Analysis of Weed Seed Bank Dynamics Across Four Different Cropping Systems in Southern Sweden

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Foreword

This thesis, “Analysis of Weed Seed Bank Dynamics Across Four Different Cropping Systems in Southern Sweden”, stands as a milestone in my journey as a student of agroecology at the Swedish University of Agricultural Sciences (SLU).

Coming from Nepal, a country where agriculture has long been the backbone of the economy and society, I have always been interested in how farming systems influence not only crop production but also the environment and the livelihoods of people. For generations, a majority of Nepalese people were engaged in farming, but in recent years, the numbers have been declining as many young people choose to migrate abroad in search of opportunities. This change poses both a challenge and a question how can agriculture be made more resilient, attractive, and sustainable for future generations?

With a background in agricultural sciences from India, and now have the chance to study agroecology in Sweden. I have been able to connect different perspectives, from traditional farming in South Asia to innovative and sustainable systems in Europe. For me, agriculture is not only about producing food but also about sustaining ecosystems and communities, where even weeds reveal how farmers adapt and how resilient their systems can be.

This work reflects not only my academic growth but also my personal journey crossing borders and cultures, learning to adapt, and discovering the common threads that connect farmers from Nepal to Sweden. It is my hope that the findings here will contribute, even in a small way, to building agricultural systems that are more sustainable, diverse, and in harmony with both people and nature.

Acknowledgement

I would like to begin by expressing my gratitude to my supervisor, Johannes Albertsson, and my co-supervisor, Imam Raj Chongtham, from the Department of Biosystems and Technology at SLU. Their guidance, constructive feedback, and encouragement have been invaluable throughout my research. I am especially thankful to Johannes for his invaluable on-site support. He not only provided academic supervision but also helped with practical aspects, such as watering the trays when I could not visit the greenhouse, and also assisted in the counting and identification of weed species. I am equally thankful to Adam Flöhr, whose assistance with the statistical analysis was crucial in interpreting the results of this study.

I am also grateful to Partnership Alnarp for providing the financial support that enabled me to conduct the greenhouse experiment. Without this funding, the practical side of this research would not have been possible.

I would also like to extend my warm thanks to my friends and colleagues at SLU. Their support and encouragement have made this journey both lighter and more enjoyable. The exchange of ideas and experiences with them enriched my time at SLU in countless ways. Finally, I owe my deepest gratitude to my family back home in Nepal. Their love, encouragement, and financial support have been the foundation of my academic journey abroad.

Abstract

Weed seed banks represent a critical component of agricultural ecosystems, influencing both current weed pressure and the long-term resilience of cropping systems. This study investigated the dynamics of weed seed banks across four contrasting cropping systems (conventional, organic, agroforestry, and perennial (Kernza-based), within the SITES Agroecological Field Experiment (SAFE) at Lönnstorp Research Station, southern Sweden. Soil samples were collected from 16 field plots and analyzed under controlled greenhouse conditions to quantify weed seedling emergence, species richness, diversity, and evenness.

A total of 3,034 weed seedlings belonging to 40 species were identified across all systems. The results showed that cropping systems play a major role in shaping the composition and balance of the weed seed bank. Conventional and organic systems had the highest weed abundance, while perennial plots had the lowest, which reflected the benefit of continuous ground cover and limited soil disturbance. The organic system contained more weed species overall, but it was heavily dominated by a few fast-growing weeds such as *Chenopodium album*, which reduced the evenness of the community. Agroforestry plots maintained a moderate number of weeds with relatively balanced diversity, suggesting that mixed vegetation and shade can help regulate weed growth.

Overall, the perennial system developed the most stable and evenly distributed weed community, while the conventional and organic systems showed clear trade-offs between productivity and ecological balance. The findings indicate that long-term weed management is not only about reducing weed numbers but also about creating resilient and diverse seed bank communities. The broader implication is that integration, rather than reliance on any single approach, may offer the most viable pathway toward sustainable weed management, balancing productivity, biodiversity, and environmental health.

Keywords: weed seed bank, perennial system, agroforestry system, organic system, conventional system, long-term weed management.

Abbreviations

SAFE	SITES Agroecological Field Experiment
SITES	Swedish Infrastructure for Ecosystem Service
REF	Reference System(Conventional system)
ORG	Organic System
AI	Agroecologically Intensified System (Agroforestry)
KER	Kernza
PER	Perennial System
WW	Winter Wheat
WRYE	Winter Rye
SD	Standard Deviation
AWM	Association Weight Matrix

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1. Introduction

Weeds are one of the most significant and costly challenges in agricultural ecosystems, competing with crops for nutrients, water, and sunlight. One of the most important factors affecting weed emergence on fields is the weed seed bank (Daouti, 2021). It is a long-term weed species reservoir and its density and composition can have permanent impacts on future crop production and weed management requirements.

In traditional farming systems, weed management is primarily done using chemical herbicides and tillage. Although effective in the short run, these are known to cause environmental degradation, herbicide-resistant weeds, and soil structural and biodiversity loss (Ofosu, 2023).

In contrast, agroecological systems, including organic farming, perennial crops, and agroforestry, emphasize ecological equilibrium and natural processes rather than chemical inputs (Rosati, Borek, and Canali, 2021). These systems are more and more promoted based on their sustainability advantage, yet their capacity for long-term weed control, especially at the soil seed bank level, is not as well understood. Organic farming systems depend on crop rotation, hand weeding or mechanical weeding, and adding organic matter, which can suppress weed infestations by competition and soil health enhancement (Mwangi et al., 2024).

Perennial-based systems with crops that endure for several years have continuous ground cover and root presence, which could limit the emergence of weeds by causing minimal disturbance (Shoenberger, 2022). Agroforestry systems, which combine trees and crops, further enhance system complexity by changing microclimates, shading regimes, and soil conditions, which could inhibit some weed species while benefiting others.

Moreover, Sweden has been a frontrunner in organic agriculture, with approximately 20% of its agricultural land certified as organic in 2023 (Jordbruksverket, 2023). The government plans to increase this to 30% by 2030, as part of larger EU sustainability objectives (Yara, 2024). Significantly, the Sörmland district was in 2024 declared the EU's most organic bio-district, yet again indicating Sweden's dedication to organic farming (CoR News, 2024). Additionally, 30 years of organic cultivation showed that plant species richness was twice that in conventional farms, according to a study from Lund University, highlighting the long-term biodiversity advantage of organic farming (Romain Carrié, Smith and Johan Ekroos, 2024).

Although sustainable agriculture has become increasingly popular, few research has addressed how these alternative systems affect weed seed bank composition and weed pressure. In order to more effectively design farm systems to restrict the use of chemical inputs but maintain productivity and environmental integrity, an understanding of the differences in the dynamics of the weed seed banks among cropping systems is essential. Through assessing diversity and density of weed seed banks in such systems, the present study aims to provide useful inputs for developing sustainable weed management strategies for agriculture today.

Previous studies have examined weed seed banks under conventional and organic management, but these have often focused on single systems or short-term effects. For instance, Benvenuti et al. (2021) reported that organic systems can sustain greater diversity of weed seeds, while Nath et al. (2024) showed that extensive herbicide use in conventional systems promotes herbicide-resistant species. Recent work by Uduwalage (2024) conducted in the SITES Lonnstorp is particularly relevant, as it assessed weed seed bank dynamics in two organic crop rotations. That study identified 24 weed species, with *Chenopodium album, Veronica arvensis, Stellaria media, and Sonchus asper* as dominant, and showed that intercropping could influence weed diversity within specific crops but did not significantly alter total weed abundance or seed bank dynamics. While such research provides insights, there is still a lack of comparative studies that evaluate weed seed banks across multiple contrasting farming systems.

1.1 Research aim

This study aims to understand how four different cropping systems, agroforestry, organic, conventional, and perennial systems, affect the formulation of weed seed banks in order to determine the most viable options that can be used in ensuring that weed populations are managed in a sustainable manner.

Two specific research questions set out to fulfil the study aim are,

1. How do the four cropping systems (conventional, organic, perennial, and agroforestry) influence the weed seedbank in terms of species composition, abundance, richness, evenness, and overall diversity?

2. What do the observed differences in the weed seedbank dynamics across these cropping systems suggest about their potential for long-term weed management?

2 Background

2.1 Variations in Weed Seed Bank Composition across Cropping Systems

Weed seed bank composition differs widely across diverse cropping systems and depends on management, crop type, soil tillage, and ecologically mediated interactions. Such differences provide the foundation for implementing effective, system-specific weed management techniques that are in harmony with sustainable agriculture.

2.1.1 Conventional and Organic Systems

In conventional cropping systems, the use of synthetic herbicides, high-intensity tillage, and monoculture crops is likely to lead to reduced weed diversity but promote dominance by herbicide-resistant or disturbance-tolerant species. According to Nath *et al.* (2024), extensive reliance on herbicides has caused worldwide surges in the numbers of populations of herbicide-resistant weeds. These systems will tend to produce low weed seed banks, which will first suppress weed problems but might produce long-term sustainability issues due to the development of resistance and loss of biodiversity.

Organic farming systems rely on mechanical weeding, crop rotation, and biological interactions. These systems tend to promote a richer weed flora as a result of minimised chemical disturbance. Nevertheless, Benvenuti *et al.* (2021) indicate that organic systems can sustain greater diversity of weed seeds, but strategic management like stale seedbed preparation can reduce seed bank size without compromising biodiversity. The diverse rotation of crops and cover cropping that is typical in organic production also affects weed species mix and dormancy patterns. However, organic approaches can be labour-intensive, often requiring more time and resources for weed management, and may also result in lower yields compared to conventional systems. Conversely, conventional systems that rely heavily on herbicides are less labour demanding and can achieve short-term productivity, but they risk environmental drawbacks such as herbicide resistance, reducing biodiversity, and potential negative impacts on soil (Fess and Benedito, 2018).

2.1.2 Perennial and Agroforestry Systems

Perennial cropping systems, such as those employing kernza or other deep-rooted species, present distinct ecological dynamics compared with annual systems. Due to minimal soil disturbance and continuous ground cover, these systems generally maintain lower total weed seed densities (Peixoto et al., 2022). Similarly, Sharma et al. (2022) report that perennial crops modify canopy structure and microclimatic conditions, reducing light availability and thus limiting the germination and reproductive success of many annual weed species. Such environmental changes can also select for weed species with extended dormancy or alternative survival strategies, gradually reshaping community composition. However, as weeds adapt to the prevailing management context, perennial systems may favour the persistence and proliferation of perennial weed species capable of enduring reduced disturbance and sustained vegetative cover (Radosevich, Holt, and Ghersa, 2007).

Agroforestry systems add structural complexity by combining trees and crops. Multi-layered vegetation structure affects soil moisture, light, and nutrient cycling, all of which impact weed seed bank composition. Previous studies, such as Gallandt (2006) and Kulkarni *et al*. (2015), suggest that such systems produce a more heterogeneous environment, which may suppress dominance by aggressive annual weeds and foster native species balance. Roots of trees and litter material can also inhibit weed emergence through the physical and chemical barrier effects.

2.1.3 Ecological Factors Shaping Weed Seed Bank Dynamics

According to the perspective of Friedman (2020), one of the key aspects specifying these distinctions is the weed life-history strategy, whether or not a weed species is an annual, biennial, or perennial, coupled with the disorder regime of the cropping system. For instance, systems like conventional agriculture with high levels of soil tillage will support rapidly germinating annual species like *Amaranthus retroflexus* and *Chenopodium album*, which can quickly colonize disturbed ground. In contrast, Favrelière *et al.* (2020) stated that low-disturbance systems like perennial or agroforestry setups may select for perennial weed species or those with more persistent seeds, such as *Cirsium arvense* or *Taraxacum officinale*, which possess greater seed dormancy and can survive in deeper soil layers. Nevertheless, Pullens *et al.* (2021) advocated that cropping system legacy effects, the persistent effect of extended management, also become important. Long-standing organic or agroforestry systems have weed seed banks representative of decades of ecological succession and filtering of species. Based on the viewpoint of Siedt *et al.* (2021), soil microbial communities within organic systems affect seed germination rates and weed suppression, resulting in a more dynamic but frequently stable weed seed bank. However, the composition and behavior of the weed seed bank also shift with the seasons and with how well cover crops survive. As an instance, perennial systems provide near permanent ground coverage, thereby inhibiting the range in which the seeds can live and exercise the photoblastic or light-sensitive properties. Agroforestry systems, particularly when managed using deciduous species, have gaps in their canopy by season, which has the capacity to potentially influence the timing and herbaceous compositions of weed species emerging and create a temporal niche diversification within the seed bank (Tian et al., 2023).

Allelopathic effects that involve certain species of plants leaving some kind of chemicals that affect the germination process in other plants near them also contribute towards changes in species in weed seed banks. Agroforestry systems, according to the opinion of Sobock et al. (2022), typically include such species as *Juglans nigra* or *black walnut,* or *Populus spp.,* producing allelochemicals, thus determining which of the weed seeds proceeds to live or to stay hidden in the soil matrix. On the other hand, Bhaduri *et al.* (2022), soil health indicators like organic matter content, microbial diversity, as well as nutrient cycling differ considerably between systems and even restrain weed seed bank dynamics. Organic matter and microbial high levels in organic and agroforestry systems would potentially increase weed seed decay or predation. The application of synthetic chemicals in conventional systems would lower soil biota that naturally regulate seed bank size, resulting in longer seed persistence and lower degradation.

Overall, these cropping systems organise the weed seed bank in a different way. The shift from intensive, homogeneous to diverse, ecologically based ones promotes a more stable and resilient weed community (Liebman et al., 2021). Knowledge of these differences enables scientists and practitioners to choose cropping systems for productivity but also sustainability potential under consideration for weed management.

2.2 Agroecological Practices and Their Role in Weed Suppression

Sustainable ways of farming are environmentally beneficial since they lower water, energy use, and emissions, and boost the amount grown and the health of the soil. However, Shah et al. (2021) stated that adopting these ways results in more weeds and leads to increased labor needs, which lowers the chances of farmers using them. Trying the wider spacing method in the System of Rice Intensification (SRI) can help by inhibiting weed growth and boosting plants' quality.

For example, Boutagayout *et al.* (2023) mention that 2 to 4 million tons of pesticides are used around the world annually, and sometimes they are misused and cause harm to the planet. There are particular concerns with water being turned unsafe and the fact that less than 0.1% of insects are killed. They damage biodiversity by hurting other parts of the ecosystem and interrupting the life cycle of helpful insects. Storing chemicals in their bodies and reacting with other chemicals raises the consequences for animals even more. Managing weeds, which lead to misfortune against the crops chemicals we use cause both drops in yield and substantial economic damage.

2.2.1 Conservation Agriculture and Policy Context

According to Cordeau (2022), Conservation Agriculture (CA) depends on three important elements: crop diversification, permanent soil cover with organic matter, and minimal or no tillage. Crop diversification typically involves rotating at least three different crops, while soil cover requires maintaining over 30% ground coverage after planting. Reduced tillage is defined as limiting soil disturbance to less than 15cm depth. In the United States, concerns about land erosion were already raised in the 1930s, which led the Soil Conservation Service to recommend soil conservation methods. Initially, these practices were difficult to implement, but advances such as new herbicides and seeder designs later made reduced tillage farming more feasible and effective for weed suppression.

Boinot, Alignier, and Storkey (2024) further note that by 2030, initiatives such as the European Green Deal and Farm to Fork strategy aim to reduce pesticide use within the EU, compelling farmers to explore alternative weed control strategies. One such approach is the Association Weight Matrix (AWM), a landscape-level management tool that promotes crop and plant diversity while reducing reliance on herbicides. By encouraging practices such as crop switching and intercropping, AWM helps maintain a balanced weed community and prevent excessive spread of aggressive species, thereby supporting both agricultural productivity and ecosystem stability.

2.3 Sustainable Weed Management Strategies in Diverse Farming Systems

2.3.1 Conventional and Organic Approaches

The dominant strategy in conventional cropping systems is to depend on herbicides to manage weeds. According to Maqsood *et al.* (2020), weed seed banks are massively disturbed by intensive monocropping, high chemical input, and mechanical tillage, often reducing weed emergence in the short term. But when this strategy is employed, herbicides often stimulate resistance in weeds and cause shifts in weed species composition. Repeated applications of herbicide can select species with resistance traits based on several studies, and these species require higher dosages or alternate herbicides (Maqsood *et al.* 2020). Deep ploughing that buries and delays the germination of seeds is a further characteristic of conventional systems, but it prolongs seed viability.

Organic farming systems, by contrast, deliberately avoid synthetic herbicides and instead depend on cultural, mechanical, and biological strategies for weed suppression. According to Sabal et al. (2024), organic systems often foster greater biodiversity and healthier soils due to reduced chemical disturbance. Yet, this ecological advantage comes with challenges: higher weed pressure, greater labor demands, and difficulties in management. Controlling the seed bank in such systems requires a combination of crop rotation, cover cropping, and manual or mechanical weeding. While these methods can be effective, they are often time-intensive and require considerable knowledge and planning on the part of farmers.

2.3.2 Technological and Reduced-Tillage Strategies

Technological advances are gradually reshaping weed management in modern agriculture. Vijayakumar et al. (2025) argue that innovations such as precision agriculture, remote sensing, and AI-driven weed detection tools provide targeted control options that minimize inputs while maximizing efficiency. These approaches are especially valuable in reducing reliance on herbicides and extending the sustainability of cropping systems, where non-chemical strategies are critical (Sabal et al., 2024). For example, GPS-guided sprayers can deliver herbicides only to infested patches, lowering chemical use and protecting beneficial plant species (Hunter III et al., 2020). On the other hand, Sabal *et al.* (2024), argued that diversified crop rotations break the lifecycle of weeds, as well as reduce certain seed populations. Though very labour-intensive, these methods improve soil structure and microbial diversity and have a natural weed-suppressive ability. With high accuracy, robotic weeders promise non-chemical control, which is especially useful in organic and reduced tillage systems. Field trials over 25 hectares of farmland show that spraying robots have cut herbicide use by about 35% and achieved 97% weed control efficacy compared to conventional broadcast sprayers (Azghadi *et al.* 2025). Furthermore, data-driven forecasting models can enable farmers to predict weed emergence patterns and apply appropriate measures at appropriate times (Marschner *et al.* 2024). Introducing technology can help farmers to integrate ecological principles with their management decision-making, to be more efficient and to maintain as good as possible, which can reduce the long-term persistence of weed seed banks.

Systems of reduced tillage, such as no-till and strip-till, have become popular due to the benefits of soil conservation. This makes weed seeds stay near the surface, so the germination is also quick. According to Muni Kumari and Durge (2024), Preemergent herbicides and mulching techniques are the major tools of weed management in these systems. Integrated practices are necessary when such systems have reduced the burial of seeds, resulting in increased surface seed bank density. Low-tilled systems can also help retain much moisture and sequester carbon, which can have indirect implications in weed control (Hussain *et al.* 2021). For example, in the US Midwest, no-till maize systems increased soil moisture by 15% and reduced weed emergence by 30%. The key to managing this challenge is a hybrid strategy that combines chemical and alternative weed controls to keep in line with the soil health objectives.

On the other hand, Vijayakumar (2024), stated that the prevention of weed seed return is a critical part of sustainable weed management in all systems. Limiting the replenishment of the seed bank can be achieved successfully regardless of the cropping method if weeds are prevented from maturing into reproductive form. Crop topping, clean harvesting, and the use of seed destructors during harvest are on the rise (Chaudhary, Chhokar, and Singh, 2022). Stale seedbed techniques, which allow weed seeds to germinate and then be destroyed, are also good at reducing viable seed banks. When combined in a variety of systems, these methods can add up and reduce the persistence and emergence of seeds in subsequent seasons.

2.3.3 Integrated Weed Management (IWM)

Integrated cropping systems use the best from conventional, organic, and reduced tillage practices for optimal weed control. According to Gao and Su (2024), plant production systems tend to use Integrated Weed Management (IWM) systems, which often employ crop rotation, mechanical weed control, the use of herbicides selected for their target activity, and the use of natural biological weed control tools, such as host-specific fungal pathogens or insects. A key feature is adaptability, in that weed control and crop-based strategies are adjusted based on weed species present, crop growth stage, and environmental conditions. For example, reducing both seed bank input and weed emergence can be achieved through timely tillage in conjunction with competitive crop varieties and selective herbicides (Zamljen, Rovanšek and Leskovšek, 2024). While this system demands higher management skills, it can be very effective in reducing the long-term accumulation of weed seed banks without compromising high impacts on weed pressure.

Nevertheless, Kocira *et al.* (2020) stated that weed ecology and seed bank dynamics must be understood to complete and tailor strategies across farming systems. Weed species have differences in seed dormancy, germination triggers, and seed longevity depending on soil type, soil moisture, and temperature. As one example, shallow tillage can promote the germination of light-sensitive seeds, which can be managed by surface treatment (Petrikovszki *et al.* 2020). Just as there are specific rotations (legumes or small grains) that will also change canopy structure and reduce light availability through to emerging weeds. Instead, farmers can make use of ecological knowledge to design cropping systems that naturally suppress weed establishment so as to decrease reliance on external inputs.

2.4 Regional Perspectives on Weed Seed Bank Dynamics

Research from different regions has shown how cropping systems can shape weed communities in ways that are very relevant for this study. In Scandinavia, for instance, perennial weeds such as *Cirsium arvense* and *Elymus repens* often flourish in conventional systems where tillage is frequent and rotations are dominated by cereals (S. Håkansson, 2003). Similarly, organic systems that rely heavily on cereals and frequent tillage may also experience problems with these perennial weeds due to the lack of competitive perennial leys and repeated soil disturbance (Grosse, Haase and Heß, 2021). By contrast, organic systems that include grass-clover leys tend to suppress these perennials and support a broader mix of weed species (Björn Ringselle et al., 2018; Salonen, Koppelmäki and Känkänen, 2017; Gruber and Claupein, 2009). Across Northern Europe, organic systems generally support higher weed species richness compared with conventional systems (Hyvönen et al., 2003). However, weeds such as *Chenopodium album* often remain abundant in organic systems where nitrogen availability is high, indicating that diversified rotations and careful nutrient management are needed to prevent their dominance (Jäck, Ajal and Weih, 2021).

Evidence from North America tells a similar story. In Minnesota, Culman et al. (2013) found that perennial grains such as Kernza provided year-round soil cover, which reduced weed emergence and stabilized soil biology. In Nebraska, Wortman et al. (2012) demonstrated that including cover crop mixtures in organic systems helped suppress annual weeds while still maintaining species richness, much like the results seen in Scandinavian organic farms. Agroforestry has also been studied in the U.S., where Jose (2009) showed that alley cropping and silvopastoral systems reduced the germination of light-demanding weeds by altering shade and soil microclimates. These examples underline how diversified and low-disturbance systems can naturally regulate weed populations in temperate climates.

3 Materials and Methods

3.1 Site description

This study was carried out at the SITES Agroecological Field Experiment (SAFE), located at the Lönnstorp research station in southern Sweden. The station is part of the Swedish University of Agricultural Sciences and has been used for research on cropping systems dynamics and agroecological processes. The SAFE experiment was established to provide a long-term platform for comparing different farming systems, with a particular focus on sustainability and ecological interactions. The soils at the site are sandy loam, typical for the region, and the area benefits from a temperate climate with a mean annual air temperature of nearly 8-9 °C and an annual precipitation of around 700-730 mm. These conditions provide relatively high yields compared to other parts of the country.

For this study, sixteen rectangular plots (50 m * 12 m) were used, arranged in four blocks (A, B, C, and D) following a randomized block design. This design was chosen to minimize the influence of spatial variability in soil and environmental conditions across the field. Each block had four systems, organic, reference (conventional), agroforestry, and perennial system (Figure 1). Each system reflects a distinct approach to crop production and land management.

Figure 1: Overview of the SITES Agroecological Field Experiment (SAFE) at Lonnstorp Research Station, showing the arrangement of the four cropping systems (organic=ORG, conventional=REF, agroforestry=AI, and perennial=PER) across four blocks (Barreiro and Albertsson, 2022).

The reference system followed a four-year rotation common to regional farming practice, including crops such as winter wheat, spring barley, oilseed rape, and sugar beet. The organic system was managed on an eight-year rotation with crops such as lupine-barley intercrops, winter rye, faba bean or pea-wheat intercrops, and grass-legume leys, avoiding synthetic inputs. The agroforestry system integrated annual cereals and legumes (winter rye, winter wheat, spring intercrops) with tree rows (apple) and hedgerows, creating a more diversified structure within the field. Finally, the perennial system consisted of intermediate wheatgrass (Kernza), both as a sole crop and intercropped with lucerne, providing a different long-term cereal-based system with minimal tillage.

The choice of 16 plots for this experiment was guided by the need to contrast management strategies ranging from high-input conventional practices to diversified and perennial systems, while maintaining a common basis for comparison. Soil samples were collected from plots where cereals were the preceding crop in all four systems: winter wheat in the conventional system, winter rye in the organic and agroforestry systems, and perennial Kernza in the perennial system. This ensured that all samples were taken under comparable crop conditions, providing a consistent reference point for evaluating weed seedbank dynamics across contrasting management systems.

3.2 Soil Sampling

Soil sampling was carried out on 10 and 11 March 2025 from 16 designated plots within the experimental site, as shown in Figure 2. The plots selected for sampling were shaded in black in the site layout (Figure 2). An auger with a core barrel of 22 mm in diameter and 25 cm in height was used to collect the samples (Figure 3).

From each plot, 20 soil cores were taken at a depth of 25 cm, following a zigzag pattern to ensure that the samples represented the entire plot area. To extract soil, the auger was inserted into the ground and rotated 180 degrees until the core barrel was filled. Each core was then emptied into a plastic basket, and the accumulated soil was transferred into labelled plastic bags for identification. We avoided taking the soil samples from the outer margins of the plots to prevent the risk of contamination from weed seeds from nearby plots.

Once collected, the soil samples were kept indoors at room temperature until they were transported by car (Figure 4) to the greenhouse. The average weight of the collected soil was determined to be 3.297 kg per bag. In the greenhouse, the soils were placed in plastic trays, where they were stored under suitable conditions until the emergence of weed seedlings.

Figure 2: Layout of the experimental site showing the sampling plots (black-shaded) from which soil samples were collected.

Figure 3: Tools and equipment used for sampling, including the auger.

Figure 4: Soil samples were transported to the greenhouse by car.

Figure 5: Soil samples stored in plastic bags inside the greenhouse before transfer into trays for germination.

3.3 Soil Sample Preparation

Soil samples were collected from the field plots and prepared for greenhouse assessment of the soil seed bank. Each sample was crushed into fine particles and transferred into plastic trays measuring 50 * 30 cm. To ensure uniform moisture retention, a fiber cloth was placed at the bottom of each tray. Since the quantity of the soil from a single plot would otherwise result in only a thin layer, Styrofoam blocks were inserted into the trays to reduce volume and maintain an adequate soil depth (approximately 4 cm) for seed germination (Figure 6).

The trays were placed inside a controlled greenhouse facility on March 12th, 2025. The greenhouse climate was maintained at nearly 17 to 18 °C, with artificial lighting provided when natural sunlight was insufficient. Watering was carried out every second day, or daily during sunny weather when evaporation was higher. The arrangement of the soil trays under artificial light is shown in Figure 7.

3.4 Weed Emergence and Identification

Weed seedling emergence was first monitored 2 weeks after placing the samples in the greenhouse. The first phase of weed identification was conducted on April 2nd, 2025 (22 days after being placed in the greenhouse). During this stage, all weed seedlings in the 16 trays were identified to species level, recorded, and removed. Following identification, the soil was again crushed and mixed into finer particles to stimulate a second flush of seed germination by light induction.

The second cycle of weed identification (Phase 2) was conducted on April 26th, 2025, which is 24 days after re-preparing the soil samples. The same procedures as in phase 1 were applied. Between cycles, careful observation and documentation of weed emergence were maintained, with field notes and reference books assisting in the identification process (Figure 8).

Figure 6: Soil tray setup with fiber cloth and Styrofoam block to adjust soil depth.

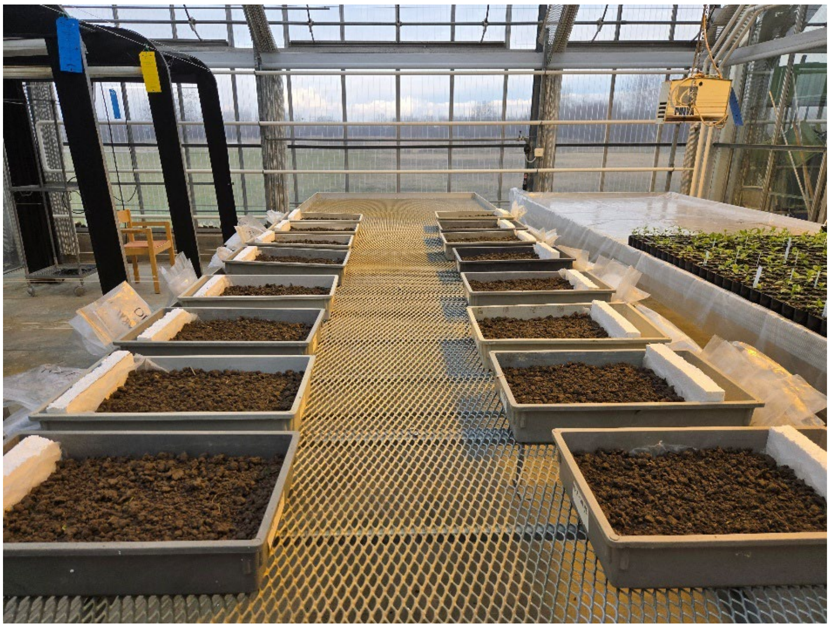

Figure 7: Arrangement of soil trays in the greenhouse under artificial lighting.

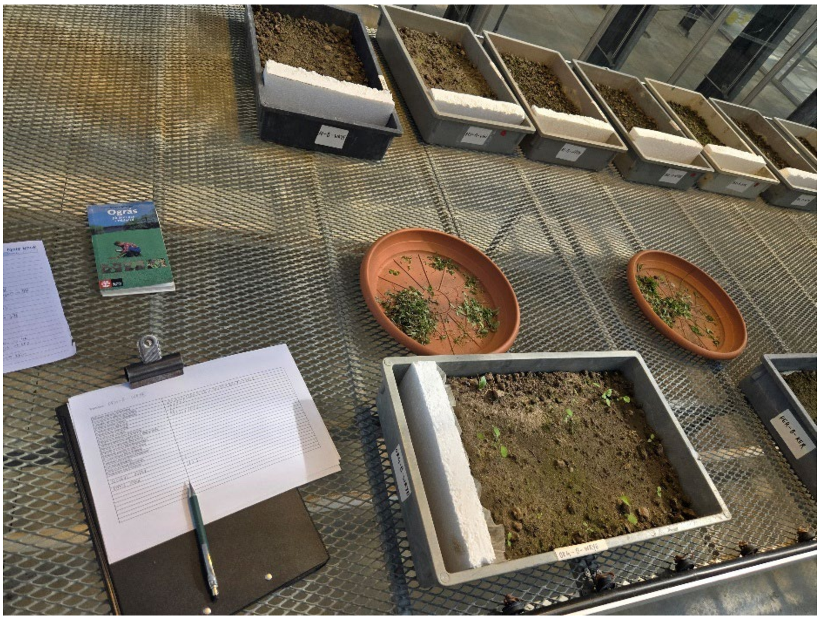

Figure 8: Weed identification process, showing identified weeds, records, and reference book.

3.5 Data analysis

The first step of the analysis involved counting and identifying weed species across 16 different samples. This process of identification allowed for the assessment of weed abundance and species richness within each plot, as well as the determination of the most common species present in the weed seed bank.

For the weed analysis, the total number of individual weeds was obtained by summing the counts from both observation phases, following the common approach used in soil seed bank studies. Several diversity indices were then calculated to further evaluate the data. These indices described how weed species were distributed among the plots and assessed both overall diversity and the evenness of species occurrence. This approach provided insights not only into the total number of species present but also into how evenly different weed species were represented across the plots.

3.5.1 Shannon Index (H′)

The Shannon Diversity Index (H′) is one of the most popular ecological indices that measures diversity within a community by taking into account both species richness (the number of species) and species evenness (the relative abundance of different species). It assists in determining the number of species within a system and to what extent the individuals are evenly distributed in those species. Mathematically, the index can be calculated as:

$$H' = -\sum (Pi \cdot \ln Pi)$$

Where Pi is the fraction of individuals in the ith species. The higher the value of H′, the more diverse, either because more species exist or because it is more evenly spread. Under the scope of this study, the Shannon Diversity Index was used to study weed communities in four different cropping systems, such as Agroforestry, Reference, Organic, and Perennial, over two observation periods. Phase 1 took place prior to any intervention, while Phase 2 was undertaken after physical removal of weeds and a resting period to monitor regrowth.

3.5.2 Pielou's Evenness Index (J′)

Pielou's Evenness Index (J′) is an ecological measure that quantifies the evenness with which individuals are distributed across the species in a community. The Shannon Diversity Index (H′) averages richness and abundance, but J′ separates out the evenness factor by normalising H′ against the greatest possible diversity (if all species were of equal abundance). It is calculated with the formula:

$$J' = \ln(S)/H'$$

Where H′ is the Shannon index and S is the richness of species. They vary from 0 (extremely uneven) to 1 (completely even). High evenness implies that no single species is dominant, which can represent a more stable and robust ecosystem.

3.5.3 Statistical Analysis

Statistical analyses were conducted to evaluate the effects of cropping systems and experimental phases on weed abundance, species richness, Shannon diversity index (H’), and Pielou's evenness index (J’). Kruskal-Wallis tests were used to assess differences across cropping systems. Data organization and preliminary calculations were performed using Microsoft Excel, while statistical analysis was done using SPSS software.

4 Result

4.1 Composition of the Seed Bank

Across systems, the seedbank was dominated by a relatively small set of species, with the top twelve taxa accounting for the vast majority of total emergence (Figure 9). However, the identity of the leading species and the evenness of the community differed distinctly by cropping system.

The weed flora in agroforestry plots was strongly shaped by *Chenopodium album*, which contributed 38.3% of all emerged individuals. The next most abundant group was *Veronica spp.* (19.1%), followed by *Fallopia convolvulus* (9.0%), *Stellaria media* (7.7%), and *Tripleurospermum perforatum* (7.2%). No other single species exceeded 5%. The "Other" category comprised 5.5%, indicating that relatively few minor species made up the remainder. Altogether, agroforestry showed a moderate dominance structure with one clear primary species, one substantial secondary group (Veronica spp.), and then a gradient of mid-ranked species.

Conventional plots exhibited a different dominance pattern led by *Polygonum aviculare* (31.4%), with *Chenopodium album* second (20.6%). Mid-tier contributions were split among *Tripleurospermum perforatum* (11.6%), the pooled "grass weed" category (8.6%), and *Sonchus asper* (8.5%). Minor contributors included *Veronica spp.* (3.9%), *Stellaria media* (3.1%), and *Fallopia convolvulus* (2.9%). The "Other" accounted for 6.1%. Compared with agroforestry, the conventional seedbank was less dominated by *Chenopodium album* and instead featured a prominent *Polygonum aviculare* component.

Organic plots were characterized by a marked single-species dominance; *Chenopodium album* represented 53.6% of total emergence, over half of the seedbank. Secondary groups were *Veronica spp.* (13.9%), *Tripleurospermum perforatum* (5.5%), and *Fallopia convolvulus* (5.3%). All other species each contributed ≤ 5% (e.g., *Persicaria maculosa* 4.0%, *Viola arvensis* 3.7%, *Stellaria media* 2.8%, "grass weed" 2.5%). The "Other" group was 5.2%.

Perennial plots showed the most even composition among the common species. The leading taxon was *Polygonum aviculare* (18.3%), followed closely by the "grass weed" group (12.4%), *Chenopodium album* (11.4%), and *Fallopia convolvulus* (11.1%). Additional contributors, *Stellaria media* (9.4%), *Veronica spp.* (8.9%), *Persicaria maculosa* (5.9%) and *Viola arvensis* (5.9%) each accounted for substantial shares. The "Other" group contributed 6.9%. The relatively even distribution across several species suggests a diversified seedbank under perennial management.

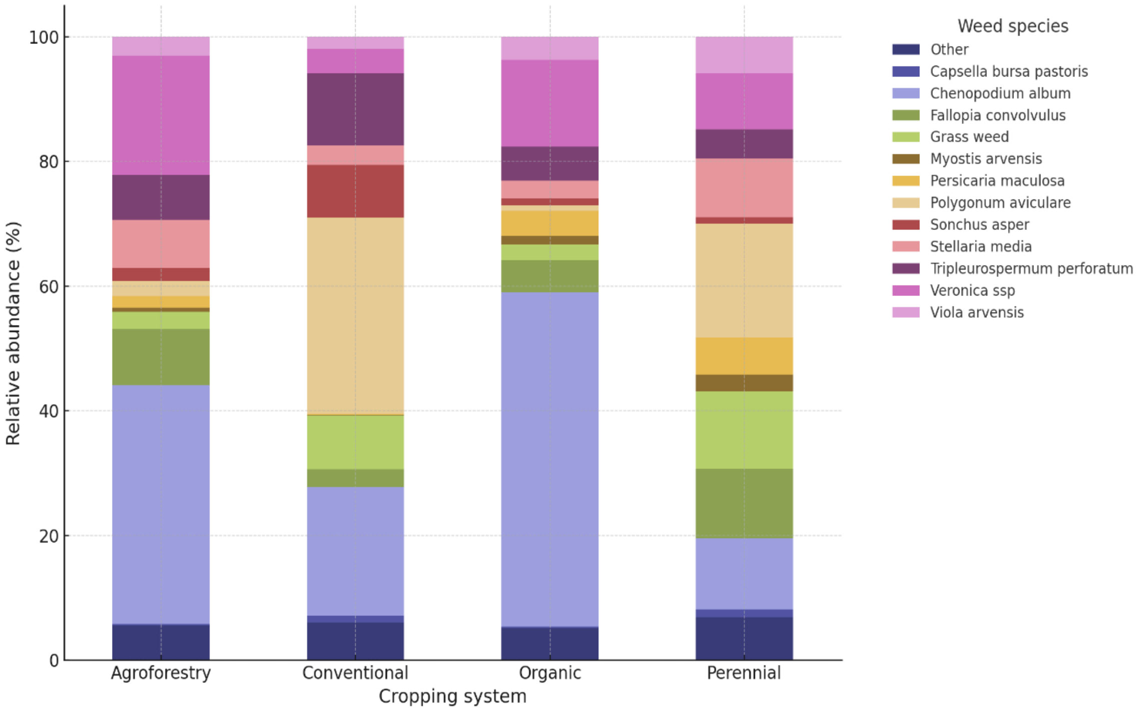

Figure 9: Stacked bar chart showing the relative abundance (%) of the top 12 weed species (plus "Other") across cropping systems. Each bar represents a cropping system, and the colored sections show each species' proportional contribution to the total weed seedbank.

4.2 Impact of treatments on the weed seed bank

To evaluate how different management practices influence the soil seed bank, weed emergence was compared across all four cropping systems included in the experiment. Each treatment was replicated across four blocks (A, B, C, and D), allowing us to assess not only the overall weed abundance but also the distribution of individual species within and across systems.

4.2.1 Weed abundance

Weed seedling emergence from the soil seed bank varied notably among the different cropping systems (Table 1). When combining both germination phases, the reference system showed the highest total weed emergence with 1,008 seedlings. This was closely followed by the organic system with 969 seedlings. In comparison, the agroforestry system had fewer weeds (653 seedlings), and the perennial system had the lowest overall emergence with 404 seedlings.

Although most weeds germinated during the first phase in all systems, the second phase still contributed additional seedlings after soil disturbance. For example, in the reference system, 913 seedlings emerged in Phase 1 and an additional 95 in Phase 2. The organic system followed a similar trend (888 and 81 seedlings, respectively), while the agroforestry plots recorded 553 seedlings in Phase 1 and 100 in Phase 2. The perennial system consistently had the lowest counts across both phases (338 and 66 seedlings).

Table 1: Total weed abundance by cropping system and phase.

Cropping System	**Phase 1**	**Phase 2**	**Total Weeds**
Agroforestry (AI)	553	100	653
Reference (REF)	913	95	1008
Organic (ORG)	888	81	969
Perennial (KER)	338	66	404

4.2.2 Seed Bank Density By Cropping System

To place the emergence counts into a field-relevant scale, I converted plot-level emergence (Phase 1 + Phase 2 combined) to weeds per square metre from a soil layer of 0 to 25 cm. Each plot was sampled with 20 soil cores of 22 mm diameter (radius = 0.011 m). Dividing each plot's total emerged weeds by this sampled area yielded densities in weeds per m^2 for the 25 cm soil layer. With four plots per system ($n = 4$), I summarised the distribution of densities using the mean, median, and standard deviation, and visualised the spread with box plots (whiskers = range, triangle = mean) as shown in Figure 10.

The perennial plots had the smallest seedbank overall and the tightest spread; mean 13284 weeds m^{-2}, median 12298 weeds m^{-2}, SD 4979, ranging from 8418 to 20125 weeds m^{-2}. This narrow range suggests lower and more stable seed banks across blocks. Agroforestry plots sat between perennial and the other cropping systems; mean 21473 weeds m^{-2}, median 22624 weeds m^{-2}, SD 8826, with a range from 10391 to 30253 weeds m^{-2}. The interquartile range (Q1–Q3: 16606–27490 weeds m^{-2}) indicates moderate plot-to-plot variability.

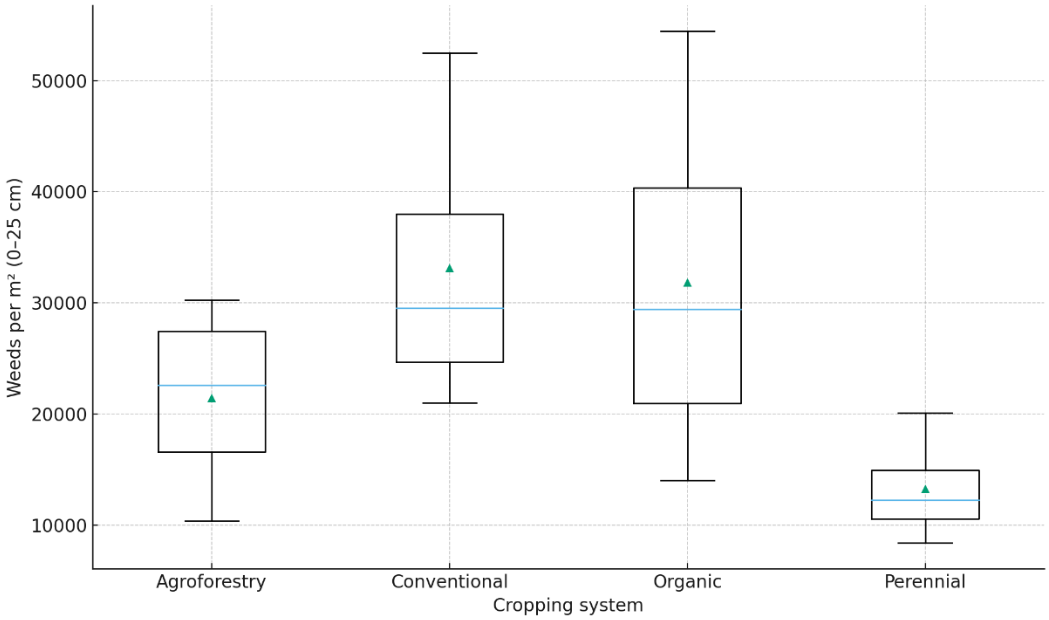

Figure 10: Distribution of soil seedbank density (weeds m⁻², in the soil layer 0–25 cm) by cropping system. Values are derived from greenhouse emergence totals (Phase 1 + Phase 2) per plot, converted to area using 20 soil cores (diameter 22 mm) per plot.

The conventional system showed high seedbank densities and clear between-plot differences; mean 33146 weeds m^{-2}, median 29529 weeds m^{-2}, SD 13816, spanning 21045 to 52482 weeds m^{-2}. The upper end of this range overlaps with the highest values observed in the entire study. Organic plots were comparable to the conventional system in central tendency but exhibited the largest variability, with mean of 31864 weeds m^{-2}, median of 29463 weeds m^{-2}, SD of 17462, with a very wide range from 14074 up to 54455 weeds m^{-2}. The broad spread reflected differences in weed flushes among blocks and the sensitivity of seed banks.

To assess whether soil seed bank densities differed among the four cropping systems, a Kruskal-Wallis test was applied. The test indicated that differences in seed bank density among systems were not statistically significant ($p = 0.080$). While the Reference and Organic plots tended to have higher weed seedbank densities and the Perennial plots generally showed the lowest values, the variation within each system was large enough that these differences could not be confirmed statistically.

4.2.3 Species Richness

Species richness was calculated as the number of unique weed species detected per plot after combining observations from Phase 1 and Phase 2. Across the four cropping systems, richness values were very similar (Table 2). Median richness ranged from 12.5–14.5 species per plot, with narrow interquartile ranges in Reference and somewhat broader spreads in Agroforestry and Organic systems.

To compare systems, the Kruskal–Wallis test on plot-level richness was used. The test showed no statistically significant differences among cropping systems ($H = 0.387$, $p = 0.9428$).

The boxplot of species richness by cropping system visually reinforces these findings (Figure 11). The medians are nearly identical across systems, and the boxes overlap extensively, indicating similar central distributions. The reference system shows the tightest spread, suggesting slightly more uniform richness among its plots, whereas agroforestry and organic systems display wider spreads, reflecting greater plot-to-plot heterogeneity. Perennial sits between these extremes, with a moderate spread and a median comparable to an agroforestry system.

Table 2: Species richness (number of weed species) observed in both Phases combined across cropping systems.

Cropping system	Richness Phase 1	Richness Phase 2	Combined
Agroforestry	23	13	27
Reference	22	15	28
Organic	28	11	29
Perennial	20	14	24

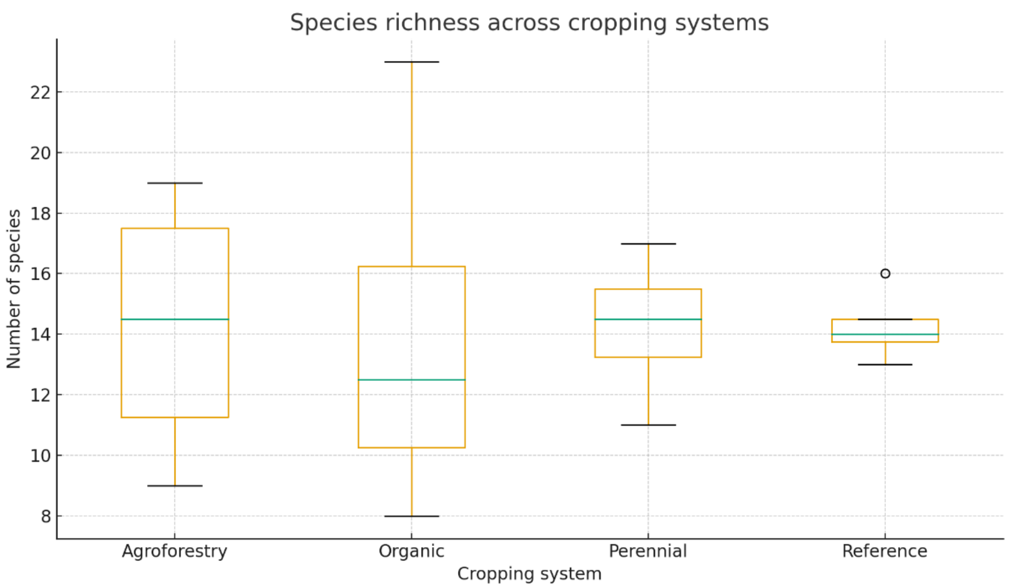

Figure 11: Boxplot of weed species richness (number of species per plot) across cropping systems with Phase 1 and Phase 2 combined.

Taken together, the descriptive statistics, the boxplot, and the Kruskal–Wallis test converge on the same conclusion: weed species richness in the seedbank is comparable across the four cropping systems in this dataset, with only modest differences in within-system variability.

4.2.3 Shannon Diversity Index (H')

Across cropping systems, Shannon diversity index showed clear differences in central tendency, although these differences were not statistically significant at $p = 0.05$. As seen in Table 3 below, the perennial system supported the most even and taxonomically diverse weed communities, while the organic system had the lowest average diversity. Agroforestry and conventional systems were nearly identical in mean H′.

Table 3: Mean ± SE of block-level H' values (natural log base), calculated after combining Phase 1 and Phase 2 counts within each block (n = 4 blocks per system).

Cropping system	**Shannon diversity index (H′)**	**Standard Deviation**	**Standard Error**
Agroforestry	1.862	0.198	0.099
Reference	1.863	0.27	0.135
Organic	1.646	0.413	0.206
Perennial	2.194	0.152	0.076

A Kruskal–Wallis test, performed on block-level H′ values to avoid parametric assumptions, indicated no overall difference among cropping systems ($H = 6.375$, $df = 3$, $p = 0.0947$). The pattern suggests a tendency toward higher diversity in the perennial system and lower diversity in the organic system, but the variability among blocks, especially in the organic fields, meant that these differences did not reach a significant level.

4.2.4 Pielou's Evenness Index (J')

Combining Phase 1 and Phase 2 counts within each block, how evenly individuals were distributed among weed species was quantified using Pielou's evenness index.

Overall, perennial fields showed the most even weed communities, with a high mean evenness value and very little variation among blocks, as shown in Table 4.

Agroforestry and reference systems exhibited intermediate evenness, while the organic system had the lowest average evenness (0.644 ± 0.065). The spread of values was widest in the organic fields, indicating that some blocks were dominated by a few species, whereas others were more balanced.

Table 4: Mean ± SE of block-level J' values. Indices were computed after combining Phase 1 and Phase 2 counts within each block (n = 4 blocks per system).

Cropping system	**Pielou's Evenness Index (J')**	**Standard Deviation**	**Standard Error**
Agroforestry	0.718	0.088	0.044
Reference	0.704	0.113	0.057
Organic	0.644	0.13	0.065
Perennial	0.832	0.041	0.021

To test for overall differences among systems, I used a Kruskal–Wallis test on block-level evenness values (non-parametric, avoiding distributional assumptions). The test indicated no statistically significant difference across cropping systems at $\alpha = 0.05$ ($H = 7.037$, $df = 3$, $p = 0.0707$). Thus, while the pattern suggests more even weed communities in perennial systems and less even communities in organic fields, the variability among blocks, especially within the organic system, meant these trends did not reach significance.

4 Discussion

5.1 Influence of Cropping Systems on Weed Seed Bank

The results revealed clear trends in soil weed seed bank dynamics among the cropping systems, even though the differences were not statistically significant when seed bank densities were compared across treatments (Kruskal–Wallis test, $p > 0.05$). Because emergence was recorded twice, we summed seedlings from both flushes to represent the active seed bank. Patterns showed that systems with greater soil disturbance tended to support larger soil seed banks, whereas reduced disturbance appeared to limit seed bank accumulation. This is consistent with the broader understanding that frequent tillage and turnover can promote germination and recruitment from buried seed reserves (Travlos et al., 2020). In contrast, the perennial Kernza system, with its continuous cover and minimal soil disruption, likely restricts key germination cues such as light and temperature fluctuations at the soil surface, thereby suppressing seed bank replenishment over time (Ryan et al., 2018). Although these patterns were not statistically conclusive, they indicate that management intensity and disturbance patterns play central roles in shaping how the weed seed bank changes over time.

Although total weed abundance provides useful context, it does not by itself reveal the underlying ecological dynamics occurring within the cropping systems. When combining both phases, the Organic system contained the greatest number of weed species (29 species), followed closely by the Reference (28), Agroforestry (27), and Perennial systems (24). However, despite these numerical differences, a Kruskal–Wallis test indicated that species richness did not differ significantly among the four systems ($H = 0.37$, $p = 0.95$). Moreover, higher richness in the Organic system did not correspond to more balanced weed communities. In several organic plots, *Chenopodium album* became strongly dominant, resulting in some of the lowest evenness values observed (Pielou's $J' \approx 0.46$ at the block scale). This finding challenges the assumption that organic management consistently promotes stable or evenly distributed biodiversity. While organic practices may indeed support a wider range of species, they can also create conditions under which fast-growing, opportunistic weeds gain a competitive advantage if not carefully managed. Similar patterns have been reported by Seufert and Ramankutty (2017), who note that organic systems often support greater diversity overall but are also more susceptible to competitive outbreaks when timely cultivation or weed control measures are not implemented.

Reference plots showed a different, though equally concerning, dynamic. Although abundance was high, no single species monopolised the community to the same extent as in organic systems, which produced relatively balanced evenness scores

(0.704). Shannon diversity values also remained moderate (1.863), suggesting the coexistence of several disturbance-adapted species. This is consistent with Menalled et al. (2001), who showed that conventional systems maintain communities of short-lived annuals well adapted to recurrent tillage and herbicide exposure. However, this apparent diversity is misleading. The reliance on herbicides encourages the development of resistant biotypes, while the seeming balance among species is sustained only through repeated disturbance. In the long term, such practices undermine ecological stability and make the system more fragile than resilient (Mortensen et al., 2012).

Agroforestry presented a more balanced outcome. Richness was high (27 species), and evenness values suggested relatively balanced communities (0.718). Shannon diversity was also higher (1.862), reflecting a more even distribution of species. These findings support the claim that structural complexity in agroforestry, through shading and root interactions, can buffer against the dominance of opportunistic weeds (Pumariño et al., 2015).

5.1.1 Perennial Weed Dynamics

The perennial plots were unique in that they combined the lowest weed abundance with some of the most stable community dynamics observed in this study. Only 404 seedlings emerged across both phases, far fewer than in conventional or organic systems. What is notable, however, is not just the lower abundance but the way in which weed communities were structured. Average evenness values remained consistently high across phases (0.832), indicating that no single species dominated the perennial seed bank. Species richness was 24 species (combined), and Shannon diversity was comparatively high ($H' \approx 2.20$ on average), consistent with a community where individuals are spread across many taxa. Taken together, these patterns suggest that perennial cover, such as Kernza, acts as a gentle ecological filter as it keeps overall seedbank pressure low and discourages the dominance of disturbance-adapted annuals such as *Chenopodium album, Stelaria media, and Fallopia convolvulus*.

These findings align with previous research showing that perennial systems, such as intermediate wheatgrass (*Kernza*), promote ecological filtering by reducing disturbance and maintaining continuous canopy cover (Culman et al., 2013). At the same time, perennial systems encourage the persistence of slower-germinating or shade-tolerant species that are less competitive and less likely to disrupt crop growth (Glover et al., 2010). From an ecological perspective, this selectivity is advantageous, since even with fewer species overall, the community that remains is well balanced and less vulnerable to domination by a single weed.

That said, no system is weed-proof. Establishing a perennial cover shifts the selective environment, and certain taxa are well-suited to those conditions. Clonal perennials such as *Cirsium arvense*, *Elymus repens*, and *Rumex spp*. can tolerate low disturbance, spread vegetatively, and slowly build dense patches under continuous cover, exactly the conditions we create in perennial systems. In Europe, *Cirsium arvense* is repeatedly identified as one of the most troublesome perennial weeds across both conventional and organic arable crops, owing to its vigorous rhizomes and yield impacts (Favrelière et al., 2020). Reduced tillage and stable canopy cover can also shift communities toward rhizomatous perennials like *Elymus repens*, which are notoriously difficult to suppress once established (Ringselle et al., 2020).

Even with wheatgrass (Kernza), which generally suppresses weeds well over time, targeted management is still needed, especially during establishment, because annuals can surge early and perennials can slowly gain ground if left unchecked(Tautges, Detjens, and Jungers, 2023). In short, perennial systems can filter the weed community and keep overall pressure low, but they still select for a different set of specialists that thrive under stability rather than disturbance, and those specialists require deliberate, integrated management (Andert et al., 2023).

5.2 Implications for Long-term Weed Management

Thinking about weed management only in terms of having more weeds or fewer weeds risks missing the larger picture. What matters for long-term sustainability is not simply how many weeds germinate in a given year, but how cropping systems shape the trajectory of the seed bank and the stability of those communities over decades (Davis, Renner and Gross, 2005). The findings from SAFE underline that each farming system comes with trade-offs. Some stabilize weed populations at low levels, others encourage diversity but at the risk of dominance, and still others suppress aggressively in the short term but create fragility in the long run.

Perennial systems

The results indicate that the perennial system reduces overall seedbank pressure while maintaining a well-balanced community. The consistent evenness and low overall abundance observed suggest that continuous canopy cover and minimal disturbance build resistance into the system itself. By doing so, perennials inherently remove many of the opportunities that weeds would otherwise exploit, reducing the need for external interventions (Duchene et al., 2022). This aligns with the arguments of Crews and Rumsey (2017), who argue that perennial grains can reduce the ecological space available to annual weeds and, over time, lead to a seed bank dominated by less competitive species. In Swedish agriculture, where a shift toward more ecological practices is already underway (OECD, 2018), perennial crops could serve as important tools for reducing reliance on chemical inputs while enhancing resilience (Crews et al., 2018; Scott et al., 2022). However, perennials do not inherently maximize biodiversity, as the stability they provide can sometimes limit species variety (Chapman et al., 2022). This suggests perennials should not be seen as replacements for other systems but as anchor points within broader rotations.

Agroforestry Weed Dynamics

The agroforestry plots in this study occupied an intermediate position between suppression and persistence. Total weed emergence was lower than in organic and conventional systems, yet considerably higher than in perennials, reflecting that structural diversity alone did not translate into consistent weed suppression. The presence of apple tree rows and hedgerows likely modified light, soil moisture, and microclimate in ways that buffered dominance by a single species, as seen in the relatively balanced evenness values ($J' = 0.718$; Table 6). At the same time, this heterogeneity may also have provided niches for certain weeds to persist, explaining why abundance remained higher than in perennials. Similar observations have been made by Pumariño et al. (2015) and Torralba et al. (2016), who argue that agroforestry can reduce weed pressure but is highly dependent on the design of canopy cover, species composition, and spacing.

Therefore, the results suggest that agroforestry systems are not inherently suppressive or vulnerable to weed pressure but are highly dependent on management practices. The types of crops cultivated between or alongside tree rows play a key role in shaping weed communities over time. For example, incorporating annual crops such as cereals can strongly influence weed dynamics by introducing both competitive and disturbance-related effects. Cereals often establish quickly and form dense canopies that reduce light availability, effectively suppressing many fast-growing annual weeds during early growth stages (Liebman, Mohler and Staver, 2001). However, because cereals have relatively shallow root systems and require frequent soil disturbance for planting and harvesting, they may also create temporary gaps that allow opportunistic weed species to emerge once the canopy is removed (Smith, Gross and Robertson, 2008).

In an agroforestry context, these interactions become more complex. Tree components can modify light conditions, soil moisture, and belowground competition, which may either strengthen or counteract the weed-suppressive effects of cereals depending on canopy structure, tree density, and management intensity (Udawatta & Jose, 2012; Pumariño et al., 2015). As such, the effectiveness of agroforestry for long-term weed management depends on how these biological and spatial interactions are balanced. Systems designed with narrower gaps between tree rows, the use of shade-tolerant understory crops, and the inclusion of tree species with strong competitive or allelopathic properties (Mathieu et al., 2025) are more likely to achieve both weed suppression and biodiversity gains. Overall, the findings of this study emphasize that agroforestry occupies an intermediate position being more balanced and diverse than conventional and organic systems, yet less consistently suppressive than perennial systems. Its contribution to long-term weed management therefore relies not simply on the presence of trees, but on thoughtful crop selection, spatial arrangement, and adaptive management over time.

Organic Systems: Richness Without Balance

The organic system in this study recorded the highest number of weed species, with 31 species identified in Phase 1, which is consistent with previous findings that organic farming often supports greater plant diversity compared to conventional systems (Birkhofer et al., 2008). However, this richness was not evenly distributed across species. A small number of weeds, particularly *Chenopodium album, Polygonum aviculare*, and *Stellaria media*, were dominant and widespread across the plots. In some cases, such as Block B, *Chenopodium album* alone accounted for 285 individuals, highlighting the strong competitive advantage of disturbance-adapted annuals under organic management.

The dominance of a few opportunistic species reflects the ecological conditions typical of organic systems. While synthetic herbicides are excluded, frequent soil tillage remains a primary management tool. Soil disturbance exposes buried seeds to light and temperature fluctuations, providing germination cues that favour fast-growing annuals such as *Chenopodium album* and *Amaranthus retroflexus* (Peigné et al., 2007). This cycle of disturbance and emergence allows these species to maintain a consistent presence in the seed bank, which explains their widespread occurrence across multiple blocks in this study. Although richness is higher, the uneven distribution of species indicates a lack of ecological balance, with potential consequences for crop competition and long-term seed bank stability.

Other studies have reported similar patterns in organic systems. Bond and Grundy (2001) found that dominance of a few competitive weeds often undermines the benefits of increased diversity, while Kushal et al. (2024) noted that organic systems require targeted interventions, such as stale seedbeds, competitive cover crops, and crop rotation, to prevent the spread of dominant species. Without such measures, the organic seed bank may become increasingly skewed toward a limited set of disturbance-adapted weeds, making management more labour-intensive and potentially less sustainable (Mohler et al., 2018). This does not mean, however, that organic systems should be regarded as failures. On the contrary, the ecological value of maintaining higher species richness and avoiding chemical residues remains an important contribution to sustainable agriculture (Bengtsson, Ahnstrom and Weibull, 2005).

In short, the organic system in this experiment illustrates both the strength and the weakness of the approach. It promotes species richness, aligning with biodiversity goals central to Swedish and EU policy (Dimitrios Kremmydas et al., 2024; Basnet et al., 2023), but also demonstrates that richness without balance is insufficient for sustainable weed management. The tendency for a few annual species to dominate is not accidental but reflects the ecological conditions created by current organic management practices. The challenge is not to reject organic farming but to address these weaknesses by moving beyond the absence of synthetic inputs toward ecologically informed management, where diversity is guided to support resilience rather than instability.

Conventional Systems: Short-Term Effectiveness, Long-Term Risks

The conventional system produced one of the highest levels of weed abundance in this study, with 1008 seedlings emerging across both phases. While diversity indices suggested a relatively balanced community, this balance was largely the result of frequent disturbance through tillage and the application of herbicides. Such practices create opportunities for disturbance-adapted annuals to germinate, resulting in communities that appear diverse but are highly dependent on continual external control (Derksen et al., 2006). Similar findings have been reported in long-term studies, where conventional farming maintains weed richness but largely of species tolerant to recurrent disturbance (Menalled, Gross and Hammond, 2001).

Although herbicides and tillage provide immediate control, their long-term consequences are less favorable. Repeated chemical use has been linked to the spread of herbicide-resistant biotypes, while intensive tillage undermines soil structure and ecological stability (Mortensen et al., 2012). In the experimental plots, no single species reached the extreme dominance seen in the reference system. However, the persistent presence of weeds in the plots, such as *Polygonum aviculare*, *Veronica spp.*, and *Tripleurospermum perforatum,* indicates that conventional farming reshapes the seed bank community rather than achieving suppression. Similar outcomes have been reported in long-term tillage studies, where conventional disturbance regimes favoured short-lived annual weeds and altered seed bank composition rather than reducing it (Kelton et al., 2011).

From a sustainability perspective, the reliance of conventional systems on chemical and mechanical inputs runs counter to the EU Farm to Fork Strategy, which aims to reduce pesticide use by 50% by 2030 (European Commission, 2020). While effective in the short term, conventional practices are increasingly incompatible with policy ambitions and environmental goals. The implication is that conventional farming can no longer serve as a stand-alone model for weed management. Instead, it must adapt by integrating practices such as cover cropping, reduced tillage, and crop diversification to slow resistance development and build ecological stability.

Cropping systems, Weed pressure, Biodiversity, and What It Means for Yield

This study's findings indicated that cropping systems influence not only the size of the soil seed bank but also its composition, and these differences translate into meaningful effects on yield. In practice, achieving high yields depends on suppressing early-season weed pressure so the crop can establish a competitive lead (Knezevic et al., 2002). This aligns with long-standing evidence that, among major pest groups, weeds pose the greatest potential threat to yield, and that yield loss is driven by the timing of weed emergence relative to the crop, with early-emerging weeds causing the most damage (Horvath et al., 2023). Looking at our combined counts from the two assessment times, the Conventional/Reference and Organic systems had the largest seedbank emergence. This pattern may signal a higher risk of crop–weed competition and, consequently, a greater likelihood of yield loss.

Community structure also matters for production, not only the total number of seedlings (Storkey and Neve, 2018). The Organic system had the highest combined richness, but richness on its own did not guarantee a balanced community. In several organic plots, *Chenopodium album* rose to dominance, and evenness dropped to some of the lowest values we measured. By contrast, the Perennial system paired a small seedbank with consistently high evenness. These results echo a broader point in weed ecology. More diverse weed floras can sometimes be less damaging to yield than communities dominated by a single aggressive species, because competitive pressure is more evenly shared and fewer individuals reach the size and timing needed to outcompete the crop (Zingsheim and Döring, 2024). In other words, the composition and balance of weed communities help explain why similar total weed densities can lead to different yield outcomes.

Perennial cover with Kernza presented a different trade-off. The seedbank was small and the community was well balanced, which reduces the likelihood of strong early competition. This fits the ecological principles of continuous cover and reduced disturbance, which limit germination cues for many disturbance-adapted annual weeds and favor a more even community structure (Culman et al., 2013; Glover et al., 2010). However, Kernza and other perennial grains are still in the early stages of crop development. Their grain yields are generally lower than those of annual wheat and often peak within the first few years of establishment, unless the system is managed for both grain and forage or supported by practices that sustain stand vigor over time. Many authors therefore frame Kernza as a multifunctional system that provides erosion control, nutrient retention, habitat, and forage, while breeding and agronomy continue to raise grain yield potential (Ryan et al., 2018). For farmers, this means that perennial systems can reduce weed pressure and stabilize communities, but the yield target is best met when production goals include both grain and forage.

A Broader Policy Perspective

Sweden's plan to increase organic farmland to 30% by 2030 (fableconsortium.org, n.d.) and the EU's Farm to Fork Strategy goal of 25% organic by 2030 (European Commission, 2020) highlight the political and environmental focus on reducing chemical inputs and promoting biodiversity. The results from this study suggest that these targets might be realistic only if the structural weaknesses of current systems are acknowledged. Organic system, while clearly contributing to higher species richness, also fostered the accidental dominance of disturbance-adapted weeds. This pattern reflects findings from other European field studies showing that in the absence of herbicides, a small number of opportunistic species often take advantage and become abundant (Birkhofer et al., 2008). Without addressing these dynamics, organic systems may fall short of delivering the stability and resilience proposed in policy frameworks.

A sustainable direction for weed management, therefore, requires moving away from contrasting systems against each other and instead recognising their complementary strengths. Perennial crops in this study demonstrated stable, evenly distributed weed communities, while agroforestry provided diversity when canopy cover was sufficient, and organic plots supported richness but lacked balance. These findings echo the broader concept of ecological intensification, where multiple practices are combined to replace external inputs with ecological processes (Wezel et al., 2013). The practical implication is that no single system offers a complete solution. Instead, designing farming systems that integrate perennial stability, agroforestry complexity, and active organic weed management can better align agricultural practice with both ecological processes and EU sustainability goals.

6 Conclusion

This research set out to understand how contrasting cropping systems influence the weed seed bank, a component of agroecosystems that is often overlooked but central to long-term weed management. By sampling soils from four systems within the SAFE experiment and monitoring seedling emergence in controlled conditions, the study revealed not only the size of the seed bank but also its composition and community balance. Across 3,034 seedlings representing 40 species, patterns emerged that pointed to the ecological fingerprints of each system. Some systems, such as reference and organic, generated higher overall emergence, while others, such as perennial plots, reduced both abundance and dominance. These outcomes highlight that the weed seed bank responds predictably to differences in soil disturbance, crop cover, and management intensity, making it a useful indicator for comparing farming systems.

The findings also demonstrate that evaluating weed pressure requires more than counting individuals. Species richness, evenness, and diversity indices showed that communities can be large but unbalanced, relatively low in abundance but stable. For example, widespread species such as *Chenopodium album* and *Polygonum aviculare* acted as indicators of disturbance across systems, while more balanced communities appeared under conditions of continuous cover and minimal soil turnover. Taken together, these results confirm that weed seed banks mirror both the ecological opportunities and constraints created by management. They provide not only a record of past practices but also a preview of future challenges, underscoring the importance of integrating seed bank assessments into strategies for sustainable agriculture. Future research should extend these insights by linking seed bank dynamics to crop yields and long-term resilience, ensuring that weed management contributes to both productivity and ecological sustainability.

7 Reference

Altieri, M.A., Nicholls, C.I., Dinelli, G. and Negri, L., (2024). Towards an agroecological approach to crop health: reducing pest incidence through synergies between plant diversity and soil microbial ecology. npj Sustainable Agriculture, 2(1), p.6.Available at: https://www.nature.com/articles/s44264-024-00016-2

Andert, S., Guguin, J., Hamacher, M., Valantin-Morison, M. and Baerbel Gerowitt (2023). How farmers perceive perennial weeds in Northern France and Eastern Germany. *Frontiers in agronomy*, 5. doi: https://doi.org/10.3389/fagro.2023.1247277

Azghadi, M.R., Olsen, A., Wood, J., Saleh, A., Calvert, B., Granshaw, T., Fillols, E. and Philippa, B., (2025). Precision robotic spot-spraying: Reducing herbicide use and enhancing environmental outcomes in sugarcane. *Computers and Electronics in Agriculture*, 235, p.110365. Available at: https://doi.org/10.1016/j.compag.2025.110365

Barreiro, A. and Albertsson, J. (2022). SITES Agroecological Field Experiment (SAFE). *SLU publication database (SLUpub)*. [online] doi: https://doi.org/10.23700/4ASX-8870

Basnet, S., Wood, A., Röös, E., Jansson, T., Fetzer, I. and Gordon, L. (2023). Organic agriculture in a low-emission world: exploring combined measures to deliver a sustainable food system in Sweden. *Sustainability Science*, 18(1), pp.501–519. doi: https://doi.org/10.1007/s11625-022-01279-9

Bengtsson, J., Ahnstrom, J. and Weibull, A.-C. (2005). The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology*, 42(2), pp.261–269. doi: https://doi.org/10.1111/j.1365-2664.2005.01005.x

Benvenuti, S., Selvi, M., Mercati, S., Cardinali, G., Mercati, V. and Mazzoncini, M. (2021). Stale seedbed preparation for sustainable weed seed bank management in organic cropping systems. *Scientia Horticulturae*, 289, p.110453. Available at: doi: https://doi.org/10.1016/j.scienta.2021.110453

Bhaduri, D., Sihi, D., Bhowmik, A., Verma, B.C., Munda, S. and Dari, B., (2022). A review on effective soil health bio-indicators for ecosystem restoration and sustainability. *Frontiers in Microbiology*, *13*, p.938481. Available at: https://doi.org/10.3389/fmicb.2022.938481

Birkhofer, K., Bezemer, T.M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fließbach, A., Gunst, L., Hedlund, K., Mäder, P., Mikola, J., Robin, C., Setälä, H., Tatin-Froux, F., Van der Putten, W.H. and Scheu, S. (2008). Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. *Soil Biology and Biochemistry*, 40(9), pp.2297–2308. doi: https://doi.org/10.1016/j.soilbio.2008.05.007

Björn Ringselle, Bertholtz, E., Magnuski, E., Lars Olav Brandsæter, Kjell Mangerud and Göran Bergkvist (2018). Rhizome Fragmentation by Vertical Disks Reduces Elymus repens Growth and Benefits Italian Ryegrass-White Clover Crops. *Frontiers in Plant Science*, 8. doi: https://doi.org/10.3389/fpls.2017.02243

Boinot, S., Alignier, A. and Storkey, J., (2024). Landscape perspectives for agroecological weed management. A review. *Agronomy for Sustainable Development*, *44*(1), p.7.Available at:https://link.springer.com/article/10.1007/s13593-023-00941-5

Bond, W. and Grundy, A.C. (2001). Non-chemical weed management in organic farming systems. *Weed Research*, 41(5), pp.383–405. doi: https://doi.org/10.1046/j.1365-3180.2001.00246.x

Boutagayout, A., Bouiamrine, E.H., Synowiec, A., Oihabi, K.E., Romero, P., Rhioui, W., Nassiri, L. and Belmalha, S., (2023). Agroecological practices for sustainable weed management in Mediterranean farming landscapes. *Environment, Development and Sustainability*, pp.1-55.Available at: https://link.springer.com/article/10.1007/s10668-023-04286-7

Chapman, E.A., Hanne Erdman Thomsen, Tulloch, S., Miguel, P., Luo, G., Najafi, J., DeHaan, L.R., Crews, T.E., Olsson, L., Lundquist, P.-O., Westerbergh, A., Pai Pedas, Søren Tang Knudsen and Palmgren, M.G. (2022). Perennials as Future Grain Crops: Opportunities and Challenges. *Frontiers in Plant Science*, 13. doi: https://doi.org/10.3389/fpls.2022.898769

Chaudhary, A., Chhokar, R.S. and Singh, S., (2022). Integrated weed management in wheat and barley: Global perspective. In New Horizons in Wheat and Barley Research: Crop Protection and Resource Management (pp. 545-615). Singapore: Springer Nature Singapore. Available at: https://www.researchgate.net/profile/Samunder-Singh-2/publication/360446728_Integrated_Weed_Management_in_Wheat_and_Barley_Global_Perspective/links/630da4f061e4553b954be000/Integrated-Weed-Management-in-Wheat-and-Barley-Global-Perspective.pdf

CoR News (2024). EU Organic Awards 2024: South Savo (Finland), Bremen (Germany) and Sörmland (Sweden) recognised for excellence in organic farming. Available at: https://cor.europa.eu/en/news/eu-organic-awards-2024-south-savo-finland-bremen-germany-and-sormland-sweden-recognised-excellence#:~:text=A%20jury%20comprising%20members%20of,as%20the%20best%20organic%20district.

Cordeau, S. (2022) *Conservation Agriculture and Agroecological Weed Management*, *MDPI*. Multidisciplinary Digital Publishing Institute. Available at: https://www.mdpi.com/2073-4395/12/4/867

Crews, T. and Rumsey, B. (2017). What Agriculture Can Learn from Native Ecosystems in Building Soil Organic Matter: A Review. *Sustainability*, 9(4), p.578. doi: https://doi.org/10.3390/su9040578

Crews, T.E., Carton, W. and Olsson, L. (2018). Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Global Sustainability*, [online] 1(1). doi: https://doi.org/10.1017/sus.2018.11

Culman, S.W., Snapp, S.S., Ollenburger, M., Basso, B. and DeHaan, L.R. (2013). Soil and Water Quality Rapidly Responds to the Perennial Grain Kernza Wheatgrass. *Agronomy Journal*, 105(3), pp.735–744. doi: https://doi.org/10.2134/agronj2012.0273

Culman, S.W., Snapp, S.S., Ollenburger, M., Basso, B. and DeHaan, L.R. (2013). Soil and Water Quality Rapidly Responds to the Perennial Grain Kernza Wheatgrass. *Agronomy Journal*, 105(3), pp.735–744. doi: https://doi.org/10.2134/agronj2012.0273

Daouti, E.L. (2021). *Weed seed predation: a promising ecosystem service in agriculture* (No. 2021: 61). https://publications.slu.se/?file=publ/show&id=113747

Davis, A.S., Renner, K.A. and Gross, K.L. (2005). Weed seedbank and community shifts in a long-term cropping systems experiment. *Weed Science*, 53(3), pp.296–306. doi: https://doi.org/10.1614/ws-04-182

DERKSEN, D.A., THOMAS, A.G., LAFOND, G.P., LOEPPKY, H.A. and SWANTON, C.J. (2006). Impact of post-emergence herbicides on weed community diversity within conservation-tillage systems. *Weed Research*, 35(4), pp.311–320. doi: https://doi.org/10.1111/j.1365-3180.1995.tb01794.x

Dimitrios Kremmydas, Beber, C., Baldoni, E., Pavel Ciaian, Fellmann, T., Gocht, A., Hristov, J., Pignotti, D., Vicario, D.R., Stepanyan, D. and Tillie, P. (2024). The EU target for organic farming: Potential economic and environmental impacts of two alternative pathways. *Applied Economic Perspectives and Policy*. doi: https://doi.org/10.1002/aepp.13470

Duchene, O., Bathellier, C., Dumont, B., David, C. and Florian Celette (2022). Weed community shifts during the aging of perennial intermediate wheatgrass crops harvested for grain in arable fields. *European Journal of Agronomy*, 143, pp.126721–126721. doi: https://doi.org/10.1016/j.eja.2022.126721

European Commission (2020). *Farm to Fork Strategy*. [online] food.ec.europa.eu. Available at: https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

fableconsortium.org. (n.d.). *Sweden - Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium*. [online] Available at: https://fableconsortium.org/sweden/

Favrelière, E., Aïcha Ronceux, Jérôme Pernel and Meynard, J.-M. (2020). Nonchemical control of a perennial weed, Cirsium arvense, in arable cropping systems. A review. *Agronomy for Sustainable Development*, 40(4). doi: https://doi.org/10.1007/s13593-020-00635-2

Favrelière, E., Ronceux, A., Pernel, J. and Meynard, J.M., (2020). Nonchemical control of a perennial weed, Cirsium arvense, in arable cropping systems. A review. *Agronomy for Sustainable Development*, *40*(4), p.31. Available at: https://link.springer.com/article/10.1007/s13593-020-00635-2

Fess, T.L. and Benedito, V.A. (2018). Organic versus Conventional Cropping Sustainability: A Comparative System Analysis. *Sustainability*, 10(1), p.272. doi: https://doi.org/10.3390/su10010272

Friedman, J. (2020). The evolution of annual and perennial plant life histories: ecological correlates and genetic mechanisms. *Annual Review of Ecology, Evolution, and Systematics*, *51*(1), 461-481. Available at: https://www.annualreviews.org/content/journals/10.1146/annurev-ecolsys-110218-024638

Gallandt, E.R. (2006). How can we target the weed seedbank? *Weed Science*, 54(3), pp.588–596. Available at:doi: https://doi.org/10.1614/ws-05-063r.1

Gao, W.T. and Su, W.H., (2024). Weed management methods for herbaceous field crops: A review. *Agronomy*, 14(3), p.486. Available at: https://doi.org/10.3390/agronomy14030486

Glover, J.D., Reganold, J.P. and Cox, C.M. (2012). Plant perennials to save Africa's soils. *Nature*, 489(7416), pp.359–361. doi: https://doi.org/10.1038/489359a

Grosse, M., Haase, T. and Heß, J. (2021). Varying tillage promotes weed diversity, while a perennial alfalfa–grass mixture promotes weed control in an organic tillage system experiment in Germany. *Renewable Agriculture and Food Systems*, 36(5), pp.465–476. doi: https://doi.org/10.1017/s1742170521000053

Gruber, S. and Claupein, W. (2009). Effect of tillage intensity on weed infestation in organic farming. *Soil and Tillage Research*, 105(1), pp.104–111. doi: https://doi.org/10.1016/j.still.2009.06.001

Holloway, T., Pérez, M., Chandler, J.O., Venceslai, N., Garcia, L., Cohn, J., Schilling, K., Seville, A., Leubner-Metzger, G. and Nakabayashi, K., (2024). Mechanisms of seed persistence in blackgrass (Alopecurus myosuroides Huds.). Weed Research, 64(3), pp.237-250. Available at: https://doi.org/10.1111/wre.12630

Horvath, D.P., Clay, S.A., Swanton, C.J., Anderson, J.V. and Chao, W.S. (2023). Weed-induced crop yield loss: a new paradigm and new challenges. *Trends in Plant Science*, 28(5). doi: https://doi.org/10.1016/j.tplants.2022.12.014

Hunter III, J.E., Gannon, T.W., Richardson, R.J., Yelverton, F.H. and Leon, R.G., (2020). Integration of remote-weed mapping and an autonomous spraying unmanned aerial vehicle for site-specific weed management. *Pest Management Science*, 76(4), pp.1386-1392. Available at: https://scijournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/ps.5651

Hussain, S., Hussain, S., Guo, R., Sarwar, M., Ren, X., Krstic, D., Aslam, Z., Zulifqar, U., Rauf, A., Hano, C. and El-Esawi, M.A., (2021). Carbon sequestration to avoid soil degradation: A review on the role of conservation tillage. *Plants*, 10(10), p.2001. Available at: https://doi.org/10.3390/plants10102001

Hyvönen, T., Ketoja, E., Salonen, J., Jalli, H. and Tiainen, J. (2003). Weed species diversity and community composition in organic and conventional cropping of spring cereals. *Agriculture, Ecosystems & Environment*, [online] 97(1-3), pp.131–149. doi: https://doi.org/10.1016/s0167-8809(03)00117-8

Jäck, O., Ajal, J. and Weih, M. (2021). Altered Nitrogen Availability in Pea–Barley Sole- and Intercrops Changes Dominance of Two Nitrophilic Weed Species. *Agronomy*, 11(4), p.679. doi: https://doi.org/10.3390/agronomy11040679

JordbruksVerket, (2023). Facts about-Swedish Agriculture._Available at: https://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_ovrigt/ovr2gb.pdf

Jose, S. (2009). Agroforestry for Ecosystem Services and Environmental benefits: an Overview. *Agroforestry Systems*, 76(1), pp.1–10.

Kelton, J., Price, A., Van Santen, E., Balkcom, K., Arriaga, F., Shaw, J., Kelton, C., Price, J., Santen, V. and Arriaga, K. (2011). Weed seed bank density and composition in a tillage and landscape variability study. *Communications in Biometry and Crop Science*, [online] 6(1), pp.21–30. Available at: https://www.ars.usda.gov/ARSUserFiles/60100500/csr/ResearchPubs/price/kelton_11a.pdf [Accessed 28 Sep. 2025].

Kinnebrew, E., Molander, C.K., Wilcox Warren, S., Horner, C.E., Izzo, V.M., Lewins, S.A., Maden, R., Galford, G.L. and Méndez, V.E., (2023). Tradeoffs of a rising agroecological practice: addressing uncertainty around tarping with participatory action research and mixed methods. Agroecology and Sustainable Food Systems, 47(3), pp.355-381.Available at:https://www.tandfonline.com/doi/abs/10.1080/21683565.2022.2146254

Knezevic, S.Z., Evans, S.P., Blankenship, E.E., Acker, R.C.V. and Lindquist, J.L. (2002). Critical period for weed control: the concept and data analysis. *Weed Science*, [online] 50(6), pp.773–786. doi: https://doi.org/10.1614/0043-1745(2002)050[0773:CPFWCT]2.0.CO;2

Kocira, A., Staniak, M., Tomaszewska, M., Kornas, R., Cymerman, J., Panasiewicz, K. and Lipińska, H., (2020). Legume cover crops as one of the elements of strategic weed management and soil quality improvement. A review. *Agriculture*, 10(9), p.394. Available at: https://doi.org/10.3390/agriculture10090394

Kulkarni, S.S., Dosdall, L.M. and Willenborg, C.J. (2015). The Role of Ground Beetles (Coleoptera: Carabidae) in Weed Seed Consumption: A Review. Weed Science, 63(2), pp.355–376. Available at: doi: https://doi.org/10.1614/ws-d-14-00067.1

Kushal, Rao, G.E., Boraiah B, Sanjay MT and Santosh Araganji (2024). A review on challenges and emerging opportunities for weed management in organic agriculture. *International Journal of Research in Agronomy*, [online] 7(8S), pp.859–869. doi: https://doi.org/10.33545/2618060x.2024.v7.i8sk.1401

Liebman, M., Huong, Woods, M.M., Hunt, N.D. and Hill, J.D. (2021). Weed seedbank diversity and sustainability indicators for simple and more diverse cropping systems. *Weed Research*, 61(3), pp.164–177. doi: https://doi.org/10.1111/wre.12466

Liebman, M., Mohler, C.L. and Staver, C. (2001). Ecological Management of Agricultural Weeds. doi: https://doi.org/10.1017/cbo9780511541810

Maqsood, Q., N Abbas, R., A Iqbal, M., A Serap, K., Iqbal, A. and Sabagh, A.E., (2020). Overviewing of weed management practices to reduce weed seed bank and to increase maize yield. *Planta daninha*, 38, p.e020199716. Available at: https://doi.org/10.1590/S0100-83582020380100075

Marschner, C.A., Colucci, I., Stup, R.S., Westbrook, A.S., Brunharo, C.A., DiTommaso, A. and Mesgaran, M.B., (2024). Modeling weed seedling emergence for time-specific weed management: a systematic review. *Weed Science*, pp.1-44. Available at: https://doi.org/10.1017/wsc.2024.25

Mathieu, A., Marc-Olivier Martin-Guay and Rivest, D. (2025). Enhancement of Agroecosystem Multifunctionality by Agroforestry: A Global Quantitative Summary. *Global Change Biology*, [online] 31(5). doi: https://doi.org/10.1111/gcb.70234

Menalled, F.D., Gross, K.L. and Hammond, M. (2001). WEED ABOVEGROUND AND SEEDBANK COMMUNITY RESPONSES TO AGRICULTURAL MANAGEMENT SYSTEMS. *Ecological Applications*, 11(6), pp.1586–1601. doi: https://doi.org/10.1890/1051-0761(2001)011[1586:waascr]2.0.co;2

Menalled, F.D., Gross, K.L. and Hammond, M. (2001). WEED ABOVEGROUND AND SEEDBANK COMMUNITY RESPONSES TO AGRICULTURAL MANAGEMENT SYSTEMS. *Ecological Applications*, 11(6), pp.1586–1601. doi: https://doi.org/10.1890/1051-0761(2001)011[1586:waascr]2.0.co;2

Mohler, C.L., Caldwell, B.A., Marschner, C.A., Cordeau, S., Maqsood, Q., Ryan, M.R. and DiTommaso, A. (2018). Weed Seedbank and Weed Biomass Dynamics in a Long-Term Organic Vegetable Cropping Systems Experiment. *Weed Science*, 66(5), pp.611–626. doi: https://doi.org/10.1017/wsc.2018.52

Monteiro, A. and Santos, S., (2022). Sustainable approach to weed management: The role of precision weed management. Agronomy, 12(1), p.118.Available at:https://www.mdpi.com/2073-4395/12/1/118

Mortensen, D.A., Egan, J.F., Maxwell, B.D., Ryan, M.R. and Smith, R.G. (2012). Navigating a Critical Juncture for Sustainable Weed

Management. *BioScience*, 62(1), pp.75–84. doi: https://doi.org/10.1525/bio.2012.62.1.12

Mortensen, D.A., Egan, J.F., Maxwell, B.D., Ryan, M.R. and Smith, R.G. (2012). Navigating a Critical Juncture for Sustainable Weed Management. *BioScience*, 62(1), pp.75–84. doi: https://doi.org/10.1525/bio.2012.62.1.12

Muni Kumari, A. and Durge, J.B., (2024). Improving Agricultural Carbon Sequestration Strategies by Eco Friendly Procedures for Managing Crop Residues and Weeds. In Adapting to Climate Change in Agriculture-Theories and Practices: Approaches for Adapting to Climate Change in Agriculture in India (pp. 361-375). *Cham: Springer Nature Switzerland*. Available at: https://www.researchgate.net/profile/Ritu-Mittal-2/publication/378588281_Green_Consumption_Behaviour_for_Sustainable_Development/links/66274c0839e7641c0be30399/Green-Consumption-Behaviour-for-Sustainable-Development.pdf#page=357

Mwangi, O., Mucheru-Muna, M., Kinyua, M., Bolo, P. and Kihara, J. (2024). Organic farming practices increase weed density and diversity over conventional practices: A meta-analysis. *Heliyon*, *10*(12). Available at: https://doi.org/10.1016/j.heliyon.2024.e32761

Nath, C.P., Singh, R.G., Choudhary, V.K., Datta, D., Nandan, R. and Singh, S.S. (2024). Challenges and alternatives of herbicide-based weed management. *Agronomy*, *14*(1), p.126. Available at:https://doi.org/10.3390/agronomy14010126

OECD. (2018). *Innovation, Agricultural Productivity and Sustainability in Sweden*. [online] Available at: https://www.oecd.org/en/publications/innovation-agricultural-productivity-and-sustainability-in-sweden_9789264085268-en.html

Ofosu, R., Agyemang, E.D., Márton, A., Pásztor, G., Taller, J. and Kazinczi, G. (2023). Herbicide resistance: Managing weeds in a changing world. *Agronomy*, *13*(6), p.1595. Available at: https://doi.org/10.3390/agronomy13061595

Peigné, J., Ball, B.C., Roger-Estrade, J. and David, C. (2007). Is conservation tillage suitable for organic farming? A review. *Soil Use and Management*, 23(2), pp.129–144. doi: https://doi.org/10.1111/j.1475-2743.2006.00082.x

Peixoto, L., Olesen, J.E., Elsgaard, L., Enggrob, K.L., Banfield, C.C., Dippold, M.A., Nicolaisen, M.H., Bak, F., Zang, H., Dresbøll, D.B. and Thorup-Kristensen, K. (2022). Deep-rooted perennial crops differ in capacity to stabilize C inputs in deep soil layers. *Scientific Reports*, *12*(1), p.5952. Available at:https://www.nature.com/articles/s41598-022-09737-1.pdf

Petrikovszki, R., Zalai, M., Tóthné Bogdányi, F. and Tóth, F., (2020). The effect of organic mulching and irrigation on the weed species composition and the soil weed seed bank of tomato. *Plants*, 9(1), p.66. Available at: https://doi.org/10.3390/plants9010066

Pullens, J.W.M., Sørensen, P., Melander, B. and Olesen, J.E., (2021). Legacy effects of soil fertility management on cereal dry matter and nitrogen grain yield of organic arable cropping systems. *European Journal of Agronomy*, *122*, p.126169. Available at: https://doi.org/10.1016/j.eja.2020.126169

Pumariño, L., Sileshi, G.W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M.N., Midega, C. and Jonsson, M. (2015). Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic and Applied Ecology*, [online] 16(7), pp.573–582. doi: https://doi.org/10.1016/j.baae.2015.08.006

Radosevich, S.R., Holt, J.S. and Ghersa, C.M. (2007). Ecology of Weeds and Invasive Plants. doi: https://doi.org/10.1002/9780470168943

Ringselle, B., De Cauwer, B., Salonen, J. and Soukup, J. (2020). A Review of Non-Chemical Management of Couch Grass (Elymus repens). *Agronomy*, 10(8), p.1178. doi: https://doi.org/10.3390/agronomy10081178

Romain Carrié, Smith, H.G. and Johan Ekroos (2024). Sensitivity to agricultural inputs and dispersal limitation determine the response of arable plants to time since transition to organic farming. *Journal of Applied Ecology*, 61(6), pp.1227–1242. doi: https://doi.org/10.1111/1365-2664.14650

Rosati, A., Borek, R. and Canali, S. (2021). Agroforestry and organic agriculture. *Agroforestry Systems*, *95*, pp.805-821. Available at: https://link.springer.com/article/10.1007/s10457-020-00559-6

Ryan, M.R., Crews, T.E., Culman, S.W., DeHaan, L.R., Hayes, R.C., Jungers, J.M. and Bakker, M.G. (2018). Managing for Multifunctionality in Perennial Grain Crops. *BioScience*, 68(4), pp.294–304. doi: https://doi.org/10.1093/biosci/biy014

Ryan, M.R., Crews, T.E., Culman, S.W., DeHaan, L.R., Hayes, R.C., Jungers, J.M. and Bakker, M.G. (2018). Managing for Multifunctionality in Perennial Grain Crops. *BioScience*, 68(4), pp.294–304. doi: https://doi.org/10.1093/biosci/biy014

Rylander, H. *et al.* (2020) 'Black Plastic Tarps Advance Organic Reduced Tillage I: Impact on Soils, Weed Seed Survival, and Crop Residue,' *HortScience*, 55(6), pp. 819–825. Available at: https://doi.org/10.21273/HORTSCI14792-19 (Accessed: 23 September 2025).

S. Håkansson (2003). Weeds and weed management on arable land: an ecological approach. *CABI Publishing eBooks*, pp.1–3. doi: https://doi.org/10.1079/9780851996516.0001

Sabal, S.K., Saxena, A., Kumar, A., Kumar, R. and Yadav, R., (2024). HOLISTIC APPROACH OF WEED MANAGEMENT IN ORGANIC PRODUCTION. *Natural Farming: Basics and Application*, p.116. Available at: https://considera.org/downloads/Published%20Papers/BookonNaturalFarming-FinalPDF.pdf#page=126

Salonen, J., Koppelmäki, K. and Känkänen, H. (2017). *'Crop diversification and weeds' (PRODIVA project 2015-2018) Weed management with cover crops in the Nordic-Baltic region -a snapshot from the references*. [online] Available at: https://projects.au.dk/fileadmin/PRODIVA_CoverCrop_review2017_final.pdf [Accessed 24 Sep. 2025].

Schwartz-Lazaro, L.M. and Copes, J.T. (2019). A Review of the Soil Seedbank from a Weed Scientists Perspective. *Agronomy*, 9(7), p.369. Available at: doi: https://doi.org/10.3390/agronomy9070369

Scott, E.I., Toensmeier, E., Iutzi, F., Rosenberg, N.A., Lovell, S.T., Jordan, N.R., Peters, T.E., Akwii, E. and Broad Leib, E.M. (2022). Policy pathways for perennial agriculture. *Frontiers in Sustainable Food Systems*, 6. doi: https://doi.org/10.3389/fsufs.2022.983398

Seufert, V. and Ramankutty, N. (2017). Many shades of gray—The context-dependent performance of organic agriculture. *Science Advances*, 3(3). doi: https://doi.org/10.1126/sciadv.1602638

Shah, T.M., Tasawwar, S., Bhat, M.A. and Otterpohl, R., (2021). Intercropping in rice farming under the system of rice intensification—An agroecological strategy for weed control, better yield, increased returns, and social–ecological sustainability. *Agronomy*, *11*(5), p.1010.Available at: https://www.mdpi.com/2073-4395/11/5/1010

Sharma, P., Singh, M.K., Verma, K. and Prasad, S.K. (2022). Soil weed seedbank under different cropping systems of middle Indo-Gangetic Plains. *Plant, Soil & Environment*, *68*(11). Available at: https://doi.org/10.17221/162/2022-PSE

Shoenberger, E. (2022). *Agronomic practices to manage competition in dual-use Kernza intermediate wheatgrass (Thinopyrum intermedium) to sustain grain yield over time* (Doctoral dissertation, UNIVERSITY OF WISCONSIN-MADISON). Available at: https://agroecology.wisc.edu/wp-content/uploads/sites/75/2023/08/Shoenberger_MS_Thesis-reduced.pdf

Siedt, M., Schäffer, A., Smith, K.E., Nabel, M., Roß-Nickoll, M. and Van Dongen, J.T., (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment*, *751*, p.141607. Available at: https://doi.org/10.1016/j.scitotenv.2020.141607

Smith, R.G., Gross, K.L. and Robertson, G.P. (2008). Effects of Crop Diversity on Agroecosystem Function: Crop Yield Response. *Ecosystems*, 11(3), pp.355–366. doi: https://doi.org/10.1007/s10021-008-9124-5

Storkey, J. and Neve, P. (2018). What good is weed diversity? *Weed Research*, 58(4), pp.239–243. doi: https://doi.org/10.1111/wre.12310

Storkey, J. and Neve, P. (2018). What good is weed diversity? *Weed Research*, 58(4), pp.239–243. doi: https://doi.org/10.1111/wre.12310

Tautges, N., Detjens, A. and Jungers, J. (2023). *Kernza ® Grower Guide*. [online] Available at: https://sustainablecropping.umn.edu/sites/sustainablecropping.umn.edu/files/2023-08/Grower%20guide_final_with_citation.pdf .

Tian, A., Halik, Ü., Fu, W., Subinur Sawirdin, Cheng, S. and Lei, J. (2023). Research History of Forest Gap as Small-Scale Disturbances in Forest Ecosystems. *Forests*, 15(1), pp.21–21. doi: https://doi.org/10.3390/f15010021

Torralba, M., Fagerholm, N., Burgess, P.J., Moreno, G. and Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment*, 230, pp.150–161. doi: https://doi.org/10.1016/j.agee.2016.06.002

Travlos, I., Gazoulis, I., Kanatas, P., Tsekoura, A., Zannopoulos, S. and Papastylianou, P. (2020). Key Factors Affecting Weed Seeds' Germination, Weed Emergence, and Their Possible Role for the Efficacy of False Seedbed Technique as Weed Management Practice. *Frontiers in Agronomy*, 2. doi: https://doi.org/10.3389/fagro.2020.00001

Udawatta, R.P. and Jose, S. (2012). Agroforestry strategies to sequester carbon in temperate North America. *Agroforestry Systems*, 86(2), pp.225–242. doi: https://doi.org/10.1007/s10457-012-9561-1

Uduwalage, Nirupama Rathnamalee Sirisena (2024). Weed Seed Bank Assessment in Two Organic Crop Rotation in Southern Sweden - Epsilon Archive for Student Projects. *Epsilon.slu.se*. [online] doi: https://stud.epsilon.slu.se/20658/1/Uduwalage-N-20241114.pdf

Vijayakumar, S. (2024). Emerging weed management techniques in agriculture: Harvest weed seed control, weed-tolerant cultivars and foam weed control. Available at: http://dx.doi.org/10.5958/0974-8164.2024.00018.8

Vijayakumar, S., Shanmugapriya, P., Saravanane, P., Ramesh, T., Murugaiyan, V. and Ilakkiya, S., (2025). Precision Weed Control Using Unmanned Aerial Vehicles and Robots: Assessing Feasibility, Bottlenecks, and Recommendations for Scaling. *NDT*, 3(2), p.10. Available at: https://doi.org/10.3390/ndt3020010

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A. and Peigné, J. (2013). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development*, 34(1), pp.1–20. doi: https://doi.org/10.1007/s13593-013-0180-7

Wortman, S.E., Francis, C.A. and Lindquist, J.L. (2012). Cover Crop Mixtures for the Western Corn Belt: Opportunities for Increased Productivity and Stability. *Agronomy Journal*, 104(3), pp.699–705. doi: https://doi.org/10.2134/agronj2011.0422

Yara (2024). Sweden's ambition to increase organic farming._Available at:https://www.yara.com/knowledge-grows/swedens-ambition-to-increase-organic-farming/

Zamljen, S.A., Rovanšek, A. and Leskovšek, R. (2024). Weed seed bank response during the early conversion period to less intensive tillage systems. *Soil and Tillage Research*, *242*, p.106164. Available at: https://doi.org/10.1016/j.still.2024.106164

Zingsheim, M.L. and Döring, T.F. (2024). Does weed diversity mitigate yield losses? *Frontiers in Plant Science*, 15. doi:https://doi.org/10.3389/fpls.2024.1395393.

Popular science summary

This thesis explores how different farming systems shape the reserve of weed seeds lying dormant in the soil, which can affect future crop growth. By comparing for systems, the study examined how many weeds appear, how many species exist, and how balanced these species are. The findings showed that the conventional and organic fields had the most weeds, while the perennial system had fewer, which may be due to its constant ground cover and very little soil disturbance. Organic fields contained many species, but a few fast and aggressive weeds, especially *Chenopodium album*, dominated. Agroforestry lies between these systems, with fewer weeds than conventional and organic, probably helped by shade and more varied vegetation.

When the results are compared, a clear pattern appears. It is not only how many weeds there are that matters, but whether the weed community is balanced. The perennial system created the most stable and even weed community, which is useful for long-term control. Conventional and organic systems showed that frequent soil disturbance or farming without herbicides can give a small number of weedy species the chance to take over, even when overall diversity looks high. This suggests that sustainable weed management should combine several ideas at once, such as keeping the soil covered, disturbing it less, and growing a wider range of crops, so that the weed seed bank is not constantly renewed. In this way, farmers can protect yields while moving toward farming that uses fewer chemicals and supports more on-farm biodiversity.

Appendix 1

Weed abundance in Block A across cropping systems and phases.

Species/Treatments	Agroforestry		Reference		Organic		Perennial	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Capsella bursa-pastoris	*1*	*0*	*10*	*3*	*0*	*0*	*0*	*0*
Cerastium fontanum	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*
Chenopodium album	*70*	*21*	*41*	*3*	*73*	*5*	*5*	*2*
Cirsium arvense	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Epilobium Ssp	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*
Fallopia convolvulus	*4*	*6*	*0*	*0*	*6*	*2*	*6*	*0*
Grass Weed	*10*	*1*	*23*	*3*	*2*	*0*	*13*	*2*
Laminum purpureum	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Myostis arvensis	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*
Oilseed Rape	*0*	*0*	*4*	*1*	*0*	*0*	*0*	*0*
Papaver dubium	*1*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Persicaria maculosa	*9*	*2*	*1*	*0*	*34*	*5*	*18*	*6*
Plantago major	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*
Polygonum aviculare	*10*	*2*	*29*	*9*	*9*	*0*	*23*	*4*
Rumex crispus	*1*	*1*	*2*	*0*	*1*	*0*	*1*	*0*
Senecio vulgaris	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Sonchus asper	*5*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Stellaria media	*1*	*9*	*19*	*2*	*2*	*4*	*2*	*2*
Tripleurospermum perforatum	*22*	*0*	*32*	*0*	*15*	*0*	*7*	*0*
Unidentified	*4*	*0*	*0*	*0*	*1*	*0*	*1*	*0*
Veronica Ssp	*11*	*7*	*10*	*2*	*12*	*0*	*5*	*3*
Viola arvensis	*0*	*1*	*0*	*0*	*2*	*0*	*1*	*0*

Weed abundance in Bock B across cropping systems and two phases

Species/Treatments	Agroforestry		Reference		Organic		Perennial	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Capsella bursa-pastoris	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Cerastium caespitosum	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Cerastium fontanum	*0*	*0*	*0*	*5*	*0*	*0*	*5*	*0*
Chenopodium album	*9*	*5*	*28*	*6*	*285*	*5*	*4*	*0*
Cirsium arvense	*3*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Fallopia convolvulus	*19*	*1*	*6*	*0*	*24*	*0*	*10*	*0*
Grass Weed	*5*	*0*	*40*	*1*	*12*	*0*	*10*	*3*
Matricaria chamomilla	*2*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Myosotis arvensis	*2*	*0*	*0*	*1*	*0*	*0*	*5*	*1*
Papaver dubiam	*0*	*0*	*1*	*0*	*0*	*0*	*1*	*0*
Persicaria maculosa	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Plantago major	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Polugonum aviculare	*0*	*0*	*16*	*2*	*0*	*0*	*0*	*0*
Rumex crispus	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*0*
Solanum nigrum	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*0*
Sonchus asper	*6*	*0*	*5*	*0*	*7*	*0*	*0*	*0*
Stellaria media	*3*	*0*	*2*	*2*	*2*	*0*	*16*	*2*
Taraxacum ssp	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*0*
Trifolium ssp	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*0*
Tripleurospermum perforatum	*0*	*0*	*21*	*8*	*2*	*0*	*4*	*0*
Unidentified	*1*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Veronica ssp	*18*	*0*	*7*	*5*	*54*	*0*	*10*	*5*
Viola arvensis	*4*	*0*	*3*	*0*	*17*	*0*	*4*	*0*

Weed abundance in Block C across the cropping systems and both phases.

Species/Treatments	Agroforestry		Reference		Organic		Perennial	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Achillea millifolium	*0*	*0*	*0*	*0*	*3*	*0*	*0*	*0*
Capsella bursa-pastoris	*1*	*0*	*1*	*1*	*2*	*0*	*4*	*1*
Cerastium caespitosum	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*0*
Chenopodium album	*95*	*13*	*64*	*8*	*102*	*17*	*30*	*4*
Cirsium arvense	*0*	*0*	*1*	*0*	*0*	*0*	*1*	*0*
Epilobium ssp	*11*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Erodium cicutarium	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Fallopia convolvulus	*13*	*3*	*20*	*0*	*8*	*2*	*17*	*0*
Fumaria officinalis	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Geranium pusillum	*1*	*1*	*3*	*0*	*2*	*0*	*0*	*0*
Grass Weed	*1*	*0*	*8*	*5*	*4*	*1*	*15*	*3*
Laminum purpureum	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Matricaria discoidea	*0*	*0*	*4*	*0*	*3*	*0*	*1*	*0*
Myostis arvensis	*2*	*0*	*0*	*0*	*11*	*4*	*0*	*0*
Oilseed Rape	*0*	*0*	*1*	*0*	*1*	*0*	*0*	*0*
Papaver dubiam	*1*	*2*	*4*	*0*	*8*	*0*	*2*	*0*
Plantago major	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Polygonum aviculare	*0*	*0*	*224*	*0*	*6*	*0*	*35*	*0*
Rumex crispus	*0*	*0*	*0*	*0*	*1*	*1*	*0*	*0*
Sisymbrium officinale	*1*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Solanum nigrum	*0*	*0*	*0*	*0*	*5*	*0*	*0*	*0*
Sonchus asper	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Stellaria media	*12*	*0*	*1*	*0*	*7*	*2*	*13*	*0*
Taraxacum ssp	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Trifolium ssp	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Tripleurospermum perforatum	*24*	*5*	*22*	*5*	*36*	*0*	*5*	*1*
Unidentified	*0*	*0*	*0*	*1*	*0*	*2*	*0*	*0*
Veronica ssp	*31*	*7*	*5*	*4*	*19*	*9*	*3*	*1*
Viola arvensis	*2*	*0*	*16*	*1*	*4*	*7*	*11*	*1*

Weed abundance in Block D across the cropping systems and both phases.

Species/Treatments	Agroforestry		Reference		Organic		Perennial	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Chenopodium album	*36*	*1*	*52*	*6*	*26*	*6*	*0*	*1*
Cirsium arvense	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*
Euphorbia helioscopia	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*
Fallopia convolvulus	*11*	*2*	*3*	*0*	*8*	*1*	*9*	*3*
Grass Weed	*1*	*0*	*5*	*2*	*5*	*0*	*4*	*0*
Matricaria discoidea	*0*	*0*	*4*	*0*	*0*	*0*	*0*	*0*
Matricaria recutita	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
Myostis arvensis	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*2*
Papaver dubiam	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Polygonum aviculare	*3*	*1*	*53*	*0*	*0*	*0*	*12*	*0*
Rumex crispus	*0*	*0*	*3*	*0*	*0*	*0*	*0*	*0*
Sonchus asper	*2*	*0*	*81*	*1*	*3*	*0*	*4*	*0*
Stellaria media	*24*	*1*	*5*	*0*	*9*	*1*	*0*	*3*
Taraxacum ssp	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*
Trifolium ssp	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*0*
Tripleurospermum perforatum	*1*	*0*	*23*	*6*	*0*	*0*	*2*	*0*
Unidentified	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
Veronica ssp	*53*	*0*	*6*	*0*	*41*	*0*	*5*	*4*
Viola arvensis	*0*	*6*	*0*	*0*	*1*	*5*	*3*	*4*

Appendix 2

Weight of soil samples (in grams) collected from each cropping system and block, collected in two plastic bags per system.

System	Block	Crop	System_Block_Crop	Bag1 (g)	Bag2 (g)
Agroforestry	A	WRYE	AI_A_WRYE	3396	3289
Agroforestry	B	WRYE	AI_B_WRYE	3583	3321
Agroforestry	C	WRYE	AI_C_WRYE	3626	3843
Agroforestry	D	WRYE	AI_D_WRYE	3131	3456
Organic	A	WRYE	Org_A_WRYE	3319	3193
Organic	B	WRYE	Org_B_WRYE	4105	4072
Organic	C	WRYE	Org_C_WRYE	3801	3587
Organic	D	WRYE	Org_D_WRYE	3316	2910
Perennial	A	KER	Per_A_KER	2991	2880.5
Perennial	B	KER	Per_B_KER	2805	2854
Perennial	C	KER	Per_C_KER	3550	3440
Perennial	D	KER	Per_D_KER	3267	3048
Reference	A	WW	Ref_A_WW	3398.5	3612.5
Reference	B	WW	Ref_B_WW	4042	4155
Reference	C	WW	Ref_C_WW	3925	3859
Reference	D	WW	Ref_D_WW	3504	3753

Appendix 3

Photos from experiment

Photo 1: Unidentified weed seedlings growing in small pots during the greenhouse trial, maintained for further identification and recording.

Photo 2: Unidentified grass-type weed seedlings growing in pots, left to mature for later identification.

Photo 3: Weed seedlings emerging densely from soil samples collected in the organic system (Block B, Winter Rye).

Photo 4: Weed seedlings emerging densely from soil samples collected in the organic system (Block C, Winter wheat).

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