RESEARCH ON THE INFLUENCE OF TEMPORARY GRASSLAND ROTATION ON ARABLE CROPS SUITABLE FOR THE FAGARAS COUNTRY
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CERCETĂRI PRIVIND INFLUENȚA ROTAȚIEI PAJIȘTILOR TEMPORARE ASUPRA CULTURILOR ARABILE PRETABILE PENTRU ȚARA FĂGĂRAȘULUI

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ABSTRACT
Temporary grasslands are recognized both for their ecological functions, such as nutrient cycling, soil quality, and also for their potential role within crop rotation frameworks. While many studies have shown the agronomic and environmental benefits of permanent grasslands, fewer have analysed the impact of temporary grassland phases as precursors, influencing coming crops in terms of system stability or yield. Results are often mixed or contradictory in the academic literature, due to methodological limitations or insufficient statistical power. The current long-term study (2008-2014) investigates the role of grassland as a precursor to suitable arable crops (potatoes, spring wheat, silage maize and forage turnips), on a rotation-based empiric design, focusing on temporal variability, yield fluctuations and the broader agronomical context in which these changes occur. Using multi-year data, we look at crop yield performance, and discuss results offering suggestions for future research. To account for structural yield differences among crops, yields were standardized within crop categories, allowing for a unified analytical framework. Results from factorial ANOVA models indicate that grassland phases contribute to yield stabilization rather than a uniform increase in production of other crops, with outcomes influenced by crop type and stationary area conditions. Our results suggest that grasslands have the potential to enhance system resilience and are valuable for sustainable crop production under increased environmental uncertainty.

REZUMAT
Pajiștile temporare sunt recunoscute atât pentru funcțiile lor ecologice, cum ar fi ciclul nutrienților, calitatea solului, cât și pentru rolul lor potențial în cadrul rotației culturilor. Deși multe studii au arătat beneficiile agronomice și de mediu ale pajiștilor permanente, mai puține au analizat impactul pajiștilor temporare ca precursori, influențând culturile viitoare în ceea ce privește stabilitatea sistemului sau producţiei. Rezultatele sunt adesea mixte sau contradictorii în literatura academică, din cauza limitărilor metodologice sau a statisticii insuficiente. Studiul actual, pe termen lung (2008-2014), investighează rolul pajiștilor ca precursor al culturilor pretabile în arabil (cartof, grâu de primăvară, porumb siloz și sfeclă furajeră), pe baza unui design empiric bazat pe rotație, concentrându-se pe variabilitatea temporală, fluctuațiile producţiei și contextul agronomic mai larg în care au loc aceste schimbări. Folosind date multianuale, analizăm performanța producţiei culturilor și discutăm rezultatele oferind sugestii pentru cercetări viitoare. Pentru a ține cont de diferențele structurale de randament între culturi, randamentele au fost standardizate în cadrul categoriilor de culturi, permițând un cadru analitic unificat. Rezultatele modelelor factoriale ANOVA indică faptul că pajiștile contribuie la stabilizarea producţiei, mai degrabă decât la o creștere uniformă a producției altor culturi, rezultatele fiind influențate de tipul de cultură și de condițiile staționare zonale. Rezultatele noastre sugerează că pajiștile au potențialul de a spori rezistența sistemului și sunt valoroase pentru producția agricolă durabilă în condiții de incertitudine crescută a mediului.

INTRODUCTION
Sustainable agricultural systems emphasize the use of crop rotation systems and the inclusion of temporary grasslands as strategies to enhance soil fertility, increase nutrient retention and boost system resilience. Temporary grasslands are commonly linked to improved soil structure, favourable biological activity and enhanced organic matter contents, factors that can increase yield in the right climatic conditions (*Bender et al., 2018, Dragomir et al., 2023*).

Despite the aforementioned theoretical advantages, empirical results in field data remain inconsistent, often exhibiting mixed results. Some studies report yield increases in arable crops after a grassland precursor, while others observe neutral or crop-specific effects. A key limitation of the academic literature lies in the heterogeneity of crop types, different soil types found in a wide variety of climatic conditions, and data collected from vastly different experimental designs, which often limit the statistical power of statistical analyses.

This study tries to address some limitations by adopting an integrated analytical model which evaluates yield responses across crops. As reflected by the domain-specific literature, the main advantages that crop rotation provides are: improving soil fertility (*Al-Musawi et al., 2025, Yang et al., 2024*), reducing soil erosion *(Moldavan et al., 2024*), weeds control (*Bender et al., 2018, Weisberger et al., 2019*), increasing soil water uptake and storage (*Shah et al., 2021, Xiao et al., 2025*) reducing greenhouse gas emission from agricultural fields (*Murakami and Iizumi 2025, Saghai et al., 2025, Yang et al. 2024*), reducing mineral fertilizer requirements (*Gokhale and Sharma, 2023, Tzemi et al., 2024*) and improving yields (*Murakami and Iizumi, 2025, Syromiatnykov et al., 2026*).

The inclusion of grasslands in crop rotation presents advantages in terms of productivity (*Wozniak, 2021, Szkutnik-Sroka et al., 2024, Xiao et al., 2025*) and economical returns (*Hassaan et al., 2024, Otto et al., 2023, Smith et al., 2017*), as well as taking into account other functions, such as the protection of water quality (*Mancinelli et al., 2025*), soils (*Francis et al., 2024, Struijk et al., 2026, Ungureanu et al., 2015*), biodiversity (*Li et al., 2019, Chopin et al., 2026, Choudhary et al., 2026*), landscape conservation and its regulatory role of biogeochemical cycles (*Dragomir et al., 2023, Mocanu, 2018, Page et al., 2025*).

Grasslands leave an appreciable amount of biomass in the soil that improves soil fertility (*Li et al., 2019, Frelih-Larsen et al., 2022, Szkutnik-Sroka et al., 2024*). Organic fertilization of land is an operation that has a positive influence on the humus content and physical properties of the soil (*Ball et al., 2005, Zhong et al., 2021, Zheng et al., 2023*). Since the usage of organic fertilizers can be difficult and expensive, the recommended procedure is to perform a rotation between grasslands and crops that are suitable for a specific area (*Fang et al., 2025, Socolar et al., 2021*).

This paper presents the results obtained by the Research-Development Institute for Grassland Brașov from Romania, in the experimental field from Făgăraș Country, during the period 2008-2014. The objective of long-term study was to investigate the role of grassland as a precursor to suitable arable crops, on a rotation-based empiric design, focusing on temporal variability, yield fluctuations and the broader agronomical context in which these changes occur. Although data collection ended in 2014, our multi-year design remains directly relevant to current climate-adaptation and sustainability frameworks, which continue to rely on crop diversification practices, including temporary grasslands as a low-input strategy for stabilizing yields under increased climate variability.

MATERIALS AND METHODS

The experimental field was located in the Făgăraş Country (a central zone of Romania), on the land of a mixed farm in Drăguș, Brașov County, at an altitude of 520 m. The soil type of the experimental field was Podzolic, with the soil acidity ranging from weak to moderate acid, with value of pH between 4.8 to 4.9 and moderate excess humidity *(Mocanu et al., 2018*). The block method was used, with the experimental field being composed of 3 blocks, each block having 5 variations alternated in 4 repetitions. The experimental field scheme is shown in Fig. 1.

The crop rotation took into account suitable crops for this area and the farm requirements, and consisted of: temporary grassland (grasses + perennial legumes), potato, forage turnips, spring wheat, and silage maize (*Mocanu et al., 2018*).

A complex mineral fertilizer, for the temporary grassland variants, was applied as follows (Mocanu et al., 2018): in 2008 – $N_{100}P_{100}K_{100}$, in 2009 – $N_{50}P_{50}K_{50}$, in 2010 – $N_{50}P_{50}K_{50}$, in 2012 – $N_{50}P_{50}K_{50}$, in 2013 – $N_{100}P_{100}K_{100}$ and in 2014 – $N_{50}P_{50}K_{50}$.

For the temporary grassland, a mixture was used in the following percentage: Grasses 70% and Legumes 30% (*Dragomir et al., 2023, Mocanu et al., 2018*), consisting of species and varieties such as: perennial grasses (*Dactylis glomerata* MAGDA, *Festuca pratensis* TRANSILVAN, *Festuca arundinacea* ADELA, *Phleum pratense* TIROM and *Lolium perenne* MATHILDE) and perennial legumes (*Trifolium pratense* ALTASWEDE, *Trifolium repens* RIVENDEL and *Lotus corniculatus* – LOTANOVA).

Fig. 1 - Scheme of the experimental field in Făgăraș Country
(Mocanu et al., 2018)

Climatic conditions varied among years (Table 1): 2012, 2013, 2014 were dry, 2010 was rainy, and 2008, 2009 and 2011 had normal values, with precipitation amounts close to the multiannual average (*Mocanu et al., 2018*).

[Table 1]

Climatic conditions in Făgăraș Country (*Mocanu et al., 2018*)

		2008	2009	2010	2011	2012	2013	2014
Average air temperatures, [ºC]	Annual average	8.5	8.9	9.3	10.6	8.8	9.1	9.5
	MAA	7.9	7.9	7.9	8.0	8.0	8.0	8.0
	Deviation	0.6	+1.0	+1.4	+2.6	+0.8	+1.1	+1.5
Atmospheric precipitation [l·m^{-2}]	Annual amount	633.6	674.6	841.3	573.5	493.0	491.7	491.3
	MAA	651.5	647	647	600.0	600.0	600.0	600.0
	Deviation	-17.9	+27.6	+194.3	-26.5	-107.0	-108.3	-108.7

MAA-Multi Annual Average

From the data presented in Table 2, it results that the soil on which the experimental field was located, in the 0...10 cm profile, is strongly acidic, poorly supplied in P and moderately supplied in K, and in the 10...20 cm area, the soil is strongly acidic, very poorly supplied in P and poorly supplied in K.

[Table 2]

The main agrochemical properties of the soil (*Mocanu et al., 2018*)

No.	**Sampling depth** (cm)	**pH**	**Hydrolytic Acidity**	**Sum of Bases**	**V** (%)	**Humus** (%)	**Nitrogen Index**	**P-AL**	**K-AL**
			me at 100 g soil					(ppm)	(ppm)
1	0...10	4.8	10.5	4.8	31.3	1.84	3.70	10.8	90.0
2	10...20	4.9	10.0	4.0	28.5	7.87	2.24	7.4	36.0

Next, the yields of potato, spring wheat, silage maize, and forage turnip grown in rotation after at least one year of temporary grassland are analysed.

Potato yields

In 2009 (normal values in terms of precipitation), potato production was 25.60 t/ha for the A1 alternative (preceding crop: temporary grassland 1st Year) and 35.10 t/ha for the B2 option (preceding crop: temporary grassland 1st Year).

In 2010 (rainy), potato production was 29.50 t/ha for the A5 option (preceding crop: 2009-temporary grassland 1st Year; 2008-silage maize), 27.20 t/ha for B1 (preceding crop: 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year), 26.30 t/ha for C2 (preceding crop: 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

In 2012 (dry), potato production was 11.47 t/ha for the B4 option (preceding crop: 2011- temporary grassland 1st Year; 2010-silage maize; 2009-forage turnip; 2008-temporary grassland 1st Year), compared to 13.97 t/ha for C1 (preceding crop: temporary grassland, 4th Year).

In 2013 (dry), potato production was 22.16 t/ha for the A3 group (preceding crop: 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-silage maize; 2009-forage turnip; 2008-spring wheat), compared to 31.27 t/ha for the B2 option (preceding crop: 2012-forage turnip; 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-potato; 2008-temporary grassland 1st Year) and respectively 29.14 t/ha for C2 (preceding crop: 2012-silage maize; 2011-temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

In 2014 (dry) potato production was 29.90 t/ha for the A2 option (preceding crop: 2013-forage turnip; 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-spring wheat; 2008-potato), compared to 41.70 t/ha for B3 (preceding crop: 2013-spring wheat; 2012-silage maize; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-spring wheat; 2008-temporary grassland 1st Year) and respectively 37.70 t/ha for the C4 alternative (preceding crop: 2013-forage turnip; 2012-spring wheat; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

Spring wheat yields

In 2009 (standard in terms of precipitation), the spring wheat production was 3.580 t/ha for option A2 (preceding crop: 2008-potato) and 4.370 t/ha for B3 (preceding crop: temporary grassland 1st Year). In the case of option B3, a positive influence of temporary grassland on spring wheat yield is observed, materializing as a 22 % production increase.

In 2010 (a rainy year) the spring wheat production was 2.075 t/ha in the case of option A1 (preceding crop: 2009-potato; 2008-temporary grassland 1st Year), 1.990 t/ha for option B2 (preceding crop: 2009-potato; 2008-temporary grassland 1st Year), 2.112 t/ha in the case of C3 (preceding crop: 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

In 2012 (a dry year), the spring wheat production was 4.253 t/ha for the B1 option (preceding crop: 2011-temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year), compared to 3.858 t/ha in the case of C4 (preceding crop: 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). It can observe that a good production was obtained in both variants, after temporary grassland 2nd Year followed by a potato and forage turnip crop, respectively.

In 2013 (a dry year), the spring wheat production was 2.553 t/ha in the case of option A4 (preceding crop: 2012-temporary grassland 3rd Year; 2011-temporary grassland 2nd Year; 2010-temporary grassland 1st Year; 2009-silage maize; 2008-forage turnip), compared to 3.267 t/ha for B3 (preceding crop: 2012-silage maize; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-spring wheat; 2008-temporary grassland 1st Year) and respectively 3.508 t/ha for option C5 (preceding crop: 2012-temporary grassland 1st Year; 2011-temporary grassland 1st Year; 2010-silage maize; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

In 2014 (a dry year), the spring wheat production was 4.312 t/ha for option A3 (preceding crop: 2013-potato; 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-silage maize; 2009-forage turnip; 2008-spring wheat), compared to 3.190 t/ha in the case of B2 (preceding crop: 2013-potato; 2012-forage turnip; 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-potato; 2008-temporary grassland 1st Year) and respectively 3.550 t/ha for the C3 option (preceding crop: 2013-silage maize; 2012-forage turnip; 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

Silage maize yields

In 2009 (standard levels of precipitation) the silage maize yield was 47.81 t/ha GM-Green Mass (19.64 t/ha DM-Dry Matter) in case of option A4 (preceding crop: 2008-forage turnip) and 48.48 t/ha GM (21.31 t/ha DM) in case of B5 (preceding crop: temporary grassland 1st Year). In B5, a positive effect of meadow on silage maize yield was observed, resulting in a 1.4% increase.

In 2010 (a rainy year), the silage maize production was 41.63 t/ha GM (14.89 t/ha DM) in the case of A3 (after: 2009-forage turnip; 2008-spring wheat), 37.60 t/ha GM (12.60 t/ha DM) for B4 (preceding crop: 2009-forage turnip; 2008-temporary grassland 1st Year), 53.10 t/ha GM (16.45 t/ha DM) in the case of C5 (preceding crop: 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

In 2012 (a dry year), the silage maize production was 8.95 t/ha GM (5.09 t/ha DM) in B3 (preceding crop: 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-spring wheat; 2008-temporary grassland 1st Year), compared to 10.10 t/ha GM (6.17 t/ha DM) in the case of C2 (preceding crop: 2011- temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). In option C2, a positive influence of the temporary grassland on the silage maize production is observed, with a production increase of 12.85 %.

In 2013 (a dry year), silage maize production was 64.51 t/ha GM (25.28 t/ha DM) in the case of A5 (preceding crop: 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 1st Year; 2008- silage maize), compared to 50.81 t/ha GM (19.95 t/ha DM) in the B1 option (preceding crop: 2012-spring wheat; 2011-temporary grassland 1st Year; 2010-potato; 2009- temporary grassland 2nd Year; 2008-temporary grassland 1st Year) and respectively 52.73 t/ha GM (22.28 t/ha DM) for C3 (preceding crop: 2012-forage turnip; 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). For option A5, a positive influence of meadow (preceding crop: meadow 2 years) on silage maize production is observed, with a production increase of 26.96 % compared to B1 and 22.34 % compared to option C3.

In 2014 (a dry year), silage maize production was 45.12 t/ha GM (17.53 t/ha DM) in the case of the A4 design (preceding crop: 2013-spring wheat; 2012-temporary grassland 3rd Year; 2011-temporary grassland 2nd Year; 2010-temporary grassland 1st Year; 2009-silage maize; 2008- forage turnip), compared to 32.00 t/ha GM (12.84 t/ha DM) for B5 (preceding crop: 2013-temporary grassland 4th Year; 2012-temporary grassland 3rd Year; 2011-temporary grassland 2nd Year; 2010-temporary grassland 1st Year; 2009-silage maize; 2008-temporary grassland 1st Year) and respectively 45.00 t/ha GM (16.96 t/ha DM) on option C1 (preceding crop: 2013-temporary grassland 1st Year; 2012- potato; 2011-temporary grassland 4th Year; 2010-temporary grassland 3rd Year; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

Forage turnip yields

In 2009 (standard year in terms of precipitation), the production of forage turnip was 56.30 t/ha in A3 (preceding crop: 2008-spring wheat) and 51.80 t/ha in B4 (preceding crop: temporary grassland 1st Year). For option B4, a negative influence of meadow on forage turnip production is observed, with a production decrease of 7.99 %.

In 2010 (a rainy year), the production of forage turnip was 68.10 t/ha in the A2 design (after: 2009-spring wheat; 2008-potato), 51.85 t/ha for B3 (preceding crop: 2009-spring wheat; 2008-temporary grassland 1st Year), 72.55 t/ha for option C4 (preceding crop: 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). In the case of C4, a positive influence of the meadow on the production of forage turnip is observed, with a production increase of 39.92 % compared to option B3 and a production increase of 6.53 % compared to A2.

In 2012 (a dry year), the production of forage turnip was 28.50 t/ha in B2 (preceding crop: 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-potato; 2008-temporary grassland 1st Year), compared to 30.50 t/ha in C3 (preceding crop: 2011-temporary grassland 1st Year; 2010-spring wheat; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). In the case of option C3, a positive influence of the grassland on the production of forage turnip is observed, with an increase in production of 7.02 %.

In 2013 (a dry year), the production of forage turnip was 40.82 t/ha for A2 (preceding crop: 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-spring wheat; 2008-potato), compared to 40.07 t/ha MV in the B4 alternative (preceding crop: 2012-potato; 2011-temporary grassland 1st Year; 2010-silage maize; 2009-forage turnip; 2008-temporary grassland 1st Year) and respectively 35.85 t/ha for C4 (preceding crop: 2012-spring wheat; 2011-temporary grassland 1st Year; 2010-forage turnip; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year). In A2, a positive influence of the grassland (preceding crop: temporary grassland 2nd Year) on the production of forage turnip is observed, with a production increase of 2.00 % compared to B4 and respectively 13.86 % compared to C4.

In 2014 (a dry year), the production of forage turnip was 58.45 t/ha for A5 (preceding crop: 2013-silage maize; 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 1st Year; 2008-silage maize), compared to 43.50 t/ha in B1 (preceding crop: 2013-silage maize; 2012-spring wheat; 2011-temporary grassland 1st Year; 2010-potato; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year) and respectively 50.08 t/ha for C5 (preceding crop: 2013-spring wheat; 2012-temporary grassland 2nd Year; 2011-temporary grassland 1st Year; 2010-silage maize; 2009-temporary grassland 2nd Year; 2008-temporary grassland 1st Year).

Hypotheses

This study aims to investigate the role of temporary grassland as a precursor in arable crop rotation using a multi-year plot-based experimental design. The overall main objective is to assess whether the duration of grassland preceding an arable crop can influence yield, and whether this effect varies across crops and annual climatic conditions.

H1: Grassland duration produces a general effect on crop yields across a multi-crop design.

H2: The effect of grassland duration differs among crop types.

H3: Inter-annual variability and climatic conditions have an effect on the relation between the variables in H1 and H2.

Data structure and empirical analyses

This study exhibits a plot-based crop rotation dataset (as previously referenced in Figure 1), followed across several consecutive years. The structure of the data collected over the years follows a longitudinal structure, with each row corresponding to a unique year and plot variant combination, including current crop, previous crop, and yield (t/ha). Statistical analyses were conducted using SPSS Version 26.

As exhibited in Figure 1, 2011 is a rest year, in which grassland was used to preserve crop rotation continuity and to compute grassland duration as a precursor for the next crops. This does not bias the statistical analyses, because the yield was a dependent variable measured only for the arable crops, therefore grassland yield is not an outcome in the present study.

Our variables of interest are:

-The independent variable (IV): grassland duration as a precursor, which was coded for statistical analyses into two categories, namely a) grass_consec_years, which represents the number of consecutive grassland years immediately preceding the current year, and b) grass_duration_cat, the categorical version for analysis (0- no grassland, 1- temporary grassland 1st Year, 2- temporary grassland 2nd Year, 3 and 3+ years- 3 or more years of consecutive grassland);

-The dependent variable (DV): yield, measured in tonnes per hectare (t/ha), analysed separately for each arable crop (potatoes, spring wheat, silage maize and forage turnips);

-Context variable: year, representing the inter-annual variability and the climatic context and year-specific management. ‘NPK’ (the complex mineral fertilizer applied on the plots of land) is collinear with ‘year’ because the annual dose is constant across crops within the same year.

Climatic conditions were classified into three categories, namely dry, normal or rainy, based on the aggregated annual rainfall patterns.

RESULTS

Given the small sample size per crop, factorial models with interactions (duration x year) could lead to unstable estimates, therefore, these analyses have been avoided. Also, due to the large inherent differences in absolute yield levels, direct comparison of raw yield figures would have been misleading. To address this and ensure accuracy, yields were standardized within each crop category using Z-scores. This statistical procedure preserves within-crop variability, while enabling a unified analysis across crops. This way, we were able to focus on relative yield performance rather than absolute magnitudes.

Factorial analysis of variance (ANOVA) models was applied using Type III sums of squares to account for unbalanced designs. The primary model included crop type, year, and grassland duration as fixed factors, along with the interaction between grassland and crop.

A secondary model examined the influence of climatic category in place of year, in order to avoid degrees-of-freedom limitations. Statistical significance was evaluated at $\alpha = 0.05$. Effect sizes were quantified using partial eta squared (ηp^2).

It appears that the overall model explained a substantial proportion of yield variability (R^2=0.587, adjusted R^2=0.443).

A significant main effect of year was observed (F=6.63, p<0.001, ηp²=0.334), indicating a strong interannual variability in yield across the study period.

It has been noted that the main effect of grassland duration did not appear to reach conventional significance level (p=0.098) suggesting that grassland duration alone does not impose a uniform influence on yield across all crops.

In contrast the interaction between crop type and grassland duration was highly significant (F=4.90, p<0.001, ηp²=0.450). This interaction accounted for a significant size of explained variance and demonstrating that the yield response to grassland duration differs significantly amongst crops.

As shown in Figure 2 and Table 3, mean standardized yields vary little across grassland duration categories, while variability increases noticeably for longer grassland phases.

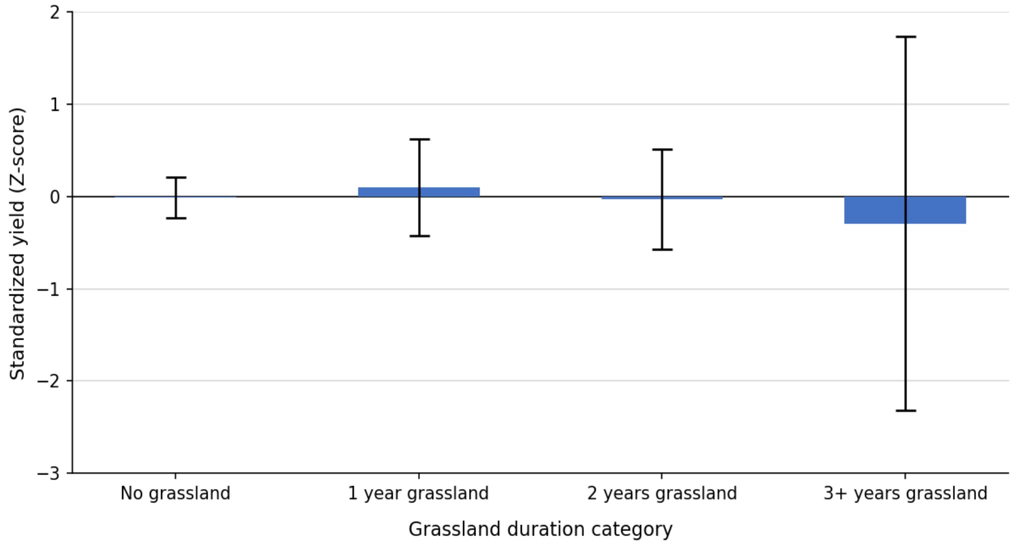

Fig. 2 - Mean standardized crop yield (Z-score) across grassland duration categories

Error bars represent 95 % confidence intervals. Yield values were standardized within crop types to account for inherent yield differences among crops. Short-term grassland phases (1–2 years) are associated with stable or slightly positive standardized yields, while the 3+ years category exhibits high variability due to limited sample size and should be interpreted with caution.

In addition, the main effect of the crop type itself was not significant once yields were standardized thus confirming that the study focus on interaction dynamics rather than crop level differences.

In the climate-based model, the climatic category showed a significant main effect on standardized yields (F=4.70, p=0.012, ηp²=0.125) highlighting the importance of environmental conditions.

At the same time, the crop x grassland duration interaction remained highly significant (p<0.001) indicating that the crop specific nature of grassland effects carry-on across climatic context. The interaction between climate and grassland duration was not significant suggesting that the climate variates overall yield levels rather than fundamentally altering grassland response patterns.

Table 3

Mean standardized crop yield (Z-score) by grassland duration category

Z-score (yield)			
Grass_duration_cat	**N**	**Mean**	**Std. Deviation**
No grassland	47	-.0133900	.73873321
1 year grassland	25	.1001461	1.27145984
2 years grassland	13	-.0306740	.90286311
3+ years grassland	5	-.2951118	1.62858376
Total	90	.0000000	.97726976

CONCLUSIONS

The results provide insight on effects of temporary grassland on crop yields are not uniform across cropping system. Instead of depicting a universal yield enhancing factor, the grassland duration interacts strongly with specific crops by producing divergent responses depending on crop specific physiological and agronomic characteristics.

Yield values were standardized within crop types. The 3+ years category shows increased dispersion due to limited sample size and should be interpreted with caution.

The absence of a significant main effect of grassland duration should not be interpreted as proof of ineffectiveness. Instead, it reflects the ecological reality that the soil-mediated benefits of grasslands are context-dependent. Crops with higher nutrient demands or greater sensitivity to soil structure appear to benefit differently from grassland phases than crops with lower input requirements.

The strong year effect highlights the role of interannual variability, reinforcing the importance of a long-term observation for further evaluating rotational effects. Climatic conditions further influenced yields but did not negate the crop dependent nature of grassland impacts.

Overall, these findings support the interpretation of temporary grasslands as a stabilizing component within crop rotations. Their primary contribution appears to consolidate yield variability and enhancing system resilience rather than maximizing mean yields across all crops.

In terms of limitations, we noted the use of the aforementioned complex mineral fertilizer NPK whose effect cannot be separated from year effects as they are constant within year across all crops. Another limitation reflects the small sample size per crop and sparse duration categories, which limits inference strength. To address any analysis-related constraints, yields were standardized within crops and analysed collectively. This approach prioritizes the detection of interaction patterns and of system-level responses when it comes to mean differences for a crop. Results must be interpreted with caution, as this exploratory study should be replicated on more crops and repetitions, in order to gather a wider variety of data for ease of comparison. Future research should combine more numerous datasets with mixed-effects statistical modeling, to further identify crop variations in different environmental conditions.

Our study is explorative research which has opened up valuable avenues for future research, while also consolidating existing academic knowledge on crop variation. It investigated the role of temporary grassland as a precursor for arable crop rotation, with the main result indicating that grassland influence crop yields primarily through crop-specific interactions, rather than a uniform main effect on crops. Grassland duration strongly interacts with the crop type, generating yield stability across variable climatic conditions. These findings challenge simplistic assumptions of universal yield enhancement, following grassland phases and instead emphasize the role of grasslands in promoting resilience and functional diversity within agricultural systems. From both an agronomic and methodological perspective, evaluating interaction structures across crops provides a more realistic understanding of rotational benefits in sustainable agriculture.

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