40% legume would be 30% ryegrass, 30% chicory, and 20% each of red and white clover, etc. Predictions shown are for ryegrass and chicory monocultures (shown at the respective G and H vertices), 50%–50% red and white clover mixture (shown at the L vertex), grass-legume, grass-herb, or legume-herb mixtures (shown on the sides of each ternary diagram) and for four species mixtures (all points in the interior of the ternary diagram; e.g., the centre point predicts for 1/3 ryegrass, 1/3 chicory, 1/6 red clover, 1/6 white clover).

Net interactions did not provide much overyielding or under-yielding in most of the mixtures (Appendix Figure A4(b)). The mixtures had digestibility values comparable to the weighted average of the constituent species' monoculture performances.

Figure 5 shows the variation in predicted average DMD for the different species mixtures of grass, legume, and herb across the two sites over the 3 years. There is not a notable reduction in the average digestibility when moving from a grass/herb monoculture or a 50:50 legume mixture (vertices of the triangle) to a mixture with multiple species (points along the edges and interior of the triangle) in a given site and year. Figure 5 also shows that for a given site and year the change in the average digestibility across a wide range of grass, legume, and herb proportions is around 3–4 units (3%–6% depending on the year and site). In order to explain the effect of mixture composition on DMD, the results of the botanical analysis of the sward throughout the experimental period are provided in Appendix Table A2.

4 | DISCUSSION

4.1 | Dry matter yield

Our results demonstrate that the average of the cultivation of MSS composed with species from different functional groups, regardless of

contrasting environments, resulted in sustained DM yield advantages at moderate N levels compared with the average of the component species in monocultures. In our study we considered four forage species important in grass-based farming systems in moderate climatic zones. Using Diversity-Interactions modelling, we showed that mixture DMY performances were often greater than what was expected from the weighted average of the component species' monoculture performances (overyielding). In our study there was no evidence of transgressive overyielding at either site in any year. However, we note that there was no monoculture that consistently produced the best DMY across years at either site, rather the best monoculture 'switched' from year to year at each site. While certain mixtures consistently performed well across years in Brody and in years 1 and 2 at Szelejewo. Thus, in addition to our research pointing to the benefit of multispecies mixtures overyielding, a key result is also the persistence of high yields of certain mixtures in contrast to the inconsistent performances of individual species in monoculture.

In our study the effect of mixtures composed by 4-species (centroid or dominated by one of them) resulted in an overyielding of around 10%–30% on average (except for the third year of use on Cambisols soil). This effect was confirmed in previous studies by Finn et al. (2013), Husse et al. (2016), Kirwan et al. (2007), Lüscher et al. (2008), Nyfeler et al. (2009), Papadopoulos et al. (2012) and Sturludótir et al. (2014). An explanation for the good performance of species

mixtures as opposed to monocultures could be related to interspecific interactions (e.g., niche partitioning and facilitation) among species in a community (Kirwan et al., 2009) and to underground processes and soil legacy effects (Kaisermann et al., 2013). As reported by Papadopoulos et al. (2012), the positive effects of biodiversity on seasonal DMY production in their study seem to be in large part the result of the inclusion of two productive species (timothy and bluegrass) in more complex mixtures, which show temporally separated growth from year to year. In addition, the inclusion of herbs and legumes in MSS provide additional functional benefits such as diversity in sward structure, promoting increased biodiversity in higher trophic levels, and improvements in overall soil quality (Capstaff & Miller, 2018; Connolly et al., 2009; Lüscher et al., 2008; McCarthy et al., 2020; Suter et al., 2021).

The effect of mixtures composed by 4-species in our experiment increased the yield stability compared to monocultures. The increased yield stability with species diversity was noticed in the 3-year period of study, particularly on Cambisols soil. This finding supports the ecological hypothesis that diversity is a source of community stability (Gross et al., 2014). According to these authors, in grasslands community biomass is stabilized because species richness impacts mean biomass more strongly than its variance. Prieto et al. (2015) also highlighted that the variations in evenness and species abundance of sown grasslands contributes to the species diversity effect on production stability and on ecosystem functioning. As reported by Hofer et al. (2016), combining species in mixtures can compensate for yield reductions caused by severe drought and it offers a practical management tool to adapt forage production to climate change. In this context even a small increase in diversity from monocultures to two- to six-species mixtures already delivers substantial benefits to reduce vulnerability on drought and increase resilience of productive grasslands (Lüscher et al., 2022). We confirmed this conclusion in our study during two periodic droughts in both locations in 2011. In particular, drought from August to September resulted in reduced DMY of the third harvest, but in such weather conditions, the average DMY of 4-species mixtures was higher than the average DMY of monocultures by 22.3% on Luvisols soil and by 8.6% on Cambisols soil. Thus, the positive effect of mixtures, which compensate for yield reductions caused by drought, was higher on a soil of sandy-loamy texture than on loamy soil. Moreover, yield variance was lower in the 4-species mixtures in both sites. This confirms the findings of Haughey et al. (2018), who demonstrated the role of higher diversity in promoting yield stability in intensively managed grassland communities in rainfed as well as drought conditions. Positive effects of biodiversity were also confirmed by Weigelt et al. (2009), who conclude that high-diversity low-input grassland communities provide not only a high diversity of plants and other organisms, but also ensure high forage yields, thus granting the basis for multifunctional managed grasslands.

One of the most important environmental conditions, which influences the DM yield of grass-based communities, is soil type mainly because of their different inherent soil fertility. As reported by Heshmati et al. (2020), site conditions strongly affected the performance of the forage species mixtures. In our study the annual DMY was on

average higher in Szelejewo on Cambisols soil which we attribute to its higher agricultural value (Rousseva et al., 2017) than in Brody on lower fertility Luvisols soil. It was likely also the effect of lower water retention on Luvisols soil due to periodic droughts in the first year of harvest. We also confirmed that perennial ryegrass, chicory, and both clovers generally have higher identity effects on Cambisols as compared to Luvisols soil. Modelling annual DM yield, we found that increasing the proportion of perennial ryegrass in the mixture generally resulted in a decrease of predicted DMY (Figure 3) and that this decline was bigger on Luvisols than Cambisols soil. This can be explained by the fact that grasses supply their demand for N solely by uptake of mineral N in the soil. If soil N levels in Luvisols were low, then the growth rate of perennial ryegrass was slower. In addition, Luvisols show less resilience to periodic water shortages in the soil than Cambisols because they have a higher proportion of sand in their granulometric composition, which is of great importance for perennial ryegrass as a shallow-rooted plant with high soil moisture requirements. In contrast, legumes supplement soil mineral N uptake with N-fixation and can thus maintain high growth rates in low soil N environments (Lüscher et al., 2014). We observed this relation in the case of red clover which contributed to increasing the annual DM yield only in Brody on Luvisols soil. In the case of chicory monoculture, the predicted annual DMY was higher on Cambisols than Luvisols soils. We also found the larger overyielding of 4-species sward compared to monocultures across the 3 years on the Luvisols soil than on the Cambisols soil. The effect was well documented over the 3 years on Luvisols and was not significant in the third year on Cambisols soil (Figure 2). The overyielding was largely driven by mixing legumes and non-legumes, and by the crossed trait combination where the shallow-rooted perennial ryegrass and white clover were combined with the deep-rooted chicory and red clover. This effect has been confirmed by other authors, for example Finn et al. (2013), Hofer et al. (2016), Brophy et al. (2017), Heshmati et al. (2020). It can be concluded that benefits of species diversity in our study was greater on less productive site. This findings corresponded with the results of Haughey et al. (2018) who showed that under rainfed conditions, yields of 4-species communities were 32% and 51% higher than the average of monoculture yields on a soil of loam texture and sandy-loam texture, respectively. Therefore, there is a need for management practices (e.g., choice of seed mixture composition) well adapted to more variable and stressful environments for maintaining the agricultural productivity of grasslands and their other ecosystem services (Goliński et al., 2018).

4.2 | Forage quality

Maximizing yield at the optimal stage of development for quality is the goal of forage production. We found that the significant species interaction effects in our study did not have a strong effect on the digestibility of herbage from mixtures over 3 years and across two contrasting environments. Usually, the overyielding of MSS is accompanied by a reduction in herbage quality (Bélanger et al., 2001;

Sanderson, 2010). Therefore, it is generally expected that an increase in DM yield will result in a decrease in nutritive quality that occurs as forage species reach successive growth stages, as reported by Bruinenberg et al. (2002), White et al. (2004), Isselstein et al. (2005), Peyraud et al. (2009) as well as Elgersma and Sørensen (2018). On the other hand Jing et al. (2017) stated that the inclusion of several species of forbs or legumes in the mixtures negatively affected the forage nutritive value. The digestibility of organic matter and NDF in grass was higher than in the forbs and legumes, and this resulted in reduced digestibility and NDF concentration when more forbs and legume species were included in MSS. Thus, we too could have expected lower nutritive value of the mixture because of their greater yield but our analysis shows that positive effect of species interaction on yield was not accompanied by a notable change ($\pm 3\%$ – 6%) in forage digestibility. This is similar to the results observed in (Sturludóttir et al., 2014) where an increased yield due to a mixture of grasses and legumes did not result in a decline in forage quality.

The crucial explanation of maintaining a high level of forage digestibility of higher-yielding MSS compared to monocultures is growth stage of species at each harvest. In our experiment the harvests were carried out when perennial ryegrass growing on monoculture plots achieved the growth stage BBCH 51–53. We observed that in mixed swards, perennial ryegrass progressed to successive growth stages more slowly. Similar effects occurred in the case of other sown species, particularly by chicory. In pure sowing chicory, especially in the second and third regrowth, quickly developed numerous reproductive shoots and reached the flowering stage, while in mixtures with ryegrass and clovers it remained in the vegetative stage, creating few reproductive shoots. Hence, we can conclude that mixtures of grass, herb, and legumes improve the relationship between DM yield and nutritive value, making it possible to increase DM yield with no negative effect on herbage DM digestibility. This relationship was confirmed in the work of Schaub, Finger, et al. (2020), in which the results show that plant diversity increases quality-adjusted yield by increasing biomass yield at a rather constant forage quality.

The nutritional quality of mixtures is largely determined by the dominant species in the mixture, and therefore, it may change as the species composition changes from year to year (Sturludóttir et al., 2014). We also analysed the dynamics of changes in the botanical composition of the swards. During 3 years of study, the proportions of species harvested in many mixtures differed greatly from the proportion of the species in sown mixtures (Appendix Table A2). After a high proportion of unsown species in the sward yield of the first regrowth in 2011, weeds practically disappeared in the subsequent re-growths. It was only in the third year of production (2013) that weeds began to appear in the botanical composition of the chicory and red clover monocultures in Brody, and perennial ryegrass, chicory and red clover in Szelejewo. During the study period in Brody, perennial ryegrass increased its proportion in 2- and 4-species mixtures, dominating in the third year of production. On the other hand, chicory receded from the sward with subsequent harvests, especially in monoculture and in mixtures with a high proportion of the herb (50%–67%) in both sites. It is worth noting that when this species had a lower proportion in sown mixtures (11%) it was more stable in the sward. Clovers sown in mixtures with perennial ryegrass as

dominants and centroids on Luvisols soil decreased their proportion in harvested sward. On the other hand, on Cambisols soil, this effect was observed to a lesser extent and concerned mainly red clover. Analysing the proportion of species in harvested re-growths, the dynamics of sward botanical composition during study years shifted towards increased perennial ryegrass in the sward and decreased proportions of chicory. This could have been the reason that average DMD did not differ much over 3 years and across two contrasting environments.

The yield distribution of aboveground herbage of mixtures and monocultures in intensively managed grasslands during the growing season can have a large impact on the forage quality (Deak et al., 2007), in particular of the average DMD evaluated in our study. We observed in both sites in the mixtures and monocultures containing perennial ryegrass a higher share of the first regrowth in the annual DM yield compared to non-grass mixtures and monocultures. This was due to the weather conditions favouring grass species in the spring. Later in the growing season the legumes and chicory performed better and therefore the share of the second and third regrowths in the total harvested annual DM yield was higher than in grass containing mixtures and monocultures. The DMD was affected both by changes in the yield distribution of different composed MSS and by previously described changes in the sward botanical composition of mixtures during the growing season. Chicory has the tendency to develop the reproductive stems in summer (Lee et al., 2015), which provide more distinct patterns of seasonal forage quality decline due to a lowered leaf-to-stem ratio in monoculture than those of the mixtures.

Ergon et al. (2016) reported that the intra-annual nutritional stability was significantly higher in the average mixture than in the average pure stand. They explained this effect by the fact that four species used in the mixtures have different seasonal patterns of stem formation and reproductive development. The diversity effect on nutritional quality observed in this study is likely to be associated with the low level of N fertilization. We also investigated the effect of diverse MSS on forage digestibility in low-input farming system. Pure perennial ryegrass swards would normally receive higher levels of N fertilization than applied in the study of Ergon et al. (2016), and this may be expected to have a similar effect on DMD as cultivation in mixtures with legumes. High intra-annual nutritional stability is often desired, especially in the context of practical farming.

We showed in our experiment that the identity effects of the species for average DMD did not differ much between two contrasting environments. In addition, the centroid community in terms of DMD gave a similar performance as the monocultures and predicted DMD across varying grass, legume, and herb proportions were quite robust. Thus in our experience, the contrasting soil types did not result in different nutritional forage quality.

5 | CONCLUSION

Annual DM yield of monocultures and 2- and 4-species mixtures composed by perennial ryegrass, chicory, white clover, and red clover differed across years and sites. Moving from the first to third year, the average interaction term increased in Brody on Luvisols soil, whereas

it decreased in Szelejewo on Cambisols soil. The predicted annual DM yield for each 4-species mixture (centroid or dominated by one of them) consistently gave comparable or higher yields than monocultures across the 3 years (except for the third year of use in Szelejewo on Cambisols soil), with high overyielding of around 10%–30% on average. In Brody on Luvisols soil the best overyielding was recorded in the third year of use for the mixtures, with the effect being around 35%–40% for centroid, chicory- and white clover dominated swards. It turned out that the monocultures yielded high in certain years but there was no evidence of transgressive overyielding at either site in any year. The identity effects of the species did not differ much between two contrasting environments for average dry matter digestibility. In general, the interaction terms for this response were small relative to the species individual effects and thus their net effect was also small.

Overall, we found positive effects of mixing species on DM yield across two contrasting environments, that were not accompanied by a notable reduction in sward DM digestibility. We also found larger overyielding of the 4-species sward on the Luvisols soil than on the Cambisols soil that indicate that multi-species swards are more promising on lower fertility soils. Additionally, the effect of mixtures composed by 4-species increased the yield stability compared to monocultures in both sites. The positive effect of mixtures, which compensate for yield reductions caused by periodical drought (summer 2011) during 3-year period of study, was higher on Luvisols soil than on Cambisols soil. This further adds to the evidence base for promoting multi-species mixtures in intensively managed grasslands.

ACKNOWLEDGEMENTS

The authors wish to acknowledge European Commission Research Directorate-General FP7-KBBE - Specific Programme “Cooperation”: Food, Agriculture and Biotechnology for financial support of this study by grant no. FP7-244983 (MULTISWARD). Caroline Brophy and Rishabh Vishwakarma were supported by the Science Foundation Ireland Frontiers for the Future programme, grant number 19/FFP/6888. Publication was co-financed within the framework of the Polish Ministry of Science and Higher Education's program: ‘Regional Excellence Initiative’ in the years 2019–2023 (No. 005/RID/2018/19).

FUNDING INFORMATION

Financial support for the Multisward project was provided by European Commission Research Directorate-General FP7-KBBE - Specific Programme “Cooperation”: Food, Agriculture and Biotechnology (grant/Award number: 244983). Caroline Brophy and Rishabh Vishwakarma were supported by the Science Foundation Ireland Frontiers for the Future Programme (grant no. 19/FFP/6888).

CONFLICTS OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Golińska, B., Vishwakarma, R., Brophy, C., & Goliński, P. (2023). Positive effects of plant diversity on dry matter yield while maintaining a high level of forage digestibility in intensively managed grasslands across two contrasting environments. *Grass and Forage Science*, 78(4), 438–461. <https://doi.org/10.1111/gfs.12644>

APPENDIX A

TABLE A1 Diversity-Interactions models fit for both the responses.

Model	Equation (followed by description of the form of the interactions)
Species Identities Model	$Response = \left[\sum_{i=1}^4 \beta_i P_i \right] * site * year + \alpha A + \epsilon$ <p>There are no species interaction effects on the response.</p>
Average Pairwise Model	$Response = \left[\sum_{i=1}^4 \beta_i P_i + \delta_{AV} \sum_{\substack{i,j=1 \\ i < j}}^4 (P_i P_j) \right] * site * year + \alpha A + \epsilon$ <p>A single interaction term is sufficient as the strength of the interaction is same for all pairs of species. Any pair of species assumed to interact in the same way.</p>
Functional Model	$Response = \left[\sum_{i=1}^4 \beta_i P_i + \delta_{FG1} P_1 P_2 + \delta_{FG2} P_3 P_4 + \delta_{FG12} \sum_{i \in \{1,2\}} \sum_{j \in \{3,4\}} (P_i P_j) \right] * site * year + \alpha A + \epsilon$ <p>Species interactions can be grouped based on their functional grouping. Here, δ_{FG1} is the interaction between the non-nitrogen fixing species (grass and herb), δ_{FG2} is the interaction between the nitrogen fixing species (both legumes) and δ_{FG12} is the interaction between the two functional groups.</p>
Additive Model	$Response = \left[\sum_{i=1}^4 \beta_i P_i + \sum_{\substack{i,j=1 \\ i < j}}^4 (\lambda_i + \lambda_j) (P_i P_j) \right] * site * year + \alpha A + \epsilon$ <p>The contribution of a particular species to a pairwise interaction is the same, irrespective of the species it interacts with. λ_i is the contribution of species i to the interaction with species j.</p>
Full Pairwise Model	$Response = \left[\sum_{i=1}^4 \beta_i P_i + \sum_{\substack{i,j=1 \\ i < j}}^4 \delta_{ij} P_i P_j \right] * site * year + \alpha A + \epsilon$ <p>Each pair of species has a unique interaction effect on the response.</p>

Note: Listed are the various DI models that were fit to the data using annual DM yield and average DMD as responses, followed by their corresponding equations and a description of the species interaction terms. The identity and interactions terms in the models were crossed with site and year. The best model from this table was selected it was further improved on by adding individual species-specific interaction terms to further explain the variability in the data. The final model selected is shown in the Results section in the main text.

TABLE A2 Proportion of the species harvested (%) during 3 years of harvest after the sowing year in 2010 in two locations: (A) Brody (Luvisols soil) and (B) Szelejewo (Cambisols soil).

(A)		Proportion of species harvested (%)																							
Year	Seeding density	Proportion of species sown (%)						Harvest 1												Harvest 2					
		G1	H1	L1	L2	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown
2011	High	67	11	11	11	32	0	0	0	68	77	13	2	8	0	71	17	0	12	0	n/a	n/a	n/a	n/a	n/a
		11	67	11	11	17	15	4	0	64	20	52	8	14	6	31	53	2	12	2	n/a	n/a	n/a	n/a	n/a
		11	11	67	11	19	0	5	3	73	66	15	10	7	2	70	18	5	4	3	n/a	n/a	n/a	n/a	n/a
		11	11	11	67	24	0	0	5	71	57	17	4	18	4	67	11	2	20	0	n/a	n/a	n/a	n/a	n/a
		25	25	25	25	29	7	0	4	60	56	22	6	16	0	60	19	3	18	0	n/a	n/a	n/a	n/a	n/a
		50	50	0	0	27	4	0	0	69	65	34	0	0	1	62	38	0	0	0	n/a	n/a	n/a	n/a	n/a
		50	0	50	0	27	0	9	0	64	82	0	15	0	3	91	0	9	0	0	n/a	n/a	n/a	n/a	n/a
		50	0	0	50	28	0	0	0	72	85	0	0	13	2	84	0	0	12	4	n/a	n/a	n/a	n/a	n/a
		0	50	50	0	0	20	18	0	63	0	65	32	0	3	0	84	16	0	0	n/a	n/a	n/a	n/a	n/a
		0	50	0	50	0	37	0	17	46	0	51	0	45	4	0	47	0	53	0	n/a	n/a	n/a	n/a	n/a
	Low	0	0	50	50	0	0	15	0	85	0	0	32	65	3	0	0	17	83	0	n/a	n/a	n/a	n/a	n/a
		100	0	0	0	32	0	0	0	68	98	0	0	0	2	100	0	0	0	0	n/a	n/a	n/a	n/a	n/a
		0	100	0	0	0	15	0	0	85	0	98	0	0	2	0	96	0	0	4	n/a	n/a	n/a	n/a	n/a
		0	0	100	0	0	0	26	0	74	0	0	97	0	3	0	0	100	0	0	n/a	n/a	n/a	n/a	n/a
		0	0	0	100	0	0	0	40	60	0	0	0	98	2	0	0	0	100	0	n/a	n/a	n/a	n/a	n/a
		67	11	11	11	33	0	0	0	67	90	6	2	2	0	88	8	0	4	0	n/a	n/a	n/a	n/a	n/a
		11	67	11	11	16	17	5	0	62	38	40	5	10	7	49	39	2	10	0	n/a	n/a	n/a	n/a	n/a
		11	11	67	11	15	6	7	0	72	58	12	7	13	10	58	25	6	10	1	n/a	n/a	n/a	n/a	n/a
		11	11	11	67	22	0	0	5	73	37	25	5	20	13	65	18	2	15	0	n/a	n/a	n/a	n/a	n/a
		25	25	25	25	20	12	0	0	68	68	16	3	4	9	72	19	3	6	0	n/a	n/a	n/a	n/a	n/a
2012	High	50	50	0	0	25	0	0	0	75	88	5	0	0	7	98	2	0	0	0	n/a	n/a	n/a	n/a	n/a
		50	0	50	0	29	0	0	0	71	89	0	7	0	4	94	0	6	0	0	n/a	n/a	n/a	n/a	n/a
		50	0	0	50	31	0	0	4	65	84	0	0	11	5	87	0	0	10	3	n/a	n/a	n/a	n/a	n/a
		0	50	50	0	0	8	18	0	74	0	51	41	0	8	0	33	67	0	0	n/a	n/a	n/a	n/a	n/a
		0	50	0	50	0	15	0	13	72	0	45	0	45	10	0	38	0	62	0	n/a	n/a	n/a	n/a	n/a
		0	0	50	50	0	0	10	20	70	0	0	32	56	12	0	0	22	78	0	n/a	n/a	n/a	n/a	n/a
		100	0	0	0	32	0	0	0	68	97	0	0	0	3	100	0	0	0	0	n/a	n/a	n/a	n/a	n/a
		0	100	0	0	0	56	0	0	44	0	89	0	0	11	0	98	0	0	2	n/a	n/a	n/a	n/a	n/a
		0	0	100	0	0	0	32	0	68	0	0	88	0	12	0	0	100	0	0	n/a	n/a	n/a	n/a	n/a
		0	0	0	100	0	0	0	40	60	0	0	0	93	7	0	0	0	100	0	n/a	n/a	n/a	n/a	n/a

TABLE A2 (Continued)

(A)		Proportion of species harvested (%)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
Year	Seeding density	Proportion of species sown (%)						Harvest 1																		Harvest 2						Harvest 3						Harvest 4																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
		11	11	67	11	11	67	70	7	15	6	3	56	12	23	6	4	64	11	16	5	4	67	5	14	10	5	36	11	17	33	3	26	32	29	10	2	82	16	0	3	73	0	23	0	4	83	0	12	5	0	29	69	0	2	0	10	0	90	0	0	84	14	2	100	0	0	0	0	89	0	0	91	0	9	0	0	97	3	0	11	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continues)

TABLE A2 (Continued)

(A)		Proportion of species harvested (%)																												
Year	Seeding density	Proportion of species sown (%)		Harvest 1												Harvest 2					Harvest 3					Harvest 4				
				G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown		
	50	50	0	0	65	34	0	0	1	69	28	0	0	3	70	30	0	0	0	0	65	28	0	0	7					
	50	0	50	0	84	0	13	0	3	55	0	35	0	10	70	0	26	0	4	62	0	36	0	2						
	50	0	0	50	53	0	0	47	0	65	0	0	30	5	70	0	0	30	0	85	0	0	15	0						
	0	50	50	0	0	2	94	0	4	0	5	90	0	5	0	3	91	0	6	0	5	90	0	5						
	0	50	0	50	0	4	0	78	18	0	10	0	84	6	0	2	0	66	32	0	2	0	55	43						
	0	0	50	0	0	0	49	51	0	0	0	76	12	12	0	0	70	30	0	0	0	30	50	20						
	100	0	0	0	86	0	0	0	14	90	0	0	0	10	100	0	0	0	0	100	0	0	0	0						
	0	100	0	0	0	32	0	0	68	0	49	0	0	51	0	31	0	0	69	0	37	0	0	63						
	0	0	0	100	0	0	71	0	29	0	0	68	0	32	0	0	61	0	39	0	0	55	0	45						
	0	0	0	0	0	0	0	83	17	0	0	0	94	6	0	0	0	97	3	0	0	0	95	5						
Low	67	11	11	11	78	2	13	6	1	79	6	9	6	0	89	3	3	5	0	93	2	2	3	0						
	11	67	11	11	64	16	10	10	0	65	25	7	3	0	60	10	10	8	12	81	14	2	3	0						
	11	11	67	11	88	7	4	1	0	83	3	6	6	2	77	3	15	5	0	80	1	10	1	8						
	11	11	11	67	47	12	10	31	0	60	9	7	21	3	55	7	8	30	0	60	3	1	31	5						
	25	25	25	25	72	14	6	8	0	66	19	9	5	1	80	8	7	5	0	90	5	3	2	0						
	50	50	0	0	87	0	0	0	13	79	0	0	0	21	85	0	0	0	15	84	0	0	0	16						
	50	0	50	0	85	0	14	0	1	65	0	35	0	0	80	0	20	0	0	85	0	15	0	0						
	50	0	0	50	88	0	0	12	0	82	0	0	8	10	79	0	0	9	12	77	0	0	12	11						
	0	50	50	0	0	4	89	0	7	0	15	75	0	10	0	5	84	0	11	0	10	65	0	25						
	0	50	0	50	0	19	0	70	11	0	5	0	72	23	0	3	0	87	10	0	5	0	83	12						
	0	0	50	0	0	0	65	18	17	0	0	70	12	18	0	0	70	22	8	0	0	65	15	20						
	100	0	0	0	98	0	0	0	2	88	0	0	0	12	100	0	0	0	0	100	0	0	0	0						
	0	100	0	0	0	29	0	0	71	0	52	0	0	48	0	30	0	0	70	0	27	0	0	73						
	0	0	100	0	0	0	73	0	27	0	0	98	0	2	0	0	82	0	18	0	0	86	0	14						
	0	0	0	100	0	0	0	77	23	0	0	0	73	27	0	0	0	87	13	0	0	0	85	15						
(B)		Proportion of species harvested (%)																												
Year	Seeding density	Proportion of species sown (%)		Harvest 1					Harvest 2					Harvest 3					Harvest 4											
				G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown							
2011	High	67	11	11	11	95	1	1	1	3	80	18	1	0	0	89	7	3	1	0	66	34	1	0	0					
		11	67	11	11	44	30	3	3	20	48	47	2	2	0	55	36	4	6	0	21	71	3	5	0					
		11	11	67	11	38	2	11	10	39	61	21	13	5	0	66	0	32	2	0	45	51	1	3	0					
		11	11	11	67	21	4	6	15	54	31	23	12	27	7	34	33	2	31	0	40	41	1	18	0					

TABLE A2 (Continued)

(B)		Proportion of species harvested (%)																							
Year	Seeding density	Proportion of species sown (%)				Harvest 1				Harvest 2				Harvest 3				Harvest 4							
		25	25	25	25	81	2	5	2	10	4	4	0	60	34	3	3	0	28	52	9	6	6		
Low	50	50	50	0	0	77	19	0	0	4	0	0	0	50	50	0	0	0	72	28	0	0	0		
	50	50	0	50	0	79	0	12	0	9	0	0	0	88	0	13	0	0	91	0	9	0	0		
	50	50	0	0	50	78	0	0	7	15	0	0	0	96	0	0	4	0	75	0	0	25	0		
	0	50	50	0	0	41	25	0	35	0	46	46	0	8	0	80	20	0	0	56	39	0	5		
	0	50	0	50	0	47	0	14	13	34	0	63	34	3	0	74	0	26	0	52	0	45	3		
	0	0	50	50	0	0	0	14	13	72	0	0	36	34	0	0	43	46	11	0	0	38	62	0	
	100	0	0	0	0	79	0	0	0	21	0	100	0	0	100	0	0	0	100	0	0	0	0	0	
	0	100	0	0	0	0	45	0	0	55	0	95	0	5	0	85	0	15	0	99	0	0	1	0	
	0	0	100	0	0	0	0	41	0	59	0	0	93	0	7	0	67	0	33	0	0	100	0	0	
	0	0	0	100	0	0	0	0	54	46	0	0	69	31	0	0	100	0	0	0	0	0	100	0	
	67	11	11	11	11	69	14	1	1	16	0	67	31	0	2	58	42	0	0	43	57	0	0	0	
	11	67	11	11	37	31	1	1	30	0	52	42	1	4	1	27	69	2	2	7	86	3	4	0	
	11	11	67	11	56	6	9	12	16	0	75	18	5	1	1	49	43	5	2	40	43	2	15	0	
	11	11	11	67	3	8	2	16	71	0	72	0	16	11	1	52	0	3	45	18	32	0	45	5	
	25	25	25	25	59	7	3	7	24	0	65	24	7	3	2	53	39	2	7	9	84	2	5	0	
	50	50	0	0	71	11	0	0	18	0	75	12	0	0	13	44	56	0	0	28	72	0	0	0	
	50	0	50	0	87	0	8	0	5	0	93	0	7	0	0	72	0	10	0	63	0	37	0	0	
50	0	0	50	90	0	0	1	9	0	91	0	0	2	8	98	0	2	0	75	0	0	25	0		
0	50	50	0	0	59	5	0	35	0	0	81	18	0	1	0	73	27	0	0	92	8	0	0		
0	50	0	50	0	49	0	13	38	0	0	74	0	20	6	0	71	0	23	6	0	76	0	24	0	
0	0	50	50	0	0	0	12	23	66	0	0	38	55	7	0	0	47	48	5	0	0	52	48	0	
100	0	0	0	0	90	0	0	0	10	0	99	0	0	1	100	0	0	0	100	0	0	0	0	0	
0	100	0	0	0	0	65	0	0	35	0	52	0	0	48	0	100	0	0	0	82	0	0	18		
0	0	100	0	0	0	0	36	0	64	0	0	46	0	54	0	0	56	0	44	0	0	75	0	25	
0	0	0	0	100	0	0	0	0	64	0	0	0	53	47	0	0	91	9	0	0	0	48	52		
2012	High	G1	H1	L1	L2	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	
		67	11	11	11	52	44	1	2	0	61	35	2	1	10	83	3	4	0	40	11	29	20	0	
		11	67	11	11	9	82	2	6	0	7	90	1	2	2	90	6	3	0	8	84	2	7	0	
		11	11	67	11	19	61	11	8	0	24	45	26	4	1	14	52	5	29	0	26	58	14	2	0
		11	11	11	67	19	33	1	46	1	10	41	26	24	0	5	79	1	15	0	21	55	7	18	0
		25	25	25	25	16	56	11	5	12	24	61	6	9	18	71	4	7	0	6	67	11	16	0	
		50	50	0	0	50	50	0	0	1	23	77	0	0	14	86	0	0	0	11	89	0	0	0	

(Continues)

TABLE A2 (Continued)

Year	Seeding density	Proportion of species sown (%)	Proportion of species harvested (%)																															
			Harvest 1								Harvest 2								Harvest 3								Harvest 4							
			G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown							
Low	50	0	50	0	31	0	11	0	58	65	0	30	0	5	65	0	35	0	0	39	0	51	0	10										
	50	0	0	50	76	0	0	24	0	76	0	0	23	2	37	0	0	63	0	54	0	0	44	2										
	0	50	50	0	0	61	39	0	0	0	53	39	0	8	0	83	17	0	0	0	62	38	0	0										
	0	50	0	50	0	70	0	30	0	0	74	0	16	10	0	66	0	34	0	0	71	0	28	0										
	0	0	50	50	0	0	42	56	2	0	0	47	50	3	0	0	42	58	0	0	0	58	38	3										
	100	0	0	0	32	0	0	0	68	100	0	0	0	0	100	0	0	0	0	97	0	0	0	3										
	0	100	0	0	0	85	0	0	15	0	75	0	0	25	0	99	0	0	1	0	56	0	0	44										
	0	0	100	0	0	0	100	0	0	0	0	100	0	0	100	0	100	0	0	0	100	0	0	0										
	0	0	0	100	0	0	0	91	9	0	0	0	58	42	0	0	0	100	0	0	0	0	58	42										
	67	11	11	11	66	34	0	0	0	30	70	0	0	0	17	83	0	0	0	8	81	10	0	1										
	11	67	11	11	0	75	14	3	8	3	72	18	1	6	2	61	9	28	0	17	67	15	2	0										
	11	11	67	11	12	43	34	11	0	29	18	41	4	8	23	34	35	8	0	5	40	50	4	0										
	11	11	11	67	9	83	1	7	0	45	0	24	23	8	23	0	4	70	3	39	24	17	20	0										
	25	25	25	25	20	56	6	17	1	24	47	4	14	12	10	43	22	25	0	6	58	12	25	0										
	50	50	0	0	37	63	0	0	0	33	67	0	0	0	6	94	0	0	0	28	58	0	0	15										
	50	0	50	0	42	0	47	0	10	52	0	46	0	2	46	0	54	0	0	38	0	62	0	0										
50	0	0	50	52	0	0	47	1	44	0	0	42	14	42	0	0	55	3	12	0	0	7	81											
0	50	50	0	0	65	35	0	0	0	53	41	0	6	0	84	16	0	0	0	66	34	0	0											
0	50	0	50	0	45	0	27	29	0	35	0	49	16	0	81	0	17	2	0	59	0	34	7											
0	0	50	50	0	0	44	56	0	0	0	44	54	2	0	0	48	52	0	0	0	65	35	0											
100	0	0	0	81	0	0	0	19	94	0	0	0	6	100	0	0	0	0	36	0	0	0	64											
0	100	0	0	0	76	0	0	24	0	83	0	0	17	0	100	0	0	0	0	64	0	0	36											
0	0	100	0	0	0	76	0	24	0	0	96	0	4	0	0	100	0	0	0	0	92	0	8											
0	0	0	100	0	0	0	60	40	0	0	0	74	26	0	0	0	83	17	0	0	0	34	66											
High	G1	H1	L1	L2	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown	G1	H1	L1	L2	Un-sown										
	67	11	11	11	51	14	15	20	0	35	25	15	24	0	2	44	16	37	0	21	18	17	43	0										
	11	67	11	11	12	49	31	7	0	13	25	30	32	0	7	50	13	31	0	29	48	2	21	0										
	11	11	67	11	24	42	26	5	3	14	10	43	30	3	44	0	32	24	0	68	0	22	10	0										
	11	11	11	67	12	25	41	22	0	13	13	41	33	0	3	8	17	71	0	20	12	17	51	0										
	25	25	25	25	29	35	25	10	1	3	15	69	12	1	2	14	44	41	0	20	55	24	1	0										
	50	50	0	0	55	41	0	0	4	31	56	0	0	13	21	53	0	0	26	44	55	0	0	2										
	50	0	50	0	52	0	47	0	1	14	0	86	0	0	22	0	78	0	0	35	0	65	0	1										
	50	0	0	50	83	0	0	17	0	19	0	0	62	0	41	0	0	59	0	39	0	0	61	0										
	0	50	50	0	0	40	59	0	0	0	14	63	0	23	0	51	28	0	21	0	0	46	0	54										

TABLE A2 (Continued)

(B)	Proportion of species harvested (%)																									
	Year	Seeding density	Proportion of species sown (%)		Harvest																					
Harvest 1			Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8	Harvest 9	Harvest 10	Harvest 11	Harvest 12	Harvest 13	Harvest 14	Harvest 15	Harvest 16	Harvest 17	Harvest 18	Harvest 19	Harvest 20	Harvest 21	Harvest 22			
Low	0	50	0	50	0	23	0	72	5	0	16	0	54	46	0	25	0	36	0	57	8	0	6	0	91	2
	0	0	50	50	0	0	25	75	1	0	0	0	54	46	0	0	18	82	0	0	33	67	0	0	58	
	100	0	0	0	63	0	0	37	74	0	0	0	0	26	22	0	0	78	42	0	0	0	0	0	62	
	0	100	0	0	0	34	0	66	0	62	0	0	0	38	0	66	0	34	0	0	100	0	0	0	0	
	0	0	100	0	0	0	97	0	3	0	0	0	100	0	0	0	100	0	0	0	0	0	0	0	0	
	0	0	0	100	0	0	0	83	17	0	0	0	0	85	15	0	0	62	38	0	0	0	0	38	62	
	67	11	11	11	58	10	25	0	8	46	47	7	0	0	19	33	47	0	0	50	33	17	0	0	0	
	11	67	11	11	2	66	26	5	1	39	3	53	5	1	12	18	53	16	0	39	11	48	1	2	2	
	11	11	67	11	25	33	34	7	0	2	23	63	12	0	24	16	43	17	0	43	18	32	6	1	1	
	11	11	11	67	42	26	19	12	1	39	22	32	7	0	20	8	24	48	0	38	42	7	14	0	0	
	25	25	25	25	28	12	42	17	0	25	7	35	33	0	22	0	32	46	0	29	0	49	22	0	0	
	50	50	0	0	28	51	0	0	21	21	60	0	0	19	7	63	0	0	31	15	54	0	0	31	0	
	50	0	50	0	42	26	19	12	1	38	0	62	0	0	17	0	81	0	2	47	0	53	0	0	0	
	50	0	0	50	28	12	42	17	0	28	0	0	61	11	16	0	0	47	37	42	0	0	18	40	0	
	0	50	50	0	0	41	58	0	1	0	19	61	0	20	0	15	55	0	30	0	19	44	0	37	0	
	0	50	0	50	0	25	0	57	19	0	39	0	26	36	0	44	0	37	20	0	34	0	41	25	0	
	0	0	50	50	0	0	64	34	2	0	0	68	32	0	0	0	42	58	0	0	0	60	40	0	0	
	100	0	0	0	53	0	0	0	47	48	0	0	0	52	27	0	0	0	73	60	0	0	0	40	0	
	0	100	0	0	0	40	0	0	60	0	11	0	0	89	0	6	0	0	94	0	39	0	0	61	0	
	0	0	100	0	0	0	67	0	33	0	0	100	0	0	0	0	54	0	46	0	0	100	0	0	0	
	0	0	0	100	0	0	0	51	49	0	0	0	0	88	12	0	0	67	33	0	0	0	50	50	0	

Note: High, seeding densities being the locally recommended; Low, seeding densities being 60% of the high density; G1, *Lolium perenne*; H1, *Cichorium intybus*; L1, *Trifolium repens*; L2, *T. pratense*; Unsown, species in harvested herbage outside the species sown.

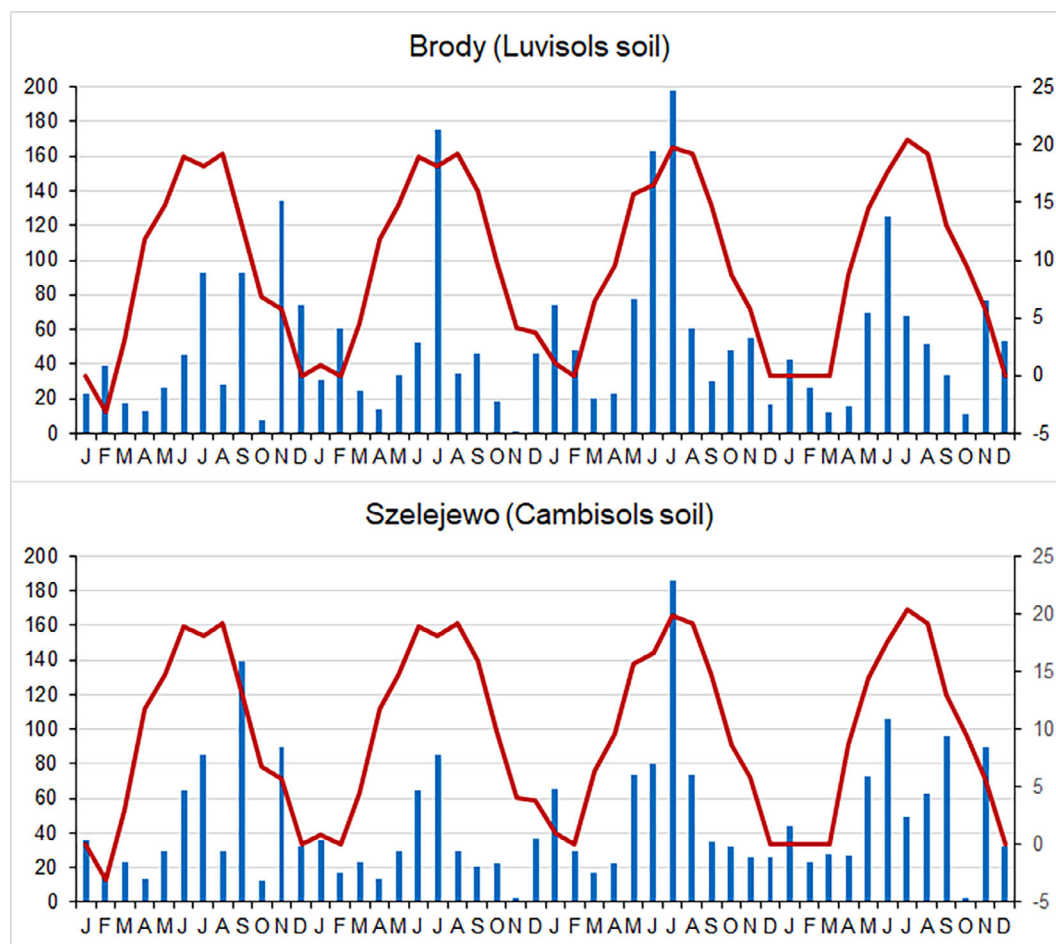


FIGURE A1 Meteorological data of the two sites: Brody (Luvisols soil) and Szelejewo (Cambisols soil) for the years 2010–2013. Monthly mean air temperatures (°C) are presented as lines and monthly precipitation sums (mm) as bars.

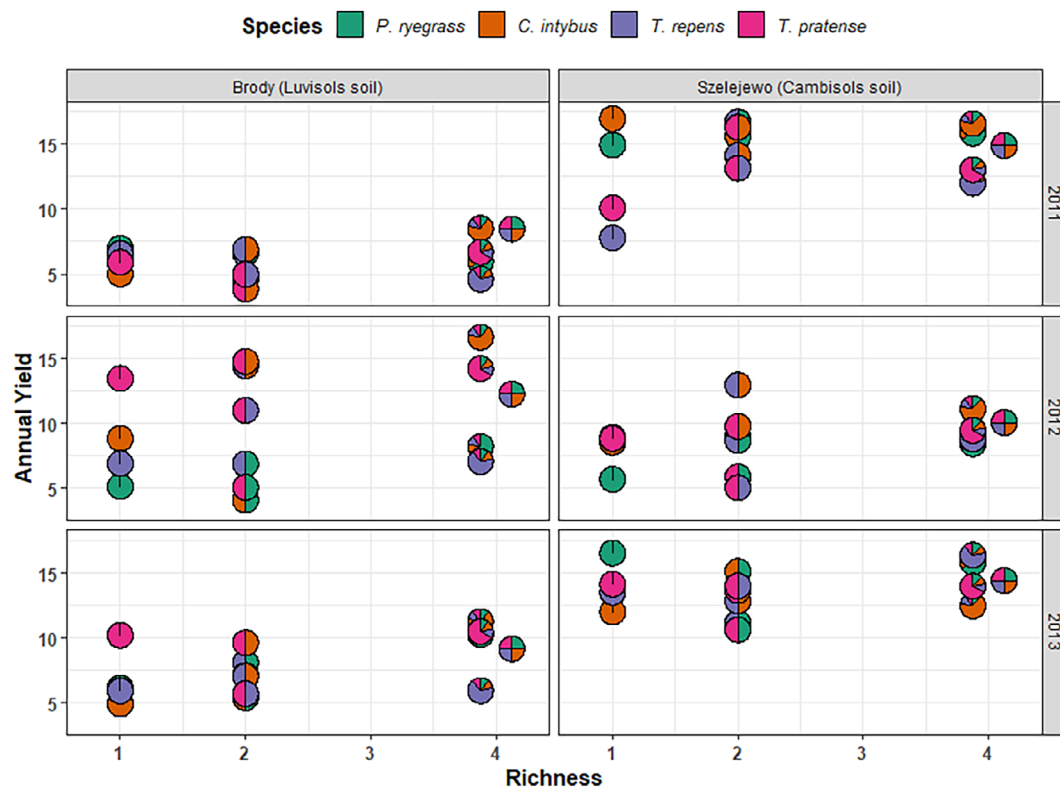


FIGURE A2 Variation in the annual yield: The variation in annual yields for the different communities in the experiment at each level of richness between both sites over the 3 years is shown. The pie-glyphs show the proportions of each species within the community. The communities are dodged by evenness for better visibility. Only the yields for communities sown at low seeding density are for better visibility and similar patterns were observed for communities at high seeding density too.

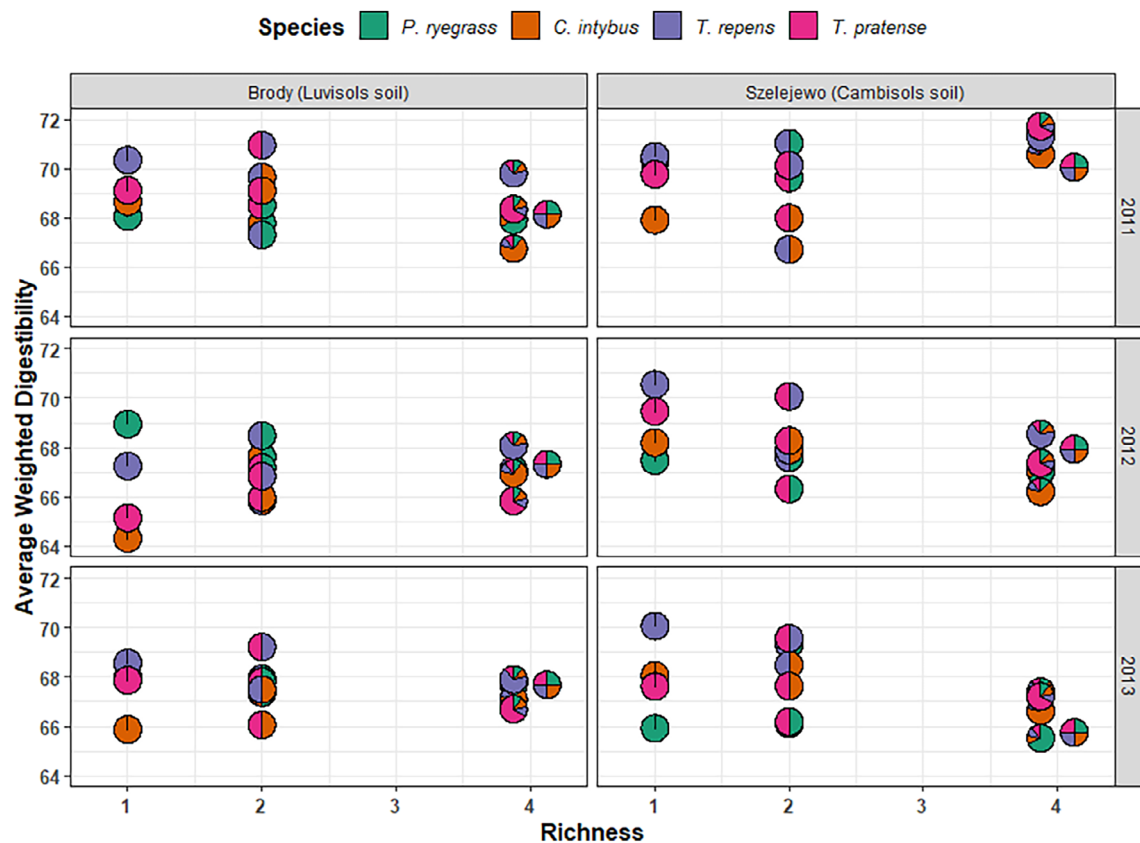


FIGURE A3 Variation in the weighted average digestibility: The variation in the weighted average digestibility for the different communities in the experiment at each level of richness between both sites over the 3 years is shown. The pie-glyphs show the proportions of each species within the community. The communities are dodged by evenness for better visibility. Only the digestibility values for communities sown at low seeding density are for better visibility and similar patterns were observed for communities at high seeding density too.

FIGURE A4 (a) Percentage overyielding in annual DM yield and (b) Percentage overyielding in average DMD: Overyielding, that is the additional yield in mixtures due to the diversity effect expressed as a percentage of the weighted average of the species identities for the different communities in the study over the 3 years and across the two sites is shown. *_D is the mixture dominated by the specific species where the proportion of dominant species is 70% and that of other three is 10%. Centroid is the community with all species being equi-proportional at 25% each.

