



CROP TYPE, FIELD POSITION, AND LANDSCAPE LEGACY AS DRIVERS OF WEED SEED-BANK DIVERSITY IN AGRICULTURAL ECOSYSTEMS

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Abstract

Weed seed banks provide an integrated record of past cropping, spatial heterogeneity, and long-term management within agricultural ecosystems. This study evaluated how crop type, field position, and landscape legacy were associated with weed seed-bank diversity across 24 paired samples from 12 agricultural fields. The dataset comprised 40 weed species from 19 botanical families and 1,458 emerged individuals. Seed-bank structure was assessed using species richness, total abundance, Shannon diversity, Simpson diversity, and community composition. Maize-associated samples exhibited the highest mean richness and abundance, but differences among maize, soybean, and wheat–soybean fields were not statistically significant. Field-position contrasts likewise showed no significant differences, although one position supported greater abundance while the other maintained higher diversity and evenness. In contrast, pronounced field-to-field variation and a stronger regional signal in community composition indicated a greater influence of persistent site conditions and cropping-history legacy. NMDS and PERMANOVA further showed substantial overlap among crop and field-position groups, suggesting that short-term agronomic categories alone did not account for the observed heterogeneity. Dominance by *Portulaca oleracea* and *Amaranthus quitensis* also contributed strongly to differences in community structure. Overall, weed seed-bank diversity was more closely associated with persistent site-level and historical influences than with short-term crop identity or field position.

Keywords: weed seed bank; crop type; field position; landscape legacy; community composition



1. Introduction

Weed seed banks are an important part of weed ecology and longer term crop management as they are the below-ground source from which future weed populations emerge. They are small, diverse, and composed, and their size, composition and diversity reflects the impact of past and current agronomic practices, such as crop rotation, tillage, fertilization, residue management, weed-control interventions and more. Seed-bank structure may carry ecological signals from previous phases of land use and management due to many weed seeds being able to survive in the soil for long periods. Weed seed banks can therefore be used not only as a tool for analysing the impact of crops today, but also to understand longer-term legacies of weed seed in agricultural landscape.

Weed seed banks can be greatly affected by management practices with respect to abundance and diversity. Under intensive rice-based rotations, Hossain et al. (2021) demonstrated that strip tillage with Crop Residue Retention (SR) not only minimized weed seed-bank but also increased weed diversity, suggesting that weed management might also promote a more diverse weed community. The effect of farming intensity on the composition of soil seed-bank and spontaneous arable vegetation was also shown by Köllmann and Waldhardt (2022), who also confirmed that a cumulative disturbance pressure affects weed communities, rather than a specific disturbance in isolation. The results reinforce the need for using different ecological parameters to estimate the seed bank (species richness, seed abundance, diversity indexes and community composition).

Another important factor affecting the dynamics of the weed seed bank is crop sequence. The competitive environment, planting timing, crops' canopy dynamics and disturbance regimes, as well as herbicide programmes, differ among crops and affect weed recruitment and seed return to soil. Weeding seed density, species diversity and community structure changed after 13 years of crop rotation with chemical and organic fertilization, as reported by Nath et al. (2022). Ghosh et al. (2023) reported similar evidence in favour of different responses of weeds in above-ground and seed-bank to conventional and conservation agriculture in a maize–wheat–mungbean cropping system. Combined, these studies indicate that there may be measurable signatures of the ecological legacy of crop identity and rotation history in the below-ground weed community.

Local environmental and management conditions also affect the effect of crop type. Weed management practices also had a significant effect on the standing weed population and soil seed bank in rice (Ramessh, 2022) and weed seed-bank characteristics varied between sandy and clay soils across different weed management practices (Sharshar et al., 2022). This variation suggests that the same crop or weed-control practice can have different seed-bank results based on the site-specific soil characteristics and the previous management history. Therefore, patterns of weed abundance and diversity need to be evaluated in the context of the field level, in addition to crop identity.

There is the added complexity of spatial context. The disturbance intensity, seed dispersal, vegetation connectivity, and establishment opportunities for weeds can vary within agricultural fields, depending on location, including crop interiors, margins, and transitional areas. In larger spatial extents, climatic, soil, crop and agricultural management differences can also influence community structure. Ren et al. (2024) demonstrated a geographical and historical context for weed seed-bank diversity and composition in herbicide-resistant crop systems in the United States. This indicates that spatial variability in weed communities may be caused by other site-level or landscape processes that occur over long time scales, as well as by short-term crop effects.



Long-term management history may also impact weed community functional structure. Repeated agronomic practices can lead to selection of specific life-history strategies, as shown by Allen et al. (2024), who showed that long-term organic systems with repeated tillage or with repeated cropping favoured specific life-history strategies compared to systems with repeated crop rotation. Similarly, McKenzie-Gopsill et al. (2024) demonstrated the influence of cultural practices on weed-community and seed-bank dynamics in a potato rotation. These results corroborate other ecological legacy studies, in which plant communities are considered a reflection of long-term ecological and management changes across seasons.

Although there is a wealth of evidence on this topic, few studies have investigated crop type, within-field position and longer-term site and landscape legacy together to account for weed seed-bank diversity. The majority of the previous research has been on a single management factor, crop rotation or regional differences individually. These dimensions are relevant as long-term crop effects can be weak or non-existent in the presence of persistent field-level and historical effects. This can allow for a distinction between short- and long-term impacts of agriculture on the ecosystem.

The present research thus investigates the diversity of weed seed-banks as a function of crop species, field location and landscape history in agricultural fields. Species richness, total abundance, Shannon diversity, Simpson diversity and community composition are used to assess seed-bank structure. The study aims to find out if current crop conditions or landscape and management legacy have greater influence on weed seed-bank structure by comparing the differences in these short-term crop-associated patterns with the differences in landscape locations that persist in the absence of cultivation.

2. Methodology

2.1 Study Design and Data Source

The variation in weed seed-bank diversity among crop types, field position and landscape-legacy conditions was examined using a quantitative observational design. An open-access database of records of weed seed-bank emergence at the species level in agricultural fields in the Rolling Pampas, Argentina (Devoto, 2026) was used for the analysis. Thirty-eight-seven records were retained (24 samples of weed communities from 12 agricultural fields after blanks were removed). A total of 40 species of weeds representing 19 botanical families and 1,458 emerged individuals were included in the dataset. Within each field two paired sampling locations were provided to enable comparison of weed seed-bank characteristics under paired field structure.

2.2 Data Preparation and Variable Definition

Data consisted of year, observation date, location, field number, sample location, plant family, genus, species, abundance, origin, morphology, life cycle, weed status, problematic-weed classification and sowing status. Data cleaning was conducted to eliminate empty data, trim data to remove unnecessary spaces, and standardize capitalization and species and sample identifiers. The abundance of repeated emergence observations were summarized by adding emergence dates together for the same species and field-position combination. Crop-history information from summer 2021–2022, winter 2022,



summer 2022–2023, and winter 2023 was retained. Crop type was assigned based on the previous summer's crop – maize, soybean or wheat-soybean.

2.3 Diversity and Landscape-Legacy Measures

Species richness, abundance, Shannon diversity and Simpson diversity were used to measure the diversity of weed seed-bank. Species richness – number of species found; Total abundance – number + emerged individuals. Shannon diversity was employed to measure both richness and evenness and Simpson diversity was employed to measure the dominance within weed communities. The two sets of sampling categories in each field represented field position. Direct GIS-based landscape measurements were not available, which led to a persistent interpretation of landscape legacy from site to site, region to region, field to field and multi-season crop histories.

2.4 Descriptive and Comparative Analysis

Species richness, abundance, Shannon diversity and Simpson diversity were calculated to produce descriptive statistics. These were mean, minimum, maximum, standard deviation and relative abundance. Diversity values were aggregated by crop categories and field locations, respectively. Paired comparisons were used to compare differences between paired field positions, and paired t-tests for normally distributed distributions, Wilcoxon signed-rank tests for non-normal distributions. ANOVA was used to assess differences between crop categories (where assumptions of ANOVA were met), and Kruskal–Wallis tests were used as non-parametric alternatives. A p value of < 0.05 was statistically significant.

2.5 Community Composition Analysis

A matrix of abundance by species was created to test for differences in the composition of weed communities as a whole. Ecological differences among communities were quantified using Bray–Curtis dissimilarity. Non-metric multidimensional scaling was employed to graphically represent similarities and separation between samples based on crop type, field position and site identity. The differences in community composition among the main grouping variables were tested using PERMANOVA. Functional composition was also calculated on an annual and perennial life cycle basis and for grasses compared to dicots, and for native versus exotic origin. The proportional abundance was used to evaluate species dominance and the most abundant weed species were identified. Landscape-legacy effects were conservatively viewed as differences in site- and cropping-history, as opposed to actual measurements of the surrounding landscape configuration.

3. Results

3.1 Overall Weed Seed-Bank Diversity and Species Dominance

The 24 samples yielded 40 weed species and 1,458 emerged individuals as indicated in Table 1. There were a mean of 8.96 ± 4.24 species per sample and a mean of 60.75 ± 70.23 individuals per sample



for the mean species richness and abundance, respectively. The Shannon and Simpson diversities were 1.646 and 0.723 respectively on average. *Portulaca oleracea* was the most abundant species accounting for 20.16% of total abundance as shown in figure 1.

Table 1. Overall characteristics of weed seed-bank diversity across 24 samples

Diversity measure	Mean	SD	Minimum	Maximum
Species richness	8.96	4.24	2	17
Total abundance	60.75	70.23	2	318
Shannon diversity	1.646	0.526	0.648	2.594
Simpson diversity	0.723	0.160	0.245	0.912

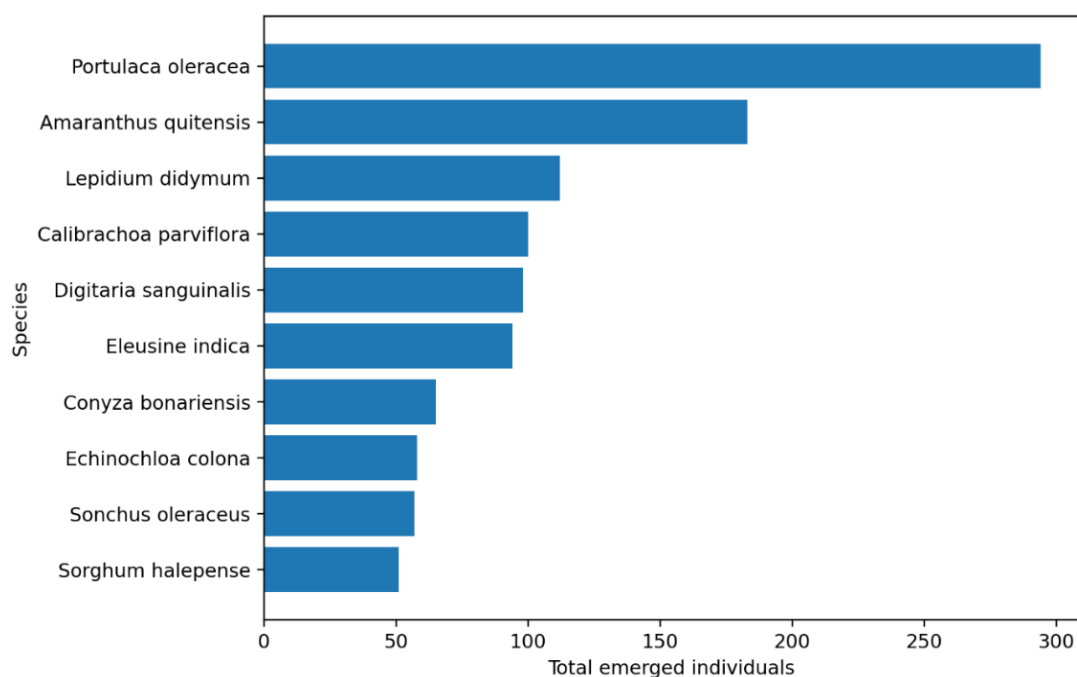


Figure 1. Dominant weed species based on total seed-bank abundance

3.2 Variation in Seed-Bank Diversity among Crop Types

Table 2 shows that maize-associated samples had the highest mean species richness of 9.80 and abundance of 75.40, followed by soybean and wheat-soybean samples. Shannon and Simpson diversity varied only slightly among crop categories.



Table 2. Weed seed-bank diversity according to preceding crop type

Crop type	n	Richness, mean $\pm$ SD	Abundance, mean $\pm$ SD	Shannon, mean $\pm$ SD	Simpson , mean $\pm$ SD
Maize	10	9.80 $\pm$ 4.85	75.40 $\pm$ 96.02	1.689 $\pm$ 0.498	0.735 $\pm$ 0.121
Soybean	8	8.88 $\pm$ 3.60	57.50 $\pm$ 49.89	1.621 $\pm$ 0.616	0.697 $\pm$ 0.227
Wheat– soybean	6	7.67 $\pm$ 4.32	40.67 $\pm$ 40.92	1.609 $\pm$ 0.538	0.736 $\pm$ 0.132

3.3 Effect of Field Position on Weed Seed-Bank Diversity

As presented in Table 3, species richness was nearly identical between positions C and R, averaging 9.00 and 8.92 species, respectively. Position R showed greater mean abundance, whereas Shannon and Simpson diversity were higher at position C.

Table 3. Comparison of weed seed-bank characteristics between paired field positions

Position	n	Richness, mean $\pm$ SD	Abundance, mean $\pm$ SD	Shannon, mean $\pm$ SD	Simpson, mean $\pm$ SD
C	12	9.00 $\pm$ 3.95	47.92 $\pm$ 40.45	1.773 $\pm$ 0.472	0.765 $\pm$ 0.123
R	12	8.92 $\pm$ 4.68	73.58 $\pm$ 91.20	1.519 $\pm$ 0.566	0.681 $\pm$ 0.186

3.4 Field-Level and Landscape-Legacy Variation

Table 4 highlights substantial field-level heterogeneity, with abundance ranging from 2 individuals at CAS3R to 318 at MSU3R and richness ranging from 2 to 17 species. Shannon diversity varied from 0.648 at CAS1R to 2.594 at MSU3C.

Table 4. Selected field-level variation in weed seed-bank diversity

Field-position	Crop history	Richness	Abundance	Shannon	Simpson
MSU3C	Maize	17	85	2.594	0.912
MSU3R	Maize	13	318	1.144	0.522
CAS2R	Maize	16	153	1.956	0.795



CAS1R	Soybean	9	113	0.648	0.245
CAS3R	Wheat-soybean	2	2	0.693	0.500

3.5 Weed Community Composition

Table 5 shows that crop type explained 10.1% of variation in community composition, field position explained 2.7%, and region explained 7.5%. None of these effects reached statistical significance, although the regional pattern was comparatively stronger.

Table 5. PERMANOVA results for weed seed-bank community composition

Factor	Pseudo-F	Variation explained (R^2)	p-value
Crop type	1.182	0.101	0.582
Field position	0.601	0.027	0.836
Region	1.775	0.075	0.080

4. Discussion

Seed-bank communities in weed samples taken from the various agricultural fields were also significantly different in composition, with more differences among the different fields within a crop category than among the previous crop categories or among the field positions within fields. The richness and abundance of maize-associated samples was numerically higher than those of the soybean and wheat-soybean samples, but this was not statistically significant. There were also differing trends in abundance and diversity depending on field position, but no consistent significant trends. The relative strength of regional signal in community composition then suggests that the length of site history and/or agricultural history is likely to be an important driver of seed bank structure.

Soil seed banks serve as a time bank of past vegetation and management. Weed seed-bank composition is a product of their composition at the time they were deposited, and can vary from one season to the next, with composition from the present day reflecting crop rotations, disturbance, weed-control tactics, seed return, dormancy, and local environmental conditions. Kumar et al. (2022) highlighted that weed seed banks are dynamic but persistent part of agroecosystems which are influenced by both biological characteristics and management. This scatter of results from very few emerged plants in some samples to over 300 in others is consistent with this cumulative view and indicates that seed-bank structure as it is now is not only dependent on current crop conditions.

Crop-type effect, though insignificant, cannot be taken as an indication that the identity of a crop is irrelevant. Each crop has different canopy characteristics, sowing dates, residue management, competition, disturbance patterns and weed management strategies which can impact weed establishment and seed carryover. Management context was shown to be important by Kaur et al. (2024) who demonstrated that sowing time and rice-residue management influenced the dynamics of



weed seed-bank in wheat. In the current study the relatively high mean richness and abundance of maize is likely to be related to crop-specific management conditions but the high within-group variation would indicate that field history and local management reduced any consistent crop-level response.

The large differences between the individual fields also highlight the role of site effects to persist. Auffret et al. (2024) highlighted a substantial variability in soil seed-bank richness, density and abundance on a global scale in a synthesis of the available data. Differences were also similar and strong among fields, although the present analysis was done in a more limited agricultural context. These differences may be due to the interaction of soil properties, crop rotation, frequency of disturbance, weed pressure in the past, dispersal of seed, and intensity of management. These processes can result in unique ecologic legacies over time, which can last beyond the recent crop.

An ecological meaningful pattern was also found with field position. The mean abundance was higher in position R and the Shannon and Simpson diversity was higher in position C. This implies that over seeding was not necessarily associated with increased diversity. The evenness was somewhat low despite relatively moderate richness for some samples with high abundance that were largely dominated by relatively few species. There is no significant overall positional effect, which suggests that there was no uniformity of responses in fields. Positional effects varied across sites and may be due to different edge influences, levels of disturbance, seed dispersal, machinery foot traffic, connectivity of vegetation or local weed control.

This is supported by the community-composition analysis. Crop type and field position accounted for comparatively small amounts of Bray–Curtis variation and regional differences exhibited a comparatively stronger pattern. Weed seed-bank community structure was also sensitive to land-use intensity and soil properties, as noted by McKenzie-Gopsill et al. (2025), indicating that more general environmental and historical factors can heavily influence community structure. The significant amount of overlap in the NMDS ordination in this study suggests that the communities were not well organised by short-term agronomic categories. In contrast, site level heterogeneity seems to have played a more significant role in compositional differentiation.

This was also due to species dominance. Nearly one-third of abundance was made up of *Portulaca oleracea* and *Amaranthus quitensis* and a few species made up small percentages. This was an irregular arrangement that can help to understand that samples that were relatively rich may exhibit moderate to low Shannon and Simpson diversities. Therefore, the richness, abundance, and dominance of weed species should be evaluated in tandem with weed evenness when assessing weed seed bank.

These patterns also can change over time due to long-term management, such as alterations in soil conditions and in-field biodiversity. Hawes, et al. (2025) shared that regenerative practices improved biodiversity and soil health, while sustaining productive cropping systems. This highlights the significance of cumulative effects on the management level and the high variability at field level as evidence of ongoing agricultural legacy. Overall, the patterns observed indicate that weed seed-bank diversity is a mixture of past and recent conditions in the crop, and of site-level influences, with the latter more likely to be evident in this data. When planning long-term weed management strategies to reduce weed pressure in the future, cropping history, spatial heterogeneity, dominant species and persistent field characteristics should all be taken into account.



5. Conclusion

Persistent field-level and historical influences were more important in the weed seed-bank diversity of the agricultural fields investigated than the previous agricultural field crop and field position. Maize-associated samples had relatively higher richness and abundance, but the differences between the various crops were not significant. Likewise, paired field positions also varied descriptively in abundance and diversity in a non-consistent fashion across fields. The high inter-site differences in richness, abundance, Shannon diversity, Simpson diversity and community composition emphasize the role of long-term ecological and management legacies in their structuring of weed seed banks. The correspondence between regional patterns and the high level of overlap in weed communities between crop and positional groups also highlight the fact that present weed communities are not solely determined by short-term agronomic conditions. A certain dominance by the few species such as *Portulaca oleracea*, *Amaranthus quitensis*, etc., also shows the importance of taking into account community evenness and species dominance besides richness. Overall, the results reflect a landscape-legacy view of weed seed banks that are a reflection of the cumulative impact of cropping history, site conditions, disturbance, and management practices. Therefore, long-term weed management plans should consider field-specific histories, spatial heterogeneity and dominant weed species rather than just the current crop identity or uniform weed control.

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