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REVIEW

Agroecological practices for sustainable weed management in Mediterranean farming landscapes

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Abstract
Weed management in agriculture is hampered by inefficient intensive methods, such as monoculture, deep plowing, and herbicides, leading to health and environmental problems. Furthermore, the prevalence of herbicide-resistant weed ecotypes in the Mediterranean, particularly in France (with over 61 ecotypes), Spain (41), and Italy (37), is a major concern, with a significant proportion of herbicides in the region. In this study, we examined the benefits of adopting agroecology as a sustainable approach for weed management in the Mediterranean region. Agroecology offers a variety of techniques and practices to improve sustainability and weed management, while preserving ecological balance and biodiversity. However, solving these challenges is multifactorial and depends on local specificities, predominant weed species, crops, sowing dates, and pedo-climatic factors. In addition, this study included a systematic analysis of agroecological weed management in Mediterranean countries, assessing the effectiveness of existing practices, and identifying areas requiring further exploration in agroecosystems. A bibliometric analysis was also included to assess the literature on agroecology and weed management quantitatively, identifying major trends, influential studies, and research gaps. The bibliometric analysis highlighted the importance of alternative herbicides in Mediterranean "weed" (with a link strength of 44), "agroecology" (22), and "biodiversity" (16). Italy has the strongest collaboration network, with a link strength of 61, followed by Turkey (44), and France (42). Using specific keywords to agroecological practices for weed management in Scopus, France worked the most in this context (around 25% of studies), followed by Spain (17%) and Italy (17%), while all other countries contributed to less than 40% of studies carried out in the Mediterranean context. Clearly, it is imperative to foster collaboration between Mediterranean countries to develop effective and sustainable weed control strategies. Understanding the challenges of herbicide-resistant weeds, exploring their reasons and mechanisms, and using systematic studies and bibliometric analyses will help to develop effective strategies for managing weeds in the Mediterranean. Agroecological management favors effective control, while promoting healthy and sustainable ecosystems, preserving biodiversity, and ensuring long-term food security.

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Keywords Agroecological weed management · Herbicide-resistant weeds · Intensive weed control · Mediterranean-farming landscapes · Sustainability

1 Introduction

Globally, pesticides are widely used, consuming about 2–4 million tons annually (Martins et al., 2021; Sharma et al., 2019). However, they are often corroded by misuse and abuse, which is ecologically unacceptable (Hanif et al., 2022). The main concerns of chemical pest control agents include contamination of water systems and deposition of residues with negative impacts on the environment; less than 0.1% of pesticides reach their intended pest targets (Marsala et al., 2020). They have unavoidable effects on the biodiversity of various aquatic and terrestrial non-target organisms and can negatively affect natural enemies by eliminating them or disrupting their life cycles (Sánchez-Bayo & Wyckhuys, 2019; Brühl et al., 2019; LeBuhn & Luna, 2021; Brühl & Zaller, 2019). Pesticides also cause possible harm to humans, animals, and other organisms, triggering a decrease in viability, migration, proliferation, and differentiation of neural stem cells and an increase in the risk of infertility in humans (Abdoli et al., 2022; Parrón et al., 2011). These negative effects can be amplified by the bioaccumulation of pesticide residues and potential synergy due to co-exposure to other synthetic products (Dara & Drabovich, 2022; Tudi et al., 2021).

Most of the pesticides used are herbicides (47.5%), followed by insecticides (29.5%) and fungicides (17.5%) (Sharma et al., 2019). The losses caused by weeds are very important. They are estimated to be between 20 and 40% of the average crop production loss worldwide, depending on the species of the weed flora, their density, biomass, and the period of their infestation (Kumar et al., 2021a). Arable weeds cause annual economic losses exceeding US$100 billion worldwide (Esposito et al., 2021). In contrast, plant diseases (plant pathogens) and insect pests cause economic losses of approximately US$220 and US$70 billion per year, respectively (FAO, 2017). In addition, production losses caused by parasitic weeds are between 30 and 80%, with economic losses between 111 and US$200 million and continuing to increase by about US$30 million annually (Rodenburg et al., 2016).

Since ancient times, farmers have always been concerned about weed control. At first, using herbicides proved to be an effective method for managing weed flora and increasing crop productivity by farmers (Sharma et al., 2019). However, the misuse of herbicides has quickly resulted in many complications not only for environmental health but also for the reciprocal effect on the weed flora itself, especially the emergence of herbicide-resistant ecotypes, due to the use of herbicides that have the same mode of action (Ghanizadeh & Harrington, 2021). Consequently, yield and economic losses are increasingly accentuated by the emergence of resistant weed biotypes, which makes chemical treatment less effective (Lykogianni et al., 2021). Hence, chemical crop protection is an overwhelming threat to effective and sustainable weed management at the global agroecosystem scale. The current challenge is to design alternative cropping systems that maintain food production while reducing chemical input. Agricultural management models and paradigms have been proposed as part of climate-smart agriculture in Africa (Kaptymer et al., 2019), such as conservation agriculture, which has various advantages, i.e., conserving soil moisture, reducing energy, machinery costs, and soil erosion while improving soil structure (Brown et al., 2021; Page et al., 2020; Robert, 2018a). Also, organic farming, a certified farming system that bans the use of synthetic pesticides, has developed in recent decades, focusing on increased biodiversity of crop rotations combined with shallow tillage, improving agroecosystems' life and structure (Kumar et al., 2021b; Rosati et al., 2021).

As an environmentally friendly paradigm, agroecology is an alternative to intensive farming. Agroecology is not a farming system. Still, it is a holistic approach to agriculture that promotes sustainability, biodiversity, and social equity in food production. It emphasizes the interconnectedness of ecological systems and recognizes the importance of local knowledge, traditional practices, and community participation in achieving agricultural sustainability (Rivera-Ferre et al., 2021) and adapting to local conditions (Katre et al., 2022). Agroecology offers a promising alternative to conventional industrial agriculture, prioritizing profitability at the expense of environmental degradation and social injustice (Katre et al., 2022; Wezel et al., 2020).

Agroecological weed management is an agricultural approach emphasizing ecological principles to maintain system resilience, biodiversity, and productivity. In agroecology, reliance on synthetic herbicides is reduced; however, they can be used in critical situations. Agroecological systems can mitigate the negative environmental impacts of conventional herbicide-based weed management by balancing weeds, crops, and agroecosystem components (Tournebize et al., 2020). Furthermore, these methods have shown potential for maintaining long-term weed suppression without inducing herbicide resistance or adverse effects on non-target organisms (Table 1). As such, this approach has gained much attention globally, particularly in Mediterranean countries, where pressures from harsh climate conditions, such as drought, are high. This represents a critical part of sustainable crop production aimed at safeguarding food security without compromising biodiversity and human health. Within this framework, agroecology proposes various weed control strategies based on ecological, social, and economic principles. However, there is no clear information on studies conducted on agroecological weed management in Mediterranean countries. However, studies have investigated the effectiveness of legume cover crops for weed control in Mediterranean countries (Boulet et al., 2021), the design of cropping systems for non-chemical weed management in European countries (Calha et al., 2019), the effects of weed management practices on plant communities in Mediterranean vineyards (Guerra et al., 2022), and the need for an ecological approach to weed science and management in different agricultural systems worldwide (MacLaren et al., 2020).

This literature review focuses on agroecological weed management, particularly in Mediterranean landscapes, and is underpinned by comprehensive rationale. This highlights the significance of considering authors' specialized knowledge and research interests, emphasizing the scarcity of literature reviews dedicated to this geographic region. The review cautions against making overly broad generalizations owing to the inherent complexities of agroecosystems and agricultural practices, emphasizing the substantial influence of local factors. It also acknowledges regional variations within the Mediterranean, stressing the importance of recognizing the uniqueness of different locales and agroecosystems. Additionally, it underscores the universal principles of agroecology, while emphasizing the critical role of adapting these principles to local conditions for advancing sustainable agriculture. Ultimately, this literature review aimed to enhance the understanding of region-specific challenges and contribute valuable insights to the global body of agroecological knowledge, emphasizing the crucial importance of adaptability in promoting sustainability. The primary focus of this study was to investigate agroecological weed management practices within Mediterranean agricultural landscapes, with the overarching goal of reducing herbicide-resistant weed proliferation. This study systematically examined the advantages of adopting agroecology as a sustainable approach to weed management in the Mediterranean context. It also includes a rigorous bibliometric analysis to quantitatively assess the

Table 1 Some benefits and challenges of intensive and agroecological weed management in the Mediterranean region

Agroecological management		Conventional management	
Advantages	Constraints	Advantages	Constraints
Facilitation of crop growth and production (Detrey, 2021); Maintenance of biodiversity (Barot et al., 2021); Natural biocontrol of crop pests and diseases (Thomine, 2021); Enrichment and improvement of agricultural soil quality (Detrey, 2021) Generally less expensive, environmentally friendly, safe, feasible, and with reproducible results (Jordan & Vatovec, 2004; Gaba et al., 2014; Mafongoya et al., 2016) Mulch retains soil moisture and reduces plant water requirements (Li et al., 2021) It also promotes early crop maturation (Chopra & Koul, 2020) Cover cropping reduced weed seed bank size and enhanced soil nitrogen content (Nichols et al., 2020) Crop diversity is less susceptible to diseases and pests compared to pure crops (Vlahova, 2022)	Mulching is expensive on a large scale, and some organic mulches have allelopathic effects on crops (Pedda et al., 2020; Monteiro & Santos, 2022). Managing multiple nutrients in crop diversification (Weerarathne et al., 2017) Lack of equipment for good management and harvesting of crop diversity (Mortensen & Smith, 2020) Agroecological transition is slow in developing countries due to the neglect of local household knowledge (Einbinder et al., 2022) Current agricultural policies do not significantly support an agroecological transition (Wang et al., 2022)	Herbicides can improve production efficiency and require less cost and human effort (Scavo & Mauromicale, 2020). Mechanical weed control can provide effective weed management (Banik & Jha, 2020)	Herbicide resistance of some weed biotypes (Torra et al., 2022) Intensive mechanization increases soil erosion, leading to a loss of fertility (Martínez-Casasnovas, & Concepcion Ramos, 2009) Herbicide use contaminates soil, water, food and air and causes disease in humans and animals (Sharma et al., 2019) Chemical herbicides can significantly decrease earthworm communities and populations (Monteiro & Santos, 2022) Mechanical methods are generally ineffective (Monteiro & Santos, 2022) Environmental pollution (Rosculete et al., 2019) Lack of application technology (Radi, 2007) Risk of phytotoxicity on crops (Gullino & Tavella, 2020) Low persistence and availability, especially in developing countries (Radi, 2007) The income of subsistence farmers is generally too low to afford them (Constantine et al., 2020) Increased carbon dioxide under climate change may increase the herbicide tolerance of some weed species (Chen et al., 2020) Impact on pollinators (Sponsler et al., 2019) Requires proper application practices (Chauhan, 2020)

existing literature on agroecology and weed management and identify key trends, influential studies, and research gaps in this field. The fundamental objective of this research is to elucidate the primary agroecological methods and perspectives that underlie sustainable weed management approaches within the Mediterranean region, drawing from recent scientific research to inform the discourse.

2 Methodology

This literature review provides an overview of agroecological weed management practices, especially in the Mediterranean region. A general overview of the different agroecological methods of weed management, including definitions, potential mechanisms, and concrete examples specific to the Mediterranean region, is presented in the following sections. Thus, the scientific search engine Scopus was consulted to study the topic systematically. The search criteria focused on literature dealing with different agroecological practices with the use of keywords such as ("weed management" OR "agroecological weed management" OR "Mediterranean landscapes" OR "herbicide-resistant" OR "alternative weed control" OR "Biological weed control") AND ("Allelopathy" OR "Crop diversity" OR "Cover crops" OR "Mulching") AND (LIMIT-TO AFFILCOUNTRY, All Mediterranean countries). In addition, an in-depth analysis was performed using bibliometric data from the Scopus database to create a network of articles associated with agroecological weed management methods in Mediterranean countries. Data from 243 papers were exported as CSV and Tab-delimited files from the most recent version of Scopus to provide an overview of the state of the research and its trajectory. The VOSviewer software used for the bibliometric analysis included various indices, such as keyword indices (for Scopus) and co-authorship distribution by country (Boutagayout et al., 2023a; Lee & Thierfelder, 2017).

3 Mediterranean characteristic

The Mediterranean spans three continents, including Spain, Italy, Greece, Tunisia, Morocco, and Egypt (Fig. 1). The region's climate is characterized by warm summers and mild winters with low precipitation, offering a wide variety of produce, such as olive groves, vineyards, citrus orchards, and grain crops that dominate the agricultural landscape. Thus, the Mediterranean climate protects plant diversity and endemism worldwide. The terrain varies from fertile plains to rugged mountain ranges and coastal cliffs, allowing farmers to produce these crops at both small and large scales (Ulbrich et al., 2012). Occasionally, agriculture is practiced on steep and hilly terrains with low soil fertility, which requires traditional agroecological practices for sustainable land use. Livestock is also important to rural communities, with pasturelands being particularly important for pastoralism; however, they are increasingly under pressure from urbanization and conversion to croplands or forests (Zeder et al., 2008).

Despite the challenges facing agricultural systems in the Mediterranean region due to climate variability and socioeconomic factors such as population growth and changing market demands, agroecology remains a key tool for the sustainable management of natural resources while ensuring food security for local communities (Lionello et al., 2014; Papamichael et al., 2022).

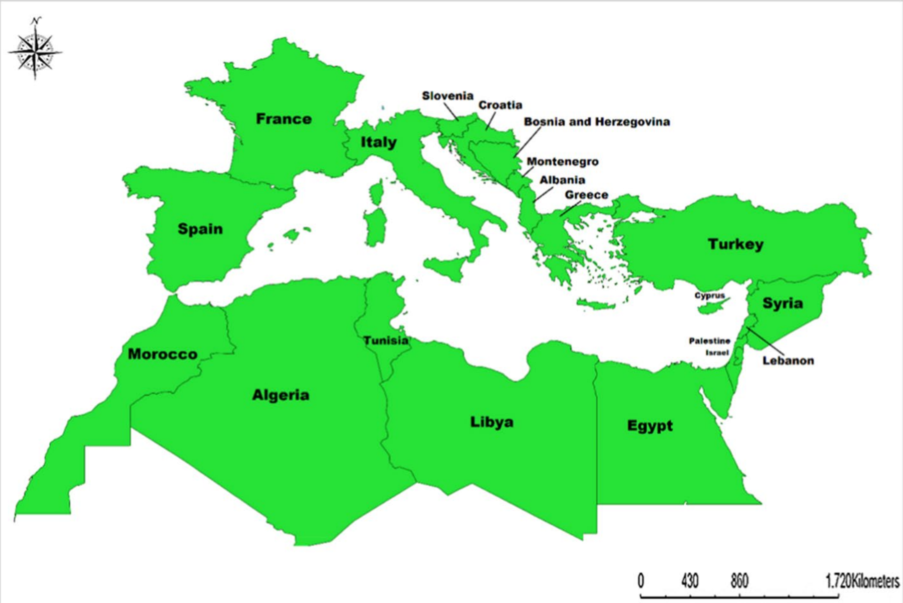

Fig. 1 Map of the study area (Mediterranean region) on agroecological weed management

4 Herbicide-resistant weeds in Mediterranean farming landscapes

Herbicide-resistant weeds are a significant challenge in Mediterranean agricultural landscapes (Garibaldi et al., 2023). Herbicide resistance is an inherited trait weeds acquire to survive and reproduce under herbicide exposure (Torra et al., 2022). The evolution of weed resistance to herbicides poses a serious threat to sustainable agriculture as it can lead to reduced crop yields and increased herbicide use (Gherekhloo et al., 2021). The presence of resistant ecotypes among weed species introduces a heightened level of complexity in weed control efforts. These ecotypes possess the ability to endure soil for extended periods, facilitating robust and enduring development. For example, weed seeds can persist in the soil for several years and germination is influenced by factors such as humidity, plant exudates, and environmental conditions (Long et al., 2015; Travlos et al., 2019). This persistence extends into the subsequent growing seasons and significantly contributes to the proliferation of resistant weed ecotypes. It is crucial to note that the impact of resistant ecotypes extends beyond self-sustainability, as there is a potential for cross-contamination with non-resistant populations, further exacerbating the existing challenge (Merotto et al., 2016; Vencill et al., 2012).

The worldwide spread of herbicide-resistant weeds is exponential (Garibaldi et al., 2023). Herbicide resistance has been reported in various weed species, including *Phalaris* spp., which are self-pollinating annual grasses commonly grown in Mediterranean climates (Gherekhloo et al., 2021).

Currently, 520 herbicide-resistant weeds exist worldwide, comprising a combination of species and sites of action. There were 268 distinct species, including 154 broadleaf weeds and 114 monocots. Weeds developed resistance to 31 known herbicide sites of action, resulting in resistance to 165 different herbicides. Herbicide-resistant weeds have been reported in 98 crops across 72 countries (Heap, 2023).

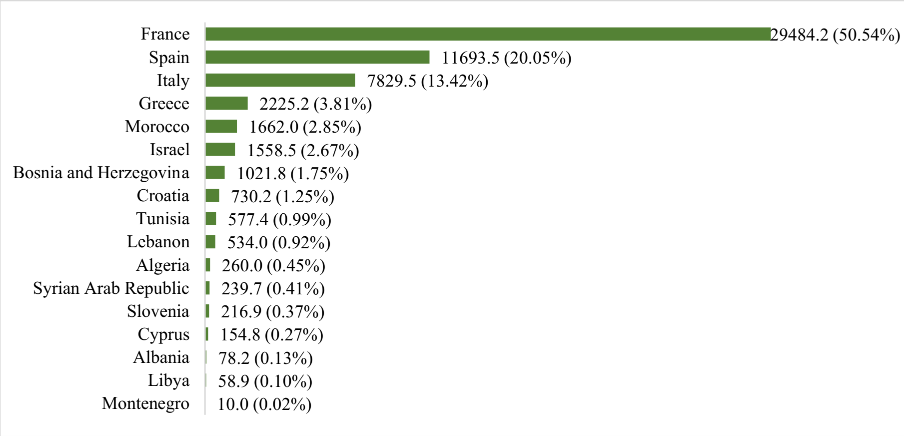

Fig. 2 Quantity of herbicides uses (tons) in agricultural landscapes of the Mediterranean countries (FAOSTAT, 2023). The results represent the data mean of 6 years (from 2015 to 2020)

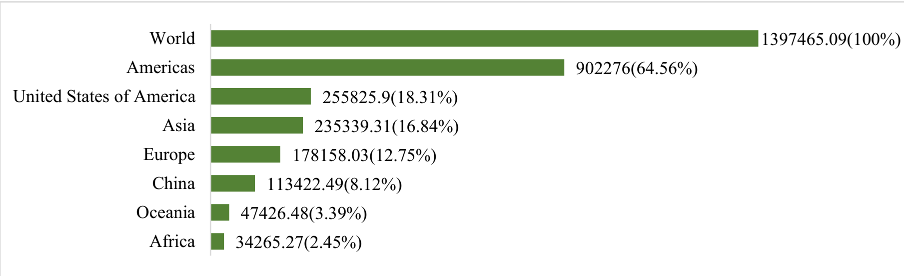

Fig. 3 Herbicide use (tons) in agricultural areas worldwide during 2020 (last data)

Herbicide resistance in Mediterranean carrier countries has been reported for a long time (since 1975). According to an international database on herbicide-resistant weeds, more than 213 unique cases of herbicide resistance have been reported in the Mediterranean region. These cases were distributed across 10 countries, including France (61), Spain (41), Italy (37), Israel (33), Greece (17), Turkey (14), Egypt (3), Syria (3), Cyprus (2), Slovenia (1), and Tunisia (1). Other countries have not yet been reported in the databases. However, a study in Morocco reported that *Lolium rigidum* was resistant to clodinafop propargyl (Topik) in the Gharb region. Atrazine was reported in 50 cases of herbicide resistance in the Mediterranean region; 25, 21, and 19 cases were generated by glyphosate, diclofop-methyl, and tribenuron-methyl, respectively. The difference between countries regarding the remaining weed cases can be explained by the difference in the quantity of herbicides used per country since France was the country that used more herbicides, followed by Spain and Italy (Fig. 2). According to the FAO, the global amount of herbicides used in the Mediterranean countries was approximately 54,815.65 tons against a total of 1,397,465.09 (tons) worldwide in 2020, with the USA and China being the largest countries (Fig. 3).

5 Reasons and mechanisms of weed resistance to herbicides

Several factors can contribute to the development of herbicide-resistant weeds, including repeated use of the same class of herbicides, overuse of herbicides, use of narrow-spectrum herbicides, inadequate weed management, and the transfer of resistance genes through hybridization (Dong et al., 2021; Kaur et al., 2022). This selection pressure favors individuals capable of herbicide resistance and increases the proportion of resistant weeds in the population. Resistance can occur at different levels, and herbicides are not responsible for the genetic mutations that lead to resistance (Hall et al., 2018; Hawkins et al., 2019). However, it can be difficult to distinguish resistant biotypes from weed escape caused by other factors, such as climate and herbicide failure (Peterson et al., 2018).

According to the literature, herbicide-resistant weeds have developed mechanisms to detoxify or avoid the effects of herbicides. One such mechanism is plant metabolism, allowing weeds to degrade herbicides rapidly (Nandula et al., 2019; Perotti et al., 2020). Another mechanism is herbicide cross-resistance; a weed or crop biotype has developed a resistance mechanism to one herbicide that allows it to resist other herbicides (Bobadilla & Tranel, 2023; Hall et al., 2018). Resistance can also occur by pumping herbicide into the cell vacuole, which involves specific transporters for the herbicide (Gaines et al., 2020; Ghanizadeh & Harrington, 2017). The genetic basis of non-target site resistance (NTSR) mechanisms has also been studied (Baucom, 2019; Franco-Ortega et al., 2021). Resistant plants carry a mutation in either ALS1 or ALS2 gene, with all mutations resulting in an amino acid substitution at the Pro1975 residue (Lu et al., 2023; Travlos et al., 2020).

6 Systematic study on agroecological weed management in the Mediterranean countries

According to the Scopus database, only 191 studies were revealed in countries of the Mediterranean region using these keywords. France took first place with 61 documents, followed by Spain and Italy (42 documents). When using specific keywords related to agroecological practices for weed management in Scopus, France was the most active in this context, accounting for approximately 25% of the studies, followed closely by Spain (17%), and Italy (17%). In contrast, all other countries collectively contributed less than 40% of the studies conducted in the Mediterranean context (Fig. 4). According to the Scopus database, other Mediterranean countries that are not listed in Fig. 4 have only one or no studies. These studies include various fields and research disciplines, notably agriculture and biological sciences (43%) and environmental sciences (21%), which reflect the multifaceted nature of agroecology (Fig. 5).

These studies on agroecological practices began in 1996, but the frequency of publication in Mediterranean countries remains very low, with a maximum of 19 documents in 2020 (Fig. 6). Studies focusing on agroecological weed management practices are limited. MacLaren et al. (2020) mention that most publications focus on weed control, and very few studies have focused on the ecological management of weed species globally. Although studies on weed control in the Mediterranean region have been published since 1966 in the Scopus database, the keyword agroecological weed management appeared only in Scopus after 2016 (Fig. 7).

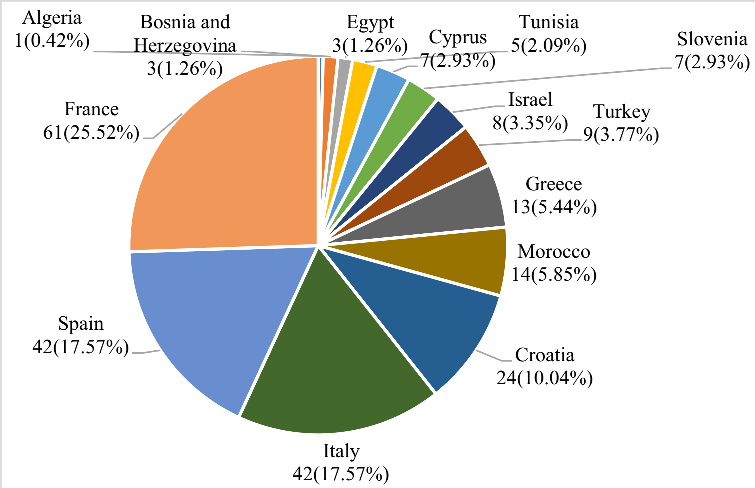

Fig. 4 The number of documents published by country using the mentioned keywords in Scopus

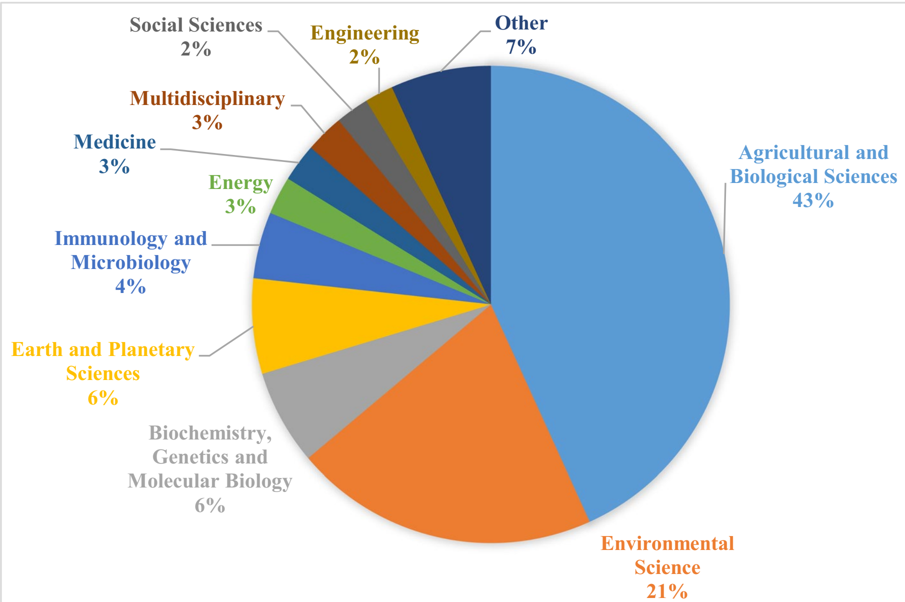

Fig. 5 Percentage of documents per subject area using the mentioned keywords in Scopus

7 Bibliometric analysis

From the selected keywords, the bibliometric analysis of Scopus focused on research on weed management in Mediterranean landscapes, with a particular emphasis on alternative herbicide methods. Network analysis revealed a strong correlation between keywords related to agroecological management practices in the studied documents. One hundred

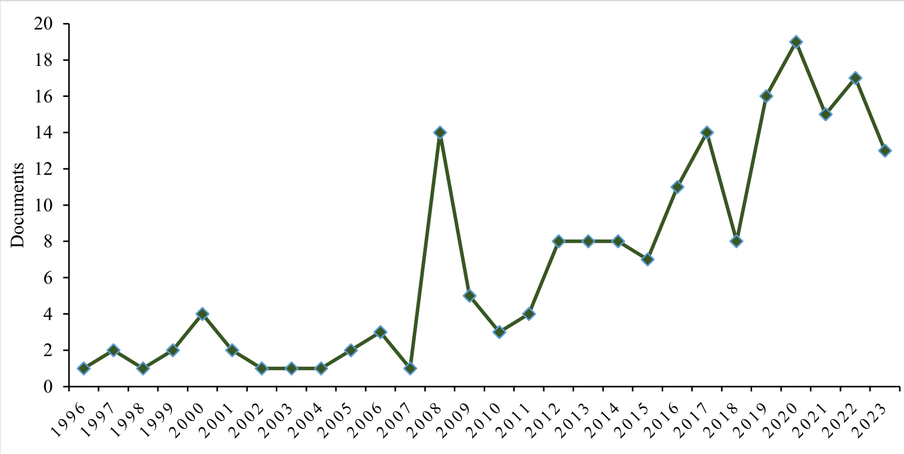

Fig. 6 The number of documents published annually in the Mediterranean using the mentioned keywords in Scopus

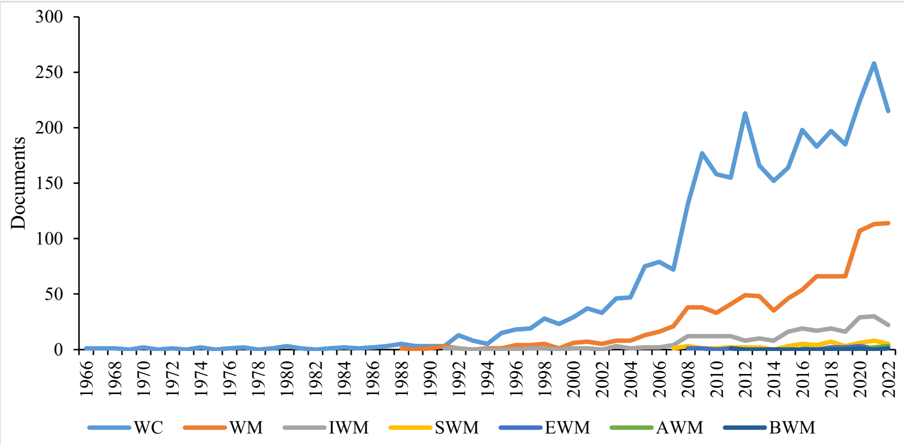

Fig. 7 Number of published articles in each year from 1966 to 2022 in the Scopus database using keywords of "weed management" (WM), "weed control" (WC), "integrated weed management" (IWM), "ecological weed management," "agroecological weed management" (EWM), or "biological weed management" (BWM) in Mediterranean countries

and eight keywords were identified, each appearing at least five times and generating four clusters comprising 39 items. The keywords with the highest link strength among the Scopus databases were "weed," "yield," "agroecology," "ecofriendly," and "biodiversity," with total link strength values of 44, 24, 22, 22, and 16, respectively. Similarly, an increasing interest in the topics of "climate change adaptations," "agricultural modeling," and "sustainability" has been observed in recent years (Fig. 8A). This suggests that herbicide use, especially in the context of herbicide-resistant weeds, is a major concern in Mediterranean agriculture, and researchers are actively exploring alternative weed control methods.

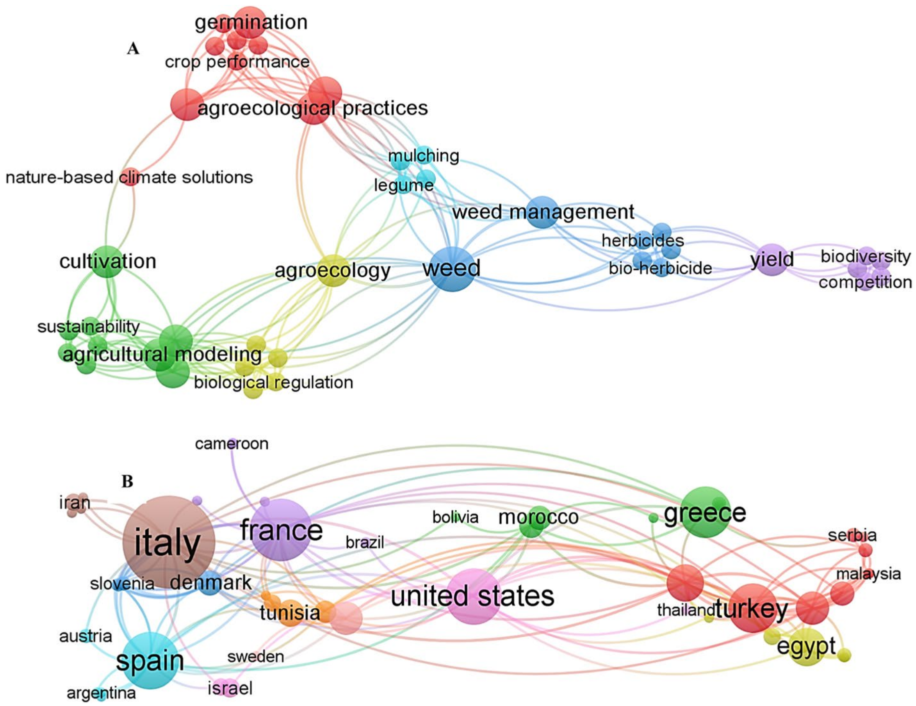

Fig. 8 Bibliometric analysis of research paper published on agroecological weed management in Mediterranean landscapes according to the Scopus database (A) and their worldwide co-authorship distribution (B). The circle diameter is proportional to the intensity of scientific activity

Analysis of co-authorship patterns offers valuable insights into global collaboration networks among various Mediterranean countries in agroecological weed management research. In this context, Italy stands out as a key player, boasting the most robust collaborative network, with a remarkable link strength of 61. Turkey (44), France (42), Spain (38), Greece (13), Egypt (12), and Slovenia (10) were notable contributors to this network of cooperation. By contrast, several other countries exhibit cooperative networks with link strengths below 10. Co-authors from Mediterranean countries and researchers from other countries were divided into 32 items and 7 clusters. The last seven clusters comprised less than eight items due to the need to strengthen collaborative links between Mediterranean countries (Fig. 8B). This suggests that researchers from these countries need to collaborate to conduct studies in the field of weed management and to share their knowledge, which could lead to results that are more comprehensive and better management practices. This collaboration could lead to the development of sustainable and effective weed management strategies.

Overall, bibliometric analysis suggests a growing interest in agroecological weed management in Mediterranean agricultural landscapes devoid of herbicide-resistant weeds. The results of this analysis could inform future research and policy decisions in weed management in the Mediterranean region and contribute to the development of sustainable and effective weed management strategies.

8 Understanding weed nuisance in agroecosystems is a key to their control

Understanding weed nuisance in agroecosystems is crucial for their control. Weeds cause adverse effects on the growth and development of the crop plant, reflected in the loss of quantity and quality of the harvested product (Benramdane, 2017). Weed nuisance is caused by the actual flora (species that emerge during the crop cycle), which has its nuisance (specific nuisance), or the potential flora, whose risk must be reduced in forecasts (Benramdane, 2017). Weed nuisance on crop yield is divided into three main types: direct, indirect, and secondary (Fig. 9) (Chemouri & Belmir, 2014; Cordeau et al., 2016), and includes various phenomena such as competition, allelopathy, and parasitism (Hannachi, 2010).

Weed competition with the crop is a direct type of nuisance, where different species compete for resources such as water, sunlight, and nutrients to survive and reproduce (Cordeau et al., 2016). Crop-weed competition occurs when individual species share the same limited resources in the same niche (temporal and spatial). However, the degree of competition depends on climatic factors, crop identity, physiological and phenological properties, crop density, weed biomass, and density, and the spatial and temporal distribution of other accompanying species. Competition determines which plants thrive and which perish (Liu et al., 2009). Weeds have developed various strategies to outcompete

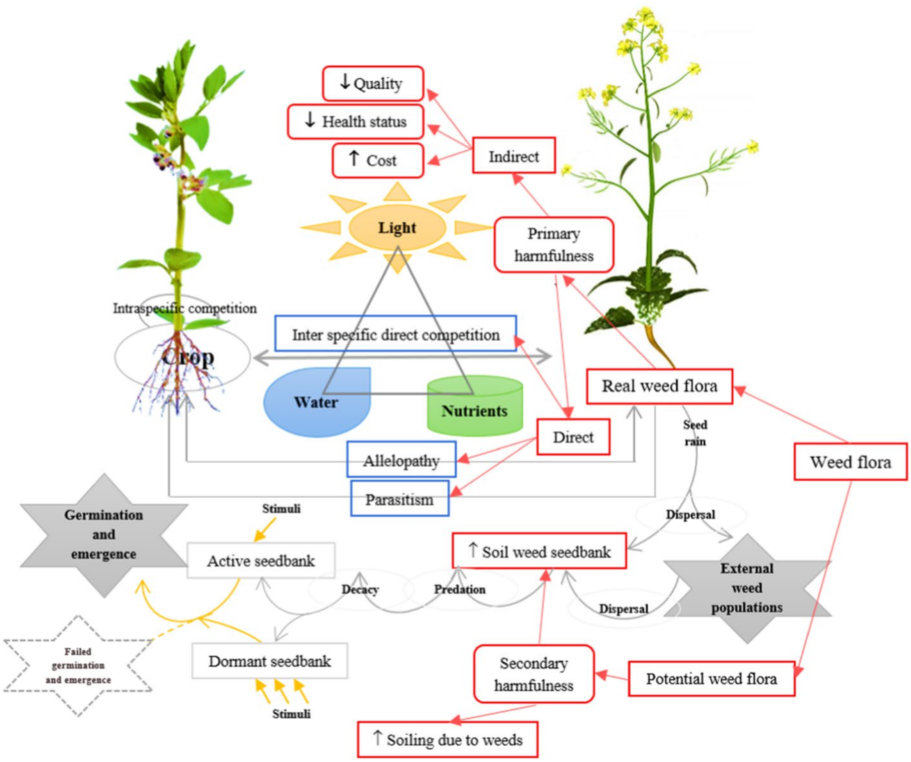

Fig. 9 Crop-weed nuisance process

other plants, such as faster growth rates, deeper root systems, or adaptations to drought (Petit et al., 2018; Singh et al., 2022). Understanding weed competition in agroecosystems is essential for effective weed control strategies. Weed identification, growth habits, and reproductive behavior should be considered when selecting agroecological weed management methods that disrupt their growth cycle at critical stages of development (Radicetti & Mancinelli, 2021). The critical period when weed control yields the best economic results is when crop-weed competition is maximal for available resources (Hussen, 2021).

The allelopathic effect results from releasing secondary metabolites (allelochemical compounds) that affect the growth and development of other weed and crop species (Li et al., 2019). Like some crops, various weeds can produce substances with high allelopathic potential, given that they are normally grown under stress conditions (Farooq et al., 2020). These allelopathic properties can likely make weed species more aggressive, such as *Avena fatua* L., *Chenopodium album* L., *Malva parviflora* L., *Chenopodium murale*, etc. (Dmitrović et al., 2015). Indeed, allelopathy of weed species can cause considerable losses in agroecosystems (Zohaib et al., 2016).

Parasitic weed species can grow partially or totally at the expense of crop species to design their life cycle by utilizing the resources necessary for their growth (Fernández-Aparicio et al., 2020). Parasites, mainly annual root parasites from the Orobanchaceae family, can kill the host and cause considerable economic damage (Masteling et al., 2019). In the Mediterranean area, namely broomrape (*Orobanche crenata* Forks) is a major limiting factor in faba bean production, with yield losses ranging from 80% (Hu et al., 2020) to the total crop loss (Masteling et al., 2019). However, successfully implementing agroecological weed control methods requires a detailed understanding of parasitic plant biology and ecology and the socioeconomic context in which farming communities operate.

9 Advantages and disadvantages of weeds in the Mediterranean agroecosystem

Commonly, weed species are plants characterized by a negative aspect greater than their benefits in the agroecosystem (Cordeau et al., 2016) (Table 2). However, it is important to know that weed species can benefit agroecosystems. There may also be synergistic (positive) relationships between weed diversity, biomass, and crop species (Adeux et al., 2019; Berquer et al., 2023). Weed community diversity can mitigate the negative effects of dominant and competitive weeds on crop yield by potentially promoting ecosystem services (Adeux et al., 2019). This is because they provide food and shelter for beneficial insects such as bees, which help pollinate crops and reduce soil erosion by stabilizing soils with their roots. In addition, weeds are a natural source of fertility when left to decompose in place, and traditional herbicides cannot do so, as they leach nutrients from the soil instead of returning them. Weeds can also host many beneficial and predatory organisms against pests and diseases affecting crops or nearby plants (Table 2).

Table 2 Some advantages and disadvantages of weed species

Advantages of weeds	Disadvantages of weeds
Biodiversity, ecosystem, and ecological functions (Smith et al., 2020)	Competition with resource crops (water, nutrients, light, etc.) (Renton & Chauhan, 2017)
Crop yield losses can be mitigated by the presence of a diverse weed community (Adeux et al., 2019)	Crop yield losses (Soltani et al., 2018) Increased farm labor costs (Sharma et al., 2021)
It regulates the abundance of dominant weeds and pest populations (Petit et al., 2018)	Effect on crop health status (Peerzada et al., 2019)
Weed diversity can help improve the health, diversity, and contribution of bees to crop yields (MacLaren et al., 2020)	Decreased quality of agricultural products (Monteiro & Santos, 2022)
Weed diversity can help design sustainable management that promotes the provision of multiple services while maintaining food production (Gaba et al., 2020)	Hosted pests and pathogens (Kumar et al., 2021b)
It can help protect soils from erosion (Seitz et al., 2019)	Risk of having more resistant crop-weed hybrids than both (Campbell et al., 2009)
Can be exploited as feed for livestock (Ekwealor et al., 2019)	They are also highly flammable, which contributes to the risk of bushfires in areas where drought is common (Pausas & Keeley, 2021)
Some weed species have aromatic and medicinal properties and are exploited in agribusiness (Saini & Saini, 2020; Tlemcani et al., 2023)	Weeds can accumulate N and cause nitrogen (N) depletion in the soil (Pradhan et al., 2022)
	Some weeds result in the deterioration of animal health and production through poisoning and injury, etc. (Ekwealor et al., 2019)

10 Agroecological weed management (AWM) in the Mediterranean landscape

Separating the prevention, control, eradication, and management strategies is important in agroecological weed management (AWM). Prevention involves preventing weeds (a potential problem) from contaminating a given agricultural area. Control consists of minimizing the competition of weeds (an existing problem) and limiting their infestations to meet economic needs and objective yields. Eradication aims to eliminate all living weed flora (100% removal of vegetative reproductive organs and seeds) (Robert, 2018a). However, weed management can be viewed as combining all these techniques to manage weeds, considering the cropping system, environment, field history, expected production goals, technology, and available and appropriate financial resources (Robert, 2018a).

Figure 10 shows the main inputs and outputs of intensive and agroecological weed management. Intensive weed management can ensure immediate weed efficiency and improve crop yields and is aimed at weed eradication based on new herbicide generations, weed seed destroyers, and gene manipulation to develop pesticide-resistant crop varieties, etc. This approach can lead to the emergence of herbicide-resistant ecotypes and fail to provide truly sustainable outcomes (MacLaren et al., 2020). Contrary, agroecological practices aim to keep the weed population below economic thresholds but also at an environmentally sound level while ensuring higher incomes and yields (short to long term) for farmers and conserving biodiversity rather than eradicating all weed flora (Berquer et al., 2023; Catarino et al., 2019; Lechenet et al., 2017; MacLaren et al., 2020). Therefore, to implement efficient management programs, it is essential to understand the biology and ecology of weed flora in a given agroecosystem (Chauhan, 2020). AWM aims to improve crop productivity and ecosystem health while reducing weed pressure by relying on ecological processes, biodiversity, and the characteristics of the whole agroecosystem components (Tataridas et al., 2022) (Fig. 11).

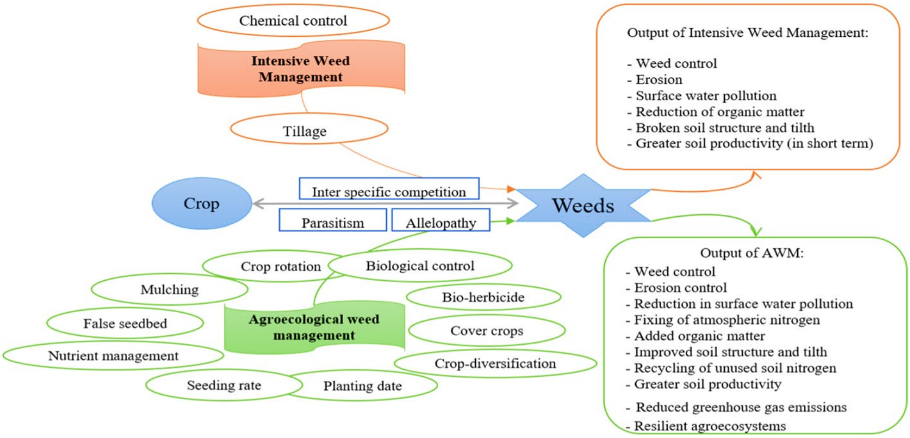

Fig. 10 Main inputs and outputs of intensive and agroecological weed management (AWM)

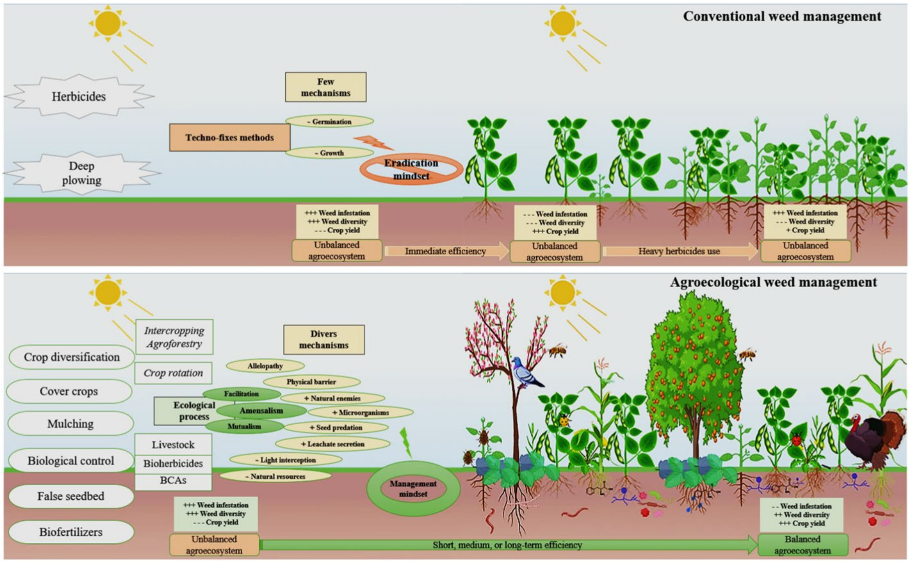

Fig. 11 Illustration of conventional and agroecological weed management in agroecosystems

For each agroecological practice, definitions, different forms, benefits, and mechanisms of weed management have been illustrated below. In addition, Table 3 shows examples of recent studies concerning AWM in the Mediterranean region. Typically, these studies lack an explicit mention of the specific weed species they target. Nonetheless, these investigations have shed light on the efficacy of cover crop mixtures in achieving comprehensive weed suppression. Scavo et al. (2018) highlighted that *Amaranthus retroflexus* L., *Diplotaxis erucoides* (L.) DC., *Portulaca oleracea* L., *Lavatera arborea* L., *Brassica campestris* L., and *Solanum nigrum* L. are among the six most prevalent weeds in Mediterranean agroecosystems. The primary weed species in agroecological weed management

Table 3 Examples of recent studies on the effects of agroecological practices on the management of weed species in Mediterranean farming landscapes

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Crop diversity					
Tunisia	Faba bean	*Orobanche foetida* L	Intercropping with fenugreek	Reduced between 31.1 and 54.5% (emergence)	Abbes et al. (2019)
French	Oilseed rape	*Vulpia myuros* L., *Veronica persica* L. and *Stellaria media* L	Intercropping with legumes	Reduced up to 35% (weed biomass)	Dayoub et al. (2022)
Italy	Wheat	-	Intercropping with legumes	Reduced up to 90% (weed biomass)	Leoni et al. (2022)
Italy	Barley and field pea	-	Intercropping barley with field pea	Reduced up to 93%(weed biomass)	Ranaldo et al. (2020)
Italy and Morocco, etc.	Wheat	-	Intercropping with clover	Reduced between 22 and 75% (weed biomass)	Radicetti et al. (2018)
Italy, Algeria, and Morocco	Cereals (oats, triticale) and legumes (field pea, chickling vetch, common vetch)	–	Intercropping of legumes with cereals	–	Annicchiarico et al. (2017)
Morocco	Faba bean and Cereals (oat, wheat)	*Polygonum aviculare* L. and *Glebionis coronaria* L	Faba bean-Cereals (oat, wheat) intercropping	Reduced between 54.90 and 57.96% (weed biomass)	Boutagayout et al. (2023b)
Allelopathy and plant extracts					
Tunisia	–	*Trifolium incarnatum*, *Silybum marianum* and *Phalaris minor*	Extracts of *C. cardunculus*	Reduced between 20 to 100% (root and hypocotyl lengths)	Kaab et al. (2020)
Italy	–	*Amaranthus retroflexus* L., *Portulaca oleracea* L., *Stellaria media* (L.) Vill., and *Anagallis arvensis* L	Extracts of *C. cardunculus*	Reduced up to 100 (weed biomass)	Scavo et al. (2020b)
Egypt	Sugar beet	–	Aqueous extract of *P. amboinicus*	Reduced up to 65% (weed biomass)	El-Metwally et al. (2022)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Algeria	–	*Sinapis arvensis* L., *Avena fatua* L., *Sonchus oleraceus* L., *Xanthium strumarium* L. and *Cyperus rotundus* L	Essential oil of *T. fontanesii* and *S. calamintha*	Reduced up to 80% (weed germination)	Benchaa et al. (2019)
Turkish	–	*Thlaspi arvense*, *Amaranthus retroflexus*, *Rumex cripus*, and *Lactuca serriola*	Essential oil of Origanum species	Reduced between 48.76 to 94% (weed germination)	Kordali et al. (2022)
Italy	–	*Amaranthus retr flexus* L., *Portulaca oleracea* L., and *Solanum nigrum* L	Aqueous extract of *Cynara cardunculus* L. leaves	Reduced between 42.5 and 58.1% (weed germination)	Scavo et al. (2018)
Morocco	Faba bean	*Polygonum aviculare* L. and *Glebionis coronaria* L	Sorghum, oat, and rapeseed in combination with a lower herbicide dose (up to 50%)	Reduced up to 68.23% (weed biomass)	Boutagayout et al. (2023c)
Spain and Italy	Vineyards	*Avena fatua* L. and *Chenopodium album* L	Pelargonic acid (natural herbicides)	Reduced between 69 and 88% (weed biomass)	Muñoz et al. (2022)
Mulching					
Morocco	Beans	*Polygonum aviculare* L. and *Glebionis coronaria* L	Plane tree leaves and oat straw	Reduced between 84 and 80% (weed biomass)	Boutagayout et al. (2020)
Spain	Vine	–	Almond and pine mulch	Reduced between 90 and 100% (Weed cover)	Cabrera-Pérez et al. (2023)
Italy	*Hedera helix* L., *Rosmarinus officinalis* L., *Vinca minor* L. and *Hypericum calycinum* L	–	Wood chips and Eco-Cover® (thick biodegradable mulch)	Reduced up to 95% (weed biomass)	Ruggeri et al. (2016)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Spain	Fresh pepper	*Cyperus rotundus* L	Biodegradable plastics and paper mulch	Reduced up to 80% (Weed cover percentage)	Marí et al. (2020)
Turkish	Cucumber	*A. retroflexus*, *C. arvensis* and *C. album*	Five mulch materials (flax, peat, chopped paper, straw and fresh grass clippings)	Reduced up to 100% (by flax mulch)	Alptekin et al. (2022)
Egypt	Sugar beet	–	Rice straw, wheat hay, peanut straw, mango leaves, flax meal, and soybean meal	Reduced up to 54% compared to hoeing (weed biomass)	El-Metwally et al. (2022)
Cover crop (CC)					
Spain	Corn or sunflower	*Lamium amplexicaule* L., *Sonchus oleraceus* L. and *Senecio vulgaris* L	CC of barley and vetch	Reduced between 51 and 63% (weed density)	Alonso-Ayuso et al. (2018)
Italy	Olive tree	*Amaranthus retroflexus* L., *Polygonum aviculare* L., and *Portulaca oleracea* L	CC of aromatic and medicinal plant	-	Las Casas et al. (2022)
Italy	Underground clover and spontaneous flora		CC of subterranean clover (*Trifolium subterraneum* L.)	Reduced between 21 and 67% (weed biomass)	Restuccia et al., (2020)
Italy	Legumes	–	CC of squarrosum clover	Reduced up to 62% (weed biomass)	Ranaldo et al. (2020)
Turkish	Apricot	*Amaranthus retroflexus* L., *Convolvulus arvensis* L., and *Sorghum halepense* (L.) Per	CC of *Vicia villosa*, *Vicia pannonica*, *Triticale* + *V. pannonica*, *Phacelia tanacetifolia*, and *Fagopyrum esculentum*	Reduced between 53.7 and 83.64% (weed biomass)	Tursun et al. (2018)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Greece	Sulla	*Avena sterilis* L	CC of *Triticum turgidum*, *Vicia sativa*, or *Sinapis alba*	Reduced up to 75% (weed biomass)	Gazoulis et al. (2022)
Crop rotation					
Italy	Cardoon, wheat and faba bean	*Sinapis arvensis* L., *Anagallis arvensis* L. and *Beta vulgaris* L	The possibility of introducing *Cynara cardunculus* L. in a rotation	Reduced between 34 and 50% of weed seed bank compared to a classical Mediterranean wheat/fertilizer rotation	Scavo et al. (2019)
Spain	Barley and camelina	*Papaver rhoeas* L	The possibility to introduce camelina in the rotation	Reduced between 34 and 70% in potential seed production of *P. rhoeas*	Codina-Pascual et al. (2022)
False seedbed					
Greece	Bersim clover and annual ryegrass	Avena sterilis L. and Sinapis arvensis L	False seedbed	Reduced weed biomass and density by up to 34 and 81%, respectively	Gazoulis et al. (2023)
Greece	Barley	*Avena sterilis* L., *Phalaris minor* and *Lolium rigidum*	False seedbed	Reduced up to 91% (weed biomass)	Kanatas et al. (2020a)
Competitive cultivars					
Italy	Wheat	–	Ancient or modern cultivars	Heritage cultivars reduced weed biomass by 56% compared to modern cultivars	Lazzaro et al. (2017)
Italy	Durum wheat	Fumaria sp., Veronica sp., and Lamium sp.	Variety "PR22D89" or "Cappelli"	The variety Cappelli reduced more than 50% compared to PR22D89 (weed biomass)	De Vita et al. (2017)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Turkish	Bread Wheat	–	Cultivars “Dogu 88” and “Kirik”	The cultivar “Dogu 88” reduced more than 35% compared to “Kirik” (weed biomass)	Bulut et al. (2022)
Arrangement and planting density					
Greece	Sulla	*Avena sterilis* L	19 and 38 cm row spacing	Reduced between 46 and 52% (weed biomass)	Gazoulis et al. (2022)
Italy	Wheat	–	Increase the density of sowing (from 250 to 400 seeds m^{-2})	Reduced up to 46% (weed biomass)	Lazzaro et al. (2017)
Italy	Durum wheat	Fumaria sp., Veronica sp., and Lamium sp.	Spatial arrangements of 5, 15, and 25 cm row spacing	Reduced up to 80% (weed biomass)	De Vita et al. (2017)
Greece	Chickpea	*Avena sterilis* L	Increased seeding rate (from 180 to 270 kg ha-1 “1.5 × recommended”)	Reduced density and total dry weed biomass by 30 and 32%, respectively	Kanatas and Gazoulis (2022)
Spain	Barley	*Lolium rigidum* L	Increased seeding rate of barley (×2)	Reduced up to 23% (weed density)	D’Amico et al. (2021)
Sowing date					
Spain	Camelina	*Diplotaxis erucoides* L., *Hordeum murinum* L., and *Senecio vulgaris* L	Late seeding (i.e., December instead of the end of October)	Reduced between 6 and 99.6% (weed cover)	Royo-Esnal et al. (2018)
Italy	Wheat	*Picris echioides*, *Ridolfia segetum*, and *Sinapis arvensis*	Early seeding (i.e., mid-November instead of mid-December)	Reduced 45% (weed biomass)	Ingraffia et al. (2022)
Tunisia	Rapeseed		Late seeding (i.e., November 27 instead of November 02)	Reduced between 14 and 84.9% (weed species)	Gargouri-Kammoun et al. (2019)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Greece	Durum wheat		Late sowing (i.e., after mid-November instead of early November)	Early sowing reduced 75% (weed density)	Karkanis et al. (2022)
Spain	Barley and winter wheat	*Bromus diandrus* Roth	Tariff seeding (mid-November or early December instead of mid-October)	Reduced between 80 and 98% (weed density)	García et al. (2014)
Nutrient management					
Spain	Corn	*Digitaria sanguinalis* (L.) Scop. and *Chenopodium album* L	Incorporation of small crushed pieces of eucalyptus (*E. globulus*) leaves (organic fertilizer)	Reduced between 38 and 80% (weed biomass)	Puig et al. (2019)
Turkish	Soft wheat	–	Organic manure	Reduced about 47% (weed biomass)	Bulut et al. (2022)
Italy	Lettuce	–	Vetch incorporated as green manure	Reduced almost 85% (weed biomass)	Testani et al. (2020)
Integrated agroecological management					
Four zones including the Mediterranean area	Wheat	–	Intercropping and living mulch (under clover as living mulch)	Reduced more than 53% compared to the sole wheat (weed biomass)	Radicetti et al. (2018)
Egypt	Onion	–	Acetic acid (natural products) and rice straw	Reduced between 88 and 91% (weed biomass)	El-Metwally et al. (2019)
Egypt	Corn or sorghum	–	Sowing date and intercropping with cowpea	Reduced about 90 and 93% compared to maize and sorghum intercropped with cowpea, respectively (weed biomass)	Abou-Keriasha et al. (2011a)

Table 3 (continued)

Country	Cash crop	Main weed species	Agroecological traitement	Weed control efficiency (%)	References
Egypt	Corn with cowpea	–	Intercropping maize with cowpea and a preceding crop of bersim	Reduced about 72% (weed biomass)	Abou-Keriasha et al. (2011b)
Greece	Soybeans	*Avena sterilis* L., *Phalaris minor* and *Lolium rigidum*	Combination of false seed-bed and pelargonic acid (natural product)	Reduced 41, 38, and 36% compared to false seed-beds, normal seedbeds, and a combination of normal seedbeds and pendimethalin (pre-emergence herbicide), respectively (Weed density)	Kanatas et al. (2020a)
Morocco	Faba bean	*Polygonum aviculare* L. and *Glebionis coronaria* L	Integration of mulching plant extracts and inter-cropping practices	Reduced between 83 and 93% (weed biomass)	Boutagayout et al. (2023d)

studies are shown in Table 3. Table 4 presents an additional illustration of weed flora associated with arable crops across various Mediterranean countries. In Europe, particularly in France, approximately 1200 field crop weeds have been identified, with 300 species considered common occurrences (Gaba et al., 2016; Jauzein, 1995). Similar to other winter pulse crops and cereals, faba beans in Europe and North Africa compete with diverse weed species. These include *Polygonum aviculare* L., *Chenopodium album* L., *Anthemis arvensis* L., *Sinapis arvensis* L., *Fumaria officinalis* L., *Glebionis coronaria* L., *Papaver rhoeas* L., *Cirsium arvense* (L.) Scop., as well as grass species *Avena sterilis* L., *Phalaris* spp., *Lolium rigidum* Gaud., and *Alopecurus myosuroides* Huds (Karkanis et al., 2016a and b; Karkanis et al., 2018; Boutagayout et al., 2023a, 2023b, 2023c, and d). Furthermore, in various Mediterranean countries, such as Spain, Greece, and Morocco, numerous broomrape species (*Orobanche* spp. and *Phelipanche* spp.) are capable of parasitizing faba beans (Rubiales et al., 2016, 2022). Notably, *Orobanche crenata* Frosk, commonly known as bean broomrape, is the predominant species infesting faba beans in this region (Ennami et al., 2017; Negewo et al., 2022; Ntatsi et al., 2018). According to Gualbert Gbèhounou (2010), some of the most challenging weeds to control in North Africa include *Ammannia coccinea*, *Avena sterilis*, *Bromus rigidus*, *Cardaria draba*, *Centaurea diluta*, *Echinochloa phyllopogon*, *Gladiolus segetum*, *Papaver rhoeas*, *Solanum elaeagnifolium*, *Viscum cruciatum*, and *Ziziphus lotus*.

10.1 Allelopathy

Allelopathy, which involves the release of chemical compounds by plants and microorganisms, can have stimulatory and inhibitory effects on other nearby plants (Farooq et al., 2020; Muhammad et al., 2019). Allelopathic substances can be used as valuable tools for agriculture, such as crop rotation with allelopathic crops, incorporation of allelopathic plant residues into the soil, use of allelopathic cover crops and mulches, and association of an allelopathic plant to control weeds without competing with the cash crop (Jabran et al., 2015). Allelopathy can provide natural weed control and reduce soil fungal and bacterial species, leading to a healthier environment for crop development, reducing nematode populations, and increasing root size and crop yields. It can also help reduce the environmental damage caused by pesticides, which can disrupt the ecological functions of agroecosystems (Benmeddour & Fenni, 2018).

However, not all allelochemicals effectively control weed growth, and their effects can vary depending on plant species. Some allelochemicals can inhibit crop germination, growth, and reproduction but mainly affect weed populations by altering the apical meristem's morphological, biochemical, physiological, and growth, which prevents shoot and root development. Allelochemicals can also affect cell walls, reduce the growth and number of new cells formed on root and shoot meristems, alter various cellular activities (membranes, photosynthesis, nutrient uptake, growth hormones, etc.), and cause biochemical imbalances (increased reactive oxygen species (ROS), antioxidants, toxins, stress hormones, etc.) (Radhakrishnan et al., 2018).

In the Mediterranean landscape, allelopathy is a common interaction between species (Chaves Lobón et al., 2003) and can be utilized for sustainable weed management (Li et al., 2019). Sorghum, sunflower, rye, wheat, rice, and barley have high allelopathic potential and can be used for weed management. In particular, sorghum is considered an important candidate for crop rotation to suppress weed flora because it releases various allelopathic compounds from its grains, stems, and root hairs, which can provide significant control over weeds compared to a rotation without an allelopathic crop (Naeem et al., 2022). Additionally, a study identified 17 wild plant species from the Mediterranean area with a potential for weed management (Araniti et al., 2012). Therefore, incorporating allelopathic crops such as sorghum, sunflower, rye, wheat, rice, and barley can provide natural pest control, preserve agroecosystem ecology, and produce high-quality plants with less overhead.

10.2 Crop diversity

Crop diversification is a sustainable agricultural practice that involves growing multiple crop species in the same field for significant periods of growth. This practice promotes interactions between crops, leading to increased yields and improved soil health (Pelzer et al., 2014). Agroforestry systems, which include trees or shrubs on at least 10% of farmland, are also a form of crop diversity (Burgess et al., 2022). The selection of the right species, variety, date, and seeding rate is crucial and should be based on the soil-climatic characteristics and cropping system. This strategic choice ensures optimal growth and yields while maintaining soil and environmental health (Gardarin et al., 2022).

Crop diversification has several advantages, including reduced pesticide use. By changing environmental conditions, associated crops are less susceptible to diseases and pests than pure crops (Gardarin et al., 2022; Vlahova, 2022). In addition, it promotes biodiversity and offers benefits on sloping or marginal lands, such as soil stability, erosion control (water and wind), and improved water flow, while increasing the overall biodiversity of the species (Sollen-Norrlin et al., 2020). These benefits make intercropping more productive per unit area than pure crops (Gardarin et al., 2022).

Crop diversification is an effective method to control weeds in the Mediterranean region. By reducing crop-weed competition and the success rate of weed seed germination, different species and/or plant varieties make the farming environment less favorable for weed growth. Intercropping is an integral part of successful weed control, and understanding the different mechanisms involved can help farmers ensure a higher success rate.

Intercropping involves several mechanisms that can effectively control weeds. Intercrops physically prevent the germination and growth of weeds by blocking the light, which is essential for weed growth. Intercropped tall and wide species can effectively shade weeds on the ground while creating a spatial barrier that prevents weed establishment (Maitra et al., 2020). Closely planted intercrops inhibit weed growth horizontally and vertically, making it more difficult for weeds to establish and compete with the desired crops (Xiang et al., 2022). Fast-growing intercrops with dense roots and aerial systems can effectively control weeds (Ali et al., 2020). Intercrops can also include those that secrete allelochemicals that inhibit weed seed germination and block the growth of young seedlings (Carton et al., 2020). In addition, woody mulch that accumulates through agroforestry practices can suppress weed growth (Kato-Noguchi, 2021). Intercropping can encourage populations of beneficial insects that prey on noxious weeds and enhance the process of complementarity and facilitation between crops (Blessing et al., 2022).

Understanding the different mechanisms behind intercropping is critical for a successful diversification strategy that can facilitate weed management and better harvest over time, which helps improve farmers' livelihoods. Crop diversification can help reduce weeds in the Mediterranean landscapes. Studies have shown it significantly reduces parasitic weed density (Scott et al., 2022). Crop diversification negatively affects weed seed germination and growth, which helps to reduce weed density (Sharma et al., 2021). However, the effects of crop diversification on weed dynamics can be positive but variable (Beillouin et al., 2021). Agricultural intensification has caused a decrease in weed richness and changes in species composition; therefore, diversification can help prevent this (José-María et al., 2010). Overall, crop diversification could be an effective strategy for weed management in Mediterranean landscapes.

10.3 Cover crops

Any plant or combination of plants that are planted after (catch crop or no crop) or during the main crop (intercrop) and will not be harvested or destroyed is considered a cover crop (Haider et al., 2019). Cover crops offer a range of benefits for agroecosystems beyond soil cover and weed management. They can help control erosion, reduce surface water pollution, fix atmospheric nitrogen, increase soil organic matter, improve soil structure, retain moisture, recycle nutrients, enhance pest control, increase microbial activity, improve grain quality, and boost soil productivity. In Mediterranean farming landscapes, where herbicide-resistant weeds are becoming more prevalent, cover crops can be a particularly valuable tool for weed management.

Cover crops can be categorized based on three primary criteria: the extent of the occupied area, the number of sown species, and employed crop management techniques (Scavo et al., 2020a). As a "living mulch," cover crops are grown in association with cash crops and can act as a protective barrier for the soil. Cover crop residues are "dead mulch" created by cutting and depositing plant material onto the soil surface. This mulch remains intact until it becomes too tall or accumulates too much biomass (Scavo et al., 2022).

The number of species planted in cover crops can vary, depending on the farmer's purpose. Cover crop monocultures (single crop species) have advantages such as reduced input costs but may not offer many benefits beyond weed control. Polyculture cover crops (mixtures of crop species) can offer various benefits, such as further reducing weed populations with different plant species, producing diverse root structures, nutrient uptake at different depths, and decomposition of organic matter to increase soil microbial populations (Baraibar et al., 2018).

Cover crops suppress weeds through a variety of mechanisms, including limiting resource availability (competition for water, light, and space), trapping nutrients, blocking sunlight, altering the soil microclimate through mulching, releasing allelochemicals through decomposed residues, and reducing weed seed stocks (Kumar et al., 2020). However, the cover crops must be properly managed to achieve optimal results. These include proper fertility management, well-timed termination, and appropriate planting times for the desired cover crop species. Some properly managed species that can provide uniform and dense ground cover include winter vetch (*Vicia villosa* Roth) and rye (*Secale cereale* L.). Other species that could be used as cover crops in Mediterranean farming landscapes include crimson clover (*Trifolium incarnatum* L.), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), peas (Pisum spp.), birdsfoot trefoil (*Lotus corniculatus* L.), common oats (*Avena sativa* L.), ryegrass (Lolium spp.), fescue (Festuca spp.), bluegrass (Poa spp.), smooth brome (*Bromus inermis* Leyss.), timothy (*Phleum pratense* L.), and orchardgrass (*Dactylis glomerata* L.) (Korres, 2018).

Cover crops are an effective tool for weed management in Mediterranean agroecosystems. For example, a 5-year study found that subterranean clover cover cropping is a good option for weed management in Mediterranean agroecosystems (Restuccia et al., 2020).

Table 4 Weed species documented in diverse arable crop-growing nations within the Mediterranean region

Weed species	Crops	Countries	References
Calendula arvensis L	Orchards	Spain	Mas et al. (2007)
Convolvulus arvensis L			
Papaver rhoeas L	Wheat		Izquierdo et al. (2009)
Parietaria judaica L	Orchards	Greece	Thanou et al. (2021)
Abutilon theophrasti Medik	Corn	Spain	San Martín et al. (2015)
Aeschynomene afraspera L	Rice	Algeria	FAO (2023)
Agropyron squarrosum (Link) Roth	Wheat	Lebanon	
Alopecurus aequalis Sobol	Vegetables		
Amaranthus blitoides S. Watson	Sugar beet	Morocco	
Amaranthus retroflexus L	Corn	France	Fried et al. (2019)
	Orchards	Spain	Mas et al. (2007)
	Corn	Syria	FAO (2023)
Amaranthus sp.	Orchards	Greece	Thanou et al. (2021)
	Cotton	Syria	FAO (2023)
	Soybean		
	Sugar beet	Lebanon	
	Wheat		
Ammannia coccinea Rottb	Rice	Morocco	FAO (2023)
Ammannia spp.		Egypt	
Anagallis arvensis L	Orchards	Spain	Mas et al. (2007)
	Wheat	France	Barilli et al. (2017)
Anagallis foemina Miller	Sugar beet	Morocco	FAO (2023)
Anthemis cotula L	Vegetables	Lebanon	
	Wheat		
Apium nodiflorum (L.) Lag			
Astragalus echinops Boiss	Vegetables		
Avena fatua L	Cereals	Cyprus	
	Flax	Egypt	
	Vegetables	Algeria	
	Wheat	Egypt	
		Algeria	
Avena sterilis ssp. Sterilis L		Greece	Travlos (2012)
		Spain	Ponce and Santin (2001)
Beta vulgaris L	Vegetables	Egypt	FAO (2023)
Brassica deserti Danin & Hedge	Wheat	Libya	
Bromus danthoniae Trin		Lebanon	
Bromus rigidus Roth	Sugar beet	Morocco	
Bromus sterilis L	Wheat	France	Barilli et al. (2017)
Bromus spp.		Libya	FAO (2023)
	Wheat and barley	Morocco	
	Wheat	Algeria	
Bupleurum subovatum Link ex Spreng		Lebanon	
Calendula arvensis L	Citrus	Morocco	
	Faba bean		
	Sugar beet		
	Wheat and barley		
Capsella bursa-pastoris (L.) Medic	Orchards	Greece	Thanou et al. (2021)
	Sugar beet	Morocco	FAO (2023)

Table 4 (continued)

Weed species	Crops	Countries	References
	Wheat	Lebanon	
		Syria	
Cardaria draba (L.) Desv	Corn	Morocco	
	Faba bean		
	Vegetables	Lebanon	
Centaurea iberica Trev. ex Spreng			
	Wheat		
Cephalaria syriaca (L.) Roem. & Schult	Wheat		
Chenopodium album L	Corn	France	Fried et al. (2019)
	Orchards	Greece	Thanou et al. (2021)
	Wheat	Spain	Izquierdo et al. (2009)
	Corn	Syria	FAO (2023)
	Faba bean	France	Karkanis et al. (2018)
	Flax	Egypt	FAO (2023)
	Sugar beet	Lebanon	
	Vegetables		
	Wheat	Egypt	
Chenopodium murale L	Sugar beet	Morocco	
Chenopodium spp.	Vegetables	Egypt	
	Wheat	Libya	
Chrysanthemum coronarium L	Sugar beet	Morocco	
Cirsium arvense L	Wheat	Spain	Romero et al. (2008)
Cirsium arvense (L.) Scop		France	Barilli et al. (2017)
		Syria	FAO (2023)
		Lebanon	
Convolvulus arvensis L	Bananas	Cyprus	
	Citrus		
	Orchards	Algeria	
	Vegetables	Lebanon	
	Wheat		
		Libya	
Conyza canadensis L	Orchards	Spain	Mas et al. (2007)
Coronopus squamatus (Forsskäl)	Vegetables	Egypt	FAO (2023)
Cuscuta campestris Yunck	Pastures	Lebanon	
Cuscuta spp.	Alfalfa	Morocco	
	Citrus		
	Clover & Alfalfa	Egypt	
	Pastures	Algeria	
	Sugar beet	Lebanon	
	Vegetables		
	Vines	Cyprus	
	Wheat	Lebanon	
Cynodon dactylon (L.) Pers	Bananas	Cyprus	
	Citrus	Cyprus	
	Sugar beet	Lebanon	
	Wheat	Lebanon	
Cyperus difformis L	Rice	Egypt	
Cyperus iria L			

Table 4 (continued)

Weed species	Crops	Countries	References
Cyperus longus L	Cotton		
Cyperus rotundus L	Corn	Spain	San Martín et al. (2015)
	Rice	Egypt	FAO (2023)
	Sugar beet	Morocco	
Cyperus spp.	Vegetables	Lebanon	
Datura ferox L	Corn	Spain	San Martín et al. (2015)
Datura stramonium L		Syria	FAO (2023)
	Vegetables	Lebanon	
Daucus carota L	Wheat	France	Barilli et al. (2017)
Digitaria sanguinalis (L.) Scop	Vegetables	Lebanon	FAO (2023)
Dinebra retroflexa (Vahl) Panz	Rice	Egypt	
Diplotaxis erucoides L	Orchards	Spain	Mas et al. (2007)
Ecballium elaterium (L.) A. Richard	Vegetables	Lebanon	FAO (2023)
Echinochloa crus-galli (L.) Beauv	Corn	France	Fried et al. (2019)
		Syria	FAO (2023)
	Cotton		
	Rice	Egypt	
		Morocco	
Echinochloa phyllopogon Koss		Morocco	
Echinochloa stagnina (Retz.) P		Egypt	
Eclipta prostrata L		Egypt	
Emex spinosus (L.) Campd	Wheat	Libya	
Eryngium spp.		Lebanon	
Erysimum officinale L			
Euphorbia spp.	Fruit Trees		
	Vines		
Fallopia convolvulus L	Wheat	France	Gaba et al. (2010)
	Cereals	Cyprus	FAO (2023)
	Faba bean	France	Karkanis et al. (2018)
	Wheat and barley	Morocco	FAO (2023)
Fumaria parviflora Lam	Sugar beet		
Galium aparine L	Wheat	France	Barilli et al. (2017)
	Wheat	Spain	Izquierdo et al. (2009)
	Fruit Trees	Lebanon	FAO (2023)
	Vines		
	Wheat		
		Syria	
Galium tricorne Stokes		Algeria	
Geranium spp.	Vegetables	Lebanon	
Hordeum murinum L	Wheat	Syria	
Hordeum spontaneum K. Koch		Lebanon	
Imperata cylindrica (L.) C.E. Hubb	Dates	Algeria	FAO (2023)
Ipomoe sp.	Orchards	France	Le Bellec et al. (2012)
Kickxia spuria (L.) Mill	Wheat	Spain	Izquierdo et al. (2009)
Lactuca scariola L	Vegetables	Egypt	FAO (2023)
	Faba bean	Spain	Giambalvo et al. (2012)
Lamium amplexicaule L	Faba bean	France	Karkanis et al. (2018)
Leontice leontopetalum L	Wheat	Libya	FAO (2023)

Table 4 (continued)

Weed species	Crops	Countries	References
Lisea syriaca L	Vegetables	Syria	
Lolium rigidum L	Wheat	Spain	Izquierdo et al. (2009)
Lolium rigidum Gaud	Cereals	Cyprus	FAO (2023)
	Sugar beet	Morocco	
	Wheat and barley		
Lolium spp.	Vegetables	Algeria	
	Wheat	Libya	
	Wheat	Algeria	
Malva sp.	Orchards	Greece	Thanou et al. (2021)
Malva sylvestris L	Vegetables	Cyprus	FAO (2023)
Medicago hispida Gaertner	Vegetables	Egypt	
Melilotus indica (L.) All	Vegetables		
Mikania micrantha	Orchards	France	Le Bellec et al. (2012)
Myagrum perfoliatum L	Wheat	Lebanon	FAO (2023)
Orobanche aegyptiaca Pers	Vegetables	Algeria	
		Cyprus	
		Egypt	
		Lebanon	
		Syria	
Orobanche crenata Forssk	Faba bean	Egypt	
	Faba bean	Morocco	
	Faba beans	Algeria	
	Legumes	Tunisia	
	Leguminous	Syria	
Orobanche foetida Poir	Legumes	Tunisia	
Orobanche ramosa L	Leguminous	Turkey	
	Sugar beet	Lebanon	
	Vegetables	Algeria	
		Cyprus	
		Egypt	
		Lebanon	
		Syria	
		Turkey	
Persicaria lapathifolia	Corn	France	Fried et al. (2019)
Papaver hybridum L	Sugar beet	Morocco	FAO (2023)
Papaver rhoeas L	Faba bean	Spain	Giambalvo et al. (2012)
	Wheat	France	Barilli et al. (2017)
	Faba bean		Karkanis et al. (2018)
	Wheat and barley	Morocco	FAO (2023)
Papaver spp.	Vegetables	Lebanon	
	Wheat		
Persicaria maculosa L	Corn	France	Fried et al. (2019)
Phalaris brachystachis L	Citrus	Syria	FAO (2023)
Phalaris minor Retz	Wheat	Greece	Travlos (2012)
	Wheat and barley	Morocco	FAO (2023)
Phalaris spp.	Faba bean	Spain	Giambalvo et al. (2012)
	Wheat	Syria	FAO (2023)
Phalaris spp.	Vegetables		

Table 4 (continued)

Weed species	Crops	Countries	References
	Wheat		
		Algeria	
	Vegetables		
Phytolacca spp.		Egypt	
Poa annua L	Legumes		
Poaceae sp.	Orchards	Greece	Thanou et al. (2021)
Polygonum aviculare L	Wheat	France	Barilli et al. (2017)
		Spain	Izquierdo et al. (2009)
	Sugar beet	Morocco	FAO (2023)
Polygonum spp.		Lebanon	
	Vegetables		
	Wheat	Libya	
Portulaca oleracea L	Corn	Syria	
	Vegetables		
Ranunculus arvensis L	Fruit Trees	Lebanon	
	Vines		
Raphanus raphanistrum L	Fruit Trees		
	Vegetables		
	Wheat	Syria	
Rapistrum rugosum (L.) All	Citrus	Libya	
	Wheat		
Ridolfia segetum	Faba bean	Spain	Giambalvo et al. (2012)
Setaria glauca (L.) Beauv	Wheat	Egypt	FAO (2023)
	Citrus	Syria	
Setaria verticillata (L.) Beauv	Bananas	Cyprus	
	Cereals		
	Citrus		
Setaria viridis P. Beauv	Corn	Syria	
	Cotton		
Setaria spp.	Soybean	Lebanon	
	Sugar beet		
Silene adenoclada Gandoger	Fruit Trees		
	Vegetables		
Silene neglecta Ten	Wheat	Libya	
Sinapis arvensis L	Faba bean	Spain	Giambalvo et al. (2012)
	Wheat	Greece	Dhima and Eleftherohorinos (2005)
	Faba bean	France	Karkanis et al. (2018)
	Sugar beet	Morocco	FAO (2023)
	Vegetables	Syria	
	Wheat		
Sisymbrium irio L	Vegetables	Egypt	
Sisymbrium sp.	Orchards	Greece	Thanou et al. (2021)
Solanum elaegnifolium Cab	Fruit trees	Tunisia	FAO (2023)
	Citrus	Morocco	
	Corn		
	Faba bean		
	Vegetables	Tunisia	
	Wheat		

Table 4 (continued)

Weed species	Crops	Countries	References
	Wheat and barley	Morocco	
	Cotton	Syria	
Solanum nigrum L	Corn	Spain	San Martín et al. (2015)
	Orchards	Greece	Thanou et al. (2021)
	Cotton	Syria	FAO (2023)
Sonchus oleraceus L	Sugar beet	Morocco	
Sonchus spp.	Citrus	Libya	
	Cotton		
Sorghum halepense (L.) Pers	Corn	Spain	San Martín et al. (2015)
		Syria	FAO (2023)
	Cotton		
	Sugar beet	Lebanon	
	Vegetables		
Urtica urens L	Sugar beet	Morocco	
Vaccaria pyramidata Medik	Wheat	Syria	
Veronica hederaefolia L			
Veronica spp.	Faba bean	France	Karkanis et al. (2018)
Vicia sativa L	Sugar beet	Morocco	FAO (2023)
Vicia spp.	Vegetables	Egypt	
Xanthium brasilicum Vell		Lebanon	
Xanthium strumarium L	Corn	Spain	San Martín et al. (2015)
		Syria	FAO (2023)
	Cotton	Turkey	
	Leguminous		

Therefore, agroecological weed management strategies utilizing cover crops can be a sustainable and effective way to manage weeds in Mediterranean farming landscapes without herbicide-resistant weeds.

10.4 Crop rotation

Crop rotation is a form of temporal crop diversification and a key element in agroecosystem management. It involves the cultivation of different crops in the same field for different years to prevent the buildup of weeds and pests specific to certain crops (Tataridas et al., 2022). Crop rotation can take many forms, such as two-year, three-year, four-year, and long-term rotations. For example, a three-year rotation could involve growing cereals such as wheat for a year, followed by legume-like peas as a green manure crop, and then growing cereals again as a cover crop before finally harvesting cereals or fodder crops, such as barley, in the third season. Four-year rotations could involve adding a short-term, intensively managed vegetable plot or an additional grain or summer fallow period into the rotation cycle (Kanatas, 2020; Shah et al., 2021; Zhao et al., 2020).

Crop rotation effectively minimizes fertilizer and herbicide use, reduces weed pressure, improves soil health, and increases yields, gross margins, and economic benefits, particularly when legumes are included (Adesina et al., 2020; Selim, 2019; Yigezu et al., 2019).

Moreover, crop rotation has a particularly effective impact on weed control because it breaks the annual cycle of weeds and crops, changing the crops' environment and reducing the growth of weeds. Crop rotation relies on crop protection through natural mechanisms, such as allopathy, shading, nutrient acquisition, physical smothering of weed seedlings, and deterrence of fungal pathogens that target certain weed types (Marques et al., 2020; Kanatas, 2020b).

Crop rotation has been shown to significantly decrease weed flora in diverse agroecosystems with different production systems, making it an effective method for weed management in the Mediterranean landscape (Calha et al., 2019; Mohler & Johnson, 2009; Royo-Esnal & Valencia-Gredilla, 2018). Furthermore, diversified grain-based cropping systems provide long-term weed control while limiting herbicide use and yield loss (Cordeau, 2022). In addition to crop rotation, other agroecological weed management practices such as no-till farming, the use of living mulch, mulching, cover crops, water management, sanitation, and fertility can be used in combination to promote sustainable and effective weed management in the Mediterranean landscape (Calha et al., 2019; Cordeau, 2022).

Finally, specific crops such as *B. carinata* and *Camelina sativa* can improve rotation-level integrated weed management strategies for summer crops by reducing the seed banks of summer weed species, making them feasible options for weed control in organic farming systems (Royo-Esnal & Valencia-Gredilla, 2018; Tiwari et al., 2021). Cropping strategies that prevent weed seed production include successive planting of short-season crops, alternating short-cycle cover crops with cash crops, and intercropping (Mohler & Johnson, 2009).

10.5 Mulching

Mulching, the practice of applying a material to the soil surface as a cover, has been used for centuries in various agricultural settings (Ranjan et al., 2017). There are three main types of mulch: organic, inorganic, and mixed. Organic mulches such as cereal straws, leaves, bark, and grass residues decompose naturally and add organic matter and nutrients to the soil. Inorganic mulches, such as rocks or black and white plastic, are primarily used in horticulture, nurseries, viticulture, and field crops (Ranjan et al., 2017; Telkar et al., 2017; Zhang et al., 2021). The appropriate mulch material used is determined by crop type, management practices, and climate conditions (Kader et al., 2019).

Mulch can be a physical barrier that blocks light transfer, reduces water loss, prevents heat uptake, releases toxic allelochemicals, and limits the moisture available to weed seeds within the mulch layer. Mulching is an effective weed management strategy in organic agriculture. However, it is important to note that some mulches have allelopathic effects on the crop species. Therefore, a strategic choice of mulch type is necessary.

In addition to weed control, the application of organic mulch has several benefits, including improved soil structure and quality, increased soil infiltration and water-holding capacity, serving as a refuge for insects and earthworms, reduced evaporation, preserving moisture, controlling soil structure and temperature, and providing a neat and consistent border around landscaped areas (Saha et al., 2018). Organic mulch facilitates root penetration and development, nutrient uptake from deeper soil layers, and reduces erosion (Telkar et al., 2017). Decomposition also increases soil microbial activity, encouraging beneficial organisms to thrive and compete with weeds for moisture and other resources (Ranjan et al., 2017).

Although biodegradable plastic mulches are not ecologically acceptable, they protect the soil from weather, limit potential mineral leaching, and are more effective at blocking weed growth than natural mulches. However, they do not provide nutrients or improve soil quality because they do not decompose quickly (Bandopadhyay et al., 2018; Boutagayout et al., 2020; Ngosong et al., 2019).

Mulching is an effective weed management method in the Mediterranean landscape (Farooq et al., 2020; Hussain et al., 2022; Verdú & Mas, 2007). It has effectively controlled weeds in orchards, maize, and sunflower crops (Verdú & Mas, 2007). In tomato crops, degradable plastic mulch has been found to control weeds, such as *C. album*, *D. sanguinalis*, and *P. oleracea* (Jabran, 2019). Different mulch materials, including organic and inorganic, have been evaluated to suppress weed flora in maize and sunflower crops (Hussain et al., 2022). In Morocco, organic mulches have also been found to ensure high weed control and reduce weed biomass by more than 80% in faba beans (Boutagayout et al., 2020).

10.6 Biological control

Biological weed control employs living organisms, known as biological control agents (BCAs), to reduce the population of target weeds to a desirable level. BCAs can range from microscopic rhizobacteria to large mammals and may include insects, herbivorous fish, other animals, pathogens, bio-herbicides, or allelopathic plants (Schaffner et al., 2020; Uludag et al., 2018).

Livestock, such as sheep, goats, and pigs, have long been used as a biological weed control method and can be effective under certain circumstances. Grazing animals can consume vegetation, reduce ground cover, limit seed production by eating plant flowers and buds, and break down weed root systems. This method aims to maintain a low weed population in pastures without using herbicides, promoting a healthier environment for the land and its inhabitants (Banda & Tanganyika, 2021). Additionally, livestock can increase ecosystem biodiversity by adding nutrient-rich organic matter to the soil through excrement (MacLaren et al., 2019).

Another approach for biological weed control is the exploitation of natural enemies. Depending on the presence of natural enemies in the agroecosystem, a distinction is made between augmented biological control (if natural enemies are already present) and classical biological control (if exotic natural enemies must be introduced) (Singh et al., 2020). Augmentation biological control aims to maintain the natural population in the best condition if it exists in a sufficient quantity. In contrast, classical biological control targets and attacks specific weeds, reducing their numbers and allowing preferred plants to thrive in the ecosystem. This approach involves the introduction of appropriate bio-agents, such as herbivorous insects (e.g., weevils, beetles, or caterpillars), that feed on the seeds or plants (above or below ground) of a target weed species (Osadebe et al., 2021).

Initially, the population of the target weeds may be large. The introduction of a biological control agent reduces weed populations. As the population of natural enemies rebalances with a lack of food, the control agent re-establishes itself. The system continues cyclically until the weed and biocontrol agent populations stabilize at a low level, reducing the competitiveness of the weed with the crop. This process can be very effective in managing weed growth and spread but requires time for populations of these organisms to begin to have an effect. Biological control agents must be selected based on their ecology and adaptation to agroecosystem conditions. They must be host-specific, starvation-resistant, have feeding habits adapted to the target weed, and be easy to multiply for maximum effectiveness. Monitoring target and non-target weeds is necessary to avoid ecosystem disruption (Ani et al., 2018; Telkar et al., 2015; Uludag et al., 2018).

Biological control agents can be vital in promoting sustainable agriculture and maintaining an ecological balance in Mediterranean landscapes. For example, bats are important arthropod predators, and in recent decades, an increasing number of studies have focused on the role of bats as natural enemies of agricultural pests, providing multiple ecosystem services to agroecosystems (Tuneu-Corral et al., 2023).

Some resources discuss biological control agents for weeds in Mediterranean countries. For example, one study examined the use of biological control of weeds globally, including in Mediterranean countries (Shaw et al., 2018). Another study investigated the effects of weed management (ground cover, pre-emergence herbicides, etc.) on the parasitoid community (*Lymaenon litoralis*, Ceranisus sp., Telenomus sp., etc.), which can be an essential biological control agent (Möller et al., 2020). An assessment of the leading 20 environmental exotic weeds in Europe, which includes several species discovered in Mediterranean countries, has been conducted to identify their potential as classical biological targets for various biocontrol agents. Some of the biocontrol agents considered include *Cleopus japonicas*, *Mecyslobus erro*, *Pseudocercospora buddleiae*, *Septoria merrillii*, Lixus sp., Aphalara sp., *Puccinia polygoni* amphibii, Mycosphaerella sp., and others. (Sheppard et al., 2006).

10.7 False seedbed

The false seedbed technique is a method of soil preparation that can be used directly after harvest or plowing (Manisankar et al., 2022). This technique involves plowing the top layer of the soil to create an optimal environment for weed seeds to germinate before crop sowing. Thus, weed elimination becomes easier and more effective through manual weeding, flaming, or tilling, among other methods. This method is considered a preventative measure for weed control because it reduces the soil seed bank before crop sowing.

To ensure that most weeds have emerged completely, the delay period between soil preparation and crop sowing must be sufficiently long, spanning several days, weeks, or months (Merfield, 2019; Pavlović et al., 2022). Once most weeds have emerged, they can be beaten with very shallow tillage, ideally less than 2 cm deep but up to a maximum of 5 cm. After weed control, the crop can be planted under appropriate conditions such as depth and density.

The false seedbed technique helps disrupt germination and temporarily delays weed growth due to shock caused by the crop. However, it also creates a more uniform stand of crops once planted, providing more competition for resources, such as light and nutrients (Kanatas et al., 2020b). Reducing competition with other plants provides more opportunities for good crop establishment and healthy harvest.

One of the main advantages of the false seedbed technique is that it presents an alternative to herbicides, preventing environmental pollution while ensuring high yields of safe and healthy food, consistent with ecological weed management. In this way, crop germination is facilitated without disturbing the distribution of seeds in the seed bank while reducing the potential for in-season weed control (Pavlović et al., 2022).

Studies have shown that the false seedbed technique reduces weed seed banks and competition for annual weeds in Mediterranean countries (Benvenuti et al., 2021; Gazoulis et al., 2023). Recent studies conducted by Gazoulis et al. (2022) demonstrated that false seedbeds reduced weed biomass by 27–34% compared to normal seedbed preparation. Consequently, the competitiveness of barley in a system that includes the false seedbed technique is greater than in no-till systems (Kanatas et al., 2020b).

10.8 Competitive cultivars

Cultivars that exhibit strong competitive traits, such as rapid growth in the early stages, large leaf area, and high root competition, offer an excellent option for reducing herbicide use in weed management (Beckie et al., 2019). These cultivars are selectively bred to grow taller or denser than their surrounding weeds, creating a physical barrier that reduces nutrient uptake and sunlight exposure and ultimately inhibits weed growth. In addition, allelopathic cultivars have been proposed to offer benefits in weed control and yield improvement (Jha et al., 2017). Crops exhibiting superior competitive ability against weeds may also enjoy higher yields, larger grains, and stronger stems (Dhillon et al., 2021).

Integrating traditional “local varieties” adapted to extreme climatic conditions, weeds, pests, and diseases can also enhance weed management (Sharma & Gupta, 2020). In Mediterranean landscapes, crop cultivars with enhanced weed competitiveness, such as wheat, which has a fast early canopy growth rate, offer an excellent example of utilizing competitive cultivars for weed management (Aharon et al., 2021). Adopting competitive cultivars can provide a more sustainable and environment-friendly approach to weed control in Mediterranean landscapes, particularly because conventional weed management practices can lead to biodiversity loss (Guerra et al., 2022).

10.9 Planting arrangement and density

Planting crops densely allows them to compete for soil nutrients, water, and light, which weeds need to survive and grow (Daramola et al., 2021). At higher crop densities, canopy closure is accelerated, reducing the light transmitted to the soil surface and consequently reducing weed growth. This decreases weed density, biomass, and seed production (Alba et al., 2020; Scavo & Mauromicale, 2020; Sharma et al., 2021). Additionally, the direction and rotation of the beds or furrows can help control weeds by providing more light and air on one side of the seedbed while shading the other, making it difficult for weeds to succeed (Brar & Gill, 2021).

However, when planning a planting arrangement and layout for weed management, growers must consider several important factors, including managing intraspecific competition between crops by ensuring an even spatial distribution and seeding rate of sunlight, water, and nutrients (Merfield, 2019).

Previous studies have shown that row spacing can affect weed growth and biomass. For example, Marín and Weiner (2014) found a 75% decrease in *Brachia brizantha* “invasive weed” biomass when comparing row spacing with a uniform spatial grid. The biomass of *P. minor* was reduced by 17% when wheat was planted with narrow row spacing (15 cm) compared with wide spacing (22.5 cm) (Mahajan & Brar, 2002). Similarly, another recent study concluded that narrow row spacing (50 cm) (at the same planting density) was beneficial for suppressing weed growth (55% less) and obtaining a higher cotton fiber yield (26% more) than wide spacing (100 cm) (Iqbal et al., 2022). Therefore, carefully considering the planting site and selecting appropriate plants can help weed control in Mediterranean landscapes.

10.10 Sowing date

The planting date can significantly impact weed management, and early planting can give adapted cultivars a competitive advantage over weeds. Early planting offers a competitive advantage for adapted cultivars because they emerge before weeds and do not receive sufficient sunlight for weed emergence and growth (Osipitan et al., 2019). However, the sowing date must be carefully chosen based on crop maturity, local weather conditions, and weed species present to manage weed infestation and composition during the growing season effectively. “One of the keys to effective weed management is to ensure that the sowing date is chosen carefully” (Kurtenbach et al., 2019).

Timing is crucial for planting to control weed growth, and finding the correct balance between early planting and exposure to pests, diseases, and extreme weather conditions is crucial. Seeding dates can be used to establish crops much earlier than the optimal date for weed emergence. This places crops in a competitive position against weeds later in development (Osipitan et al., 2019). In addition, drilling dates can influence weed emergence and the window for weed control.

Several studies have demonstrated the significance of sowing dates in weed control, with different sowing dates having varying effects on weed suppression and crop yields. The critical period for weed control in corn in the Mediterranean region was determined to be from 131 to 927 growing degree days (Uremis et al., 2009). The effect of sowing date on yield and weed control was also studied in lentils, with earlier sowing resulting in higher grain yield (Wang et al., 2013). Therefore, carefully considering the sowing and drilling dates can significantly contribute to weed control in Mediterranean landscapes.

10.11 Nutrient management

Organic or synthetic amendments can directly influence the level of nutrients in the soil and affect the dynamics and competition of weeds with crops (Kaur et al., 2018; Little et al., 2021). Conversely, biofertilizers can stimulate crop growth and control bio-aggressors such as weeds, diseases, and pests (Sansinenea, 2021).

Effective nutrient management for weed control can be achieved by following two general principles: preventing weeds from thriving in the cropping environment and using the soil nutrient balance to promote positive weed growth. The use of concentrated organic matter, such as brassica manure, seed cake, and neem cake, can reduce weed populations. Composting these materials leads to high temperatures that decrease weed seed viability, whereas lower nutrient uptake by weeds under these conditions results in higher crop yields. Long-term application of organic manure enhances its efficacy in reducing weed growth and nutrient removal by weeds (Ghosh et al., 2020, 2022). However, soil nitrogen, particularly nitrate, can stimulate the germination of many weed seeds. Applying fertilizers containing large amounts of nitrogen, such as manure (especially liquid manure), immediately before or during crop establishment can lead to significant weed flushes. It is crucial to delay the application of these materials until the crop is established to prevent weed germination through crop competition and shade (Merfield, 2019). In addition, the use of biochar can indirectly affect weed management by improving soil fertility and crop growth, which can reduce weed pressure (Brozović et al., 2021).

It is important to apply nutrients accurately and at the right time to ensure their availability to crops rather than weeds (Chauhan, 2020). Thus, plant residues and nutrient management could be effective methods for weed control in Mediterranean countries. However, the effectiveness of soil amendments for weed control may vary depending on the specific conditions in the Mediterranean region and the type of amendment used. Further research is needed to assess the efficacy of different soil amendments for weed control in this region.

10.12 Automating agroecology

Agroecology is a valuable approach to sustainable agriculture, and its automation offers great potential for weed management. Robotics and modeling are becoming increasingly important for weed management. Tools such as precision farming robots (ecological weeders), GPS-guided weeders, and technology database systems can enable smart agroecological practices to identify problematic weeds with greater accuracy and target them more effectively to reduce their infestation in the agroecosystem (Ditzler & Driessen, 2022). Instead of toxic chemicals, these robots use sensors, cameras, and special algorithms to identify weeds and pull them out of the ground. This automation also reduces the labor and time spent on weed control, so that farmers can focus their resources on other aspects of production while achieving efficient and more resilient outcomes (Fennimore & Cutulle, 2019). This data-driven approach reduces the time required to search for noxious weeds in a given area while reducing the impact on human and environmental health (Chauhan, 2020; Gerhards et al., 2022; Singh et al., 2019). Additionally, the use of digital technologies in agroecology promotes better communication between farmers and researchers, which can lead to innovations in this field.

10.13 Integrated agroecological weed management in the Mediterranean landscape

Integrated agroecological weed management practices encompass a holistic approach to weed control, which prioritizes biodiversity and ecosystem health. This strategy involves a combination of various agroecological practices cited in the literature and preventative measures, such as using high-purity seeds suitable for specific agroecosystem conditions, cleaning seeding tools, filtering irrigation water, composting manure, and proactively managing hard-to-control exotic species before dispersal. Traditional chemical control and deep tillage methods are used to minimize the environmental impacts. By monitoring field conditions and understanding the factors that influence weed growth, producers can select the most appropriate techniques for their situation while minimizing potential crop impacts (Robert, 2018b).

Transitioning to agroecology and diversified cropping systems, such as selecting the most suitable crop and cover crop cultivars, and implementing practices such as no-till farming, living mulch, crop rotation, mulching, cover crops, water management, sanitation, and fertility, can be effective in reducing herbicide use and promoting soil fertility, pest management, climate change mitigation, and biodiversity (Cordeau, 2022). Weed suppression can also be achieved through intercropping and cover cropping, with higher planting densities leading to better weed control (Calha et al., 2019; Fernando & Shrestha, 2023). However, the adoption of these practices in the Mediterranean region requires careful consideration, and more research is needed to develop effective integrated agroecological weed management strategies tailored to the Mediterranean climate (MacLaren et al., 2020).

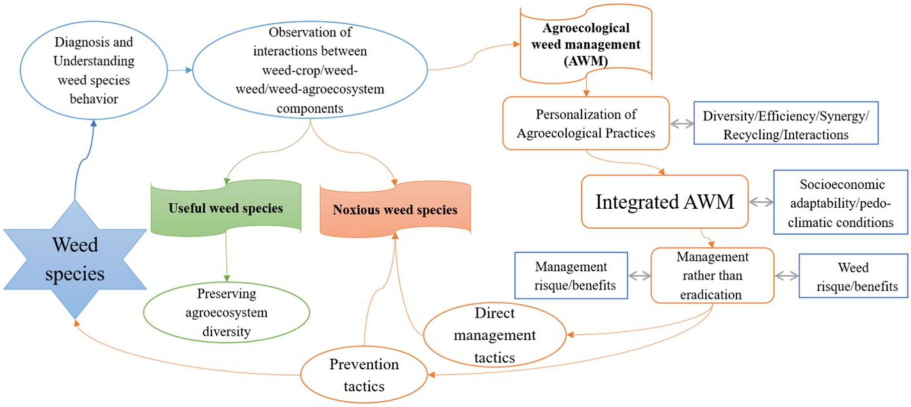

Fig. 12 Schematic representation of the tactics of an agroecological weed management (AWM) strategy. Diagnosis and prevention form the basis and must be combined with direct agroecological control following an appropriate decision-making process linked to the specific weed flora/diversity/effectiveness/synergy/recycling/interaction/socioeconomic suitability/soil-climatic conditions/risks and benefits of management/risks and benefits of weeds

Agroecological weed management practices exhibit a variety of interactions that can be synergistic, antagonistic, or indifferent, depending on their combination. For example, crop diversity, crop rotation, and cover crops act synergistically to create a complex farming environment, discourage weed growth, and promote biodiversity (Nicolétis et al., 2019). Similarly, biological controls, false seedbeds, and competitive cultivars can amplify each other by reducing weed competition. However, certain associations can be antagonistic, such as the use of mulch with competitive cultivars, which can hinder growth of the latter. Sometimes, practices, such as sowing date or nutrient management, can seem indifferent when implemented in isolation. Ultimately, the effectiveness of automating agroecology and integrated agroecological weed management in the Mediterranean landscape depends on its implementation in combination with other practices. Adaptation to local conditions, including the soil type, climate, and crop growth, is fundamental (Altieri & Nicholls, 2017). This customization is essential, with different approaches for sandy and clay soils, as well as for Mediterranean climatic variations. Crop sensitivity to weed competition must also guide the practice. Thus, the agroecological management of adaptive weeds promotes sustainable agriculture in the Mediterranean region. This requires a thorough understanding of weed species and the personalization of practices, an approach that integrates various methods and recognizes the value of useful weeds (Page et al., 2020; Tu et al., 2001). The adoption of local agroecological practices and collaboration between farmers is also essential for preserving biodiversity and promoting sustainable and resilient agriculture in the Mediterranean landscape (Fig. 12).

11 Conclusion and recommendations

The management of herbicide-resistant weeds in Mediterranean agricultural landscapes is a crucial challenge that requires a transition to sustainable management practices. Traditional chemical herbicides have largely contributed to the emergence of such resistance, making agroecology a promising solution for achieving more balanced management, while preserving biodiversity. This study highlights the advantages of agroecological practices in this region. It emphasizes that solving the challenges of agroecological weed management in Mediterranean landscapes is a complex, multifactorial process. This highlights that agroecological practices focus primarily on managing weed flora rather than eradicating it, maintaining an economically viable threshold while preserving the biodiversity of agroecosystems. Furthermore, it reminds us that there is no universal solution for weed management in the Mediterranean, as the success of agroecological strategies is highly dependent on site-specific conditions such as predominant weed species, crop growth, sowing date, and pedo-climatic factors, among others. Finally, this review highlights the importance of systematic studies and bibliometric analyses in guiding the development of effective weed management strategies in Mediterranean agricultural landscapes. This highlights that the integration of agroecological practices enables farmers to implement more sustainable weed management methods, while preserving biodiversity and guaranteeing long-term food security.

However, to promote the optimal integration of agroecological weed management practices, it is imperative to continue developing and adapting them to the specific features of each local agroecosystem. Meta-analyses are essential to assess the effectiveness of current practices and identify areas for improvement. To overcome the limitations of the current methods, it is necessary to initiate a paradigm shift that emphasizes the promotion of diverse weed communities beneficial to agroecosystems. Interdisciplinary collaboration among ecologists, weed scientists, and agronomists is central to developing tailor-made approaches for each agroecosystem. Simultaneously, it is crucial to strengthen agroecological management skills and facilitate access to information and resources for farmers. Research must continue to explore the benefits offered by weeds, integrate traditional knowledge, assess environmental and social impacts, and promote the social acceptability of agroecological transition.

Farms embarking on agroecological transition should consider several important recommendations. First, the adoption of integrated agroecological management practices is crucial, emphasizing a holistic approach that prioritizes biodiversity and ecosystem health. This encompasses a combination of practices and preventive measures, including the use of high-purity seeds, maintaining clean seeding tools, employing filtered irrigation water, composting manure, and managing exotic species. The transition to agroecology and diversified cropping systems is essential, involving the exploration of agroecology, selection of suitable crops and cover crop cultivars, and implementation of practices such as living mulch, crop rotation, mulching, cover crops, water management, sanitation, and nutrient management to reduce herbicide use and foster sustainability. Customizing practices based on local conditions and tailoring agroecological approaches to factors such as soil type, climate, and crop growth are paramount for effective implementation. The application of ecological principles in agroecosystems enhances weed control, emphasizing the investigation of synergies among different agroecological weed management practices. Cultivating an agroecological observer's perspective extends beyond agronomy, development of observational skills to diagnose interactions within the agroecosystem, including the management of weeds rather than their eradication, and recognition of the benefits of beneficial weed flora. Balancing an economically viable threshold while preserving biodiversity is crucial, highlighting the importance of economic viability while conserving biodiversity and recognizing the value of useful weeds. Regularly monitoring field conditions and tailoring techniques to specific situations are critical steps to minimize potential crop impacts and ensure a responsive and adaptive approach. Encouraging collaboration and knowledge sharing is vital, fostering collaboration among farmers to exchange local agroecological practices, emphasizing the significance of preserving biodiversity, and collectively promoting sustainable and resilient agriculture. Strengthening farmers' agroecological management skills and facilitating access to information and resources are paramount for successful integration into the agroecological transition. Lastly, promoting ongoing research is crucial, encompassing the exploration of the benefits offered by weeds, integration of traditional knowledge, assessment of environmental and economic impacts, and enhancement of the social acceptability of agroecological transition.

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Data Availability Statement In accordance with the findings of this study, the authors affirmed that the data can be accessed within the article. Additionally, the corresponding author is willing to provide raw data supporting the findings of the study upon reasonable request.

Declaration

Conflicts of interest The authors declare no conflict of interest.

References

Abbes, Z., Trabelsi, I., Kharrat, M., & Amri, M. (2019). Intercropping with fenugreek (*Trigonella foenum-*graecum) enhanced seed yield and reduced Orobanche foetida infestation in faba bean (*Vicia faba*). *Biological Agriculture & Horticulture, 35*(4), 238–247. https://doi.org/10.1080/01448765.2019.1616614

Abdoli, S., Masoumi, S. Z., & Kazemi, F. (2022). Environmental and occupational factors and higher risk of couple infertility: A systematic review study. *Middle East Fertility Society Journal, 27*(1), 1–27. https://doi.org/10.1186/s43043-022-00124-4

Abou-Keriasha, M. A., Gadallah, R. A., & El-Wakil, N. M. H. (2011a). The influence of preceding crops and intercropping maize with cowpea on productivity and associated weeds. *Egyptian Journal of Agronomy, 33*(1), 1–18. https://doi.org/10.21608/agro.2011.146

Abou-Keriasha, M. A., Ibrahim, S. T., & Mohamadain, E. E. A. (2011b). Effect of cowpea intercropping date in maize and sorghum fields on productivity and infestation weed. *Egyptian Journal of Agronomy, 33*(1), 35–49. https://doi.org/10.21608/agro.2011.14

Adesina, I., Bhowmik, A., Sharma, H., & Shahbazi, A. (2020). A review on the current state of knowledge of growing conditions, agronomic soil health practices and utilities of hemp in the United States. *Agriculture, 10*(4), 129. https://doi.org/10.3390/agriculture10040129

Adeux, G., Munier-Jolain, N., Meunier, D., Farcy, P., Carlesi, S., Barberi, P., & Cordeau, S. (2019). Diversified grain-based cropping systems provide long-term weed control while limiting herbicide use and yield losses. *Agronomy for Sustainable Development, 39*(4), 1–13. https://doi.org/10.1007/s13593-019-0587-x

Aharon, S., Fadida-Myers, A., Nashef, K., Ben-David, R., Lati, R. N., & Peleg, Z. (2021). Genetic improvement of wheat early vigor promote weed-competitiveness under Mediterranean climate. *Plant Science, 303*, 110785. https://doi.org/10.1111/j.1365-3180.2006.00497.x

Alba, O. S., Syrovy, L. D., Duddu, H. S., & Shirtliffe, S. J. (2020). Increased seeding rate and multiple methods of mechanical weed control reduce weed biomass in a poorly competitive organic crop. *Field Crops Research, 245*, 107648. https://doi.org/10.1016/j.fcr.2019.107648

Ali, H., Sarwar, N., Ahmad, S., Farooq, O., Nahar, K., & Hasanuzzaman, M. (2020). Cotton-based intercropping systems. *Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies*, 321–340. https://doi.org/10.1007/978-981-15-1472-2_17

Alonso-Ayuso, M., Gabriel, J. L., García-González, I., Del Monte, J. P., & Quemada, M. (2018). Weed density and diversity in a long-term cover crop experiment background. *Crop Protection, 112*, 103–111. https://doi.org/10.1016/j.cropro.2018.04.012

Alptekin, H., & Gürbüz, R. (2022). The effect of organic mulch materials on weed control in cucumber (*Cucumis sativus* L.) Cultivation. *Journal of Agriculture, 5*(1), 68–79. https://doi.org/10.46876/ja.1126331

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change, 140*, 33–45. https://doi.org/10.1007/s10584-013-0909-y

Alyokhin, A., Nault, B., & Brown, B. (2020). Soil conservation practices for insect pest management in highly disturbed agroecosystems—A review. *Entomologia Experimentalis Et Applicata, 168*(1), 7–27. https://doi.org/10.1111/eea.12863

Ani, O., Onu, O., Okoro, G., & Uguru, M. (2018). Overview of biological methods of weed control. *Biological Approaches for Controlling Weeds*. https://doi.org/10.5772/intechopen.76219

Annicchiarico, P., Alami, I. T., Abbas, K., Pecetti, L., Melis, R. A. M., & Porqueddu, C. (2017). Performance of legume-based annual forage crops in three semi-arid Mediterranean environments. *Crop and Pasture Science, 68*(11), 932–941. https://doi.org/10.1071/CP17068

Araniti, F., Sorgonà, A., Lupini, A., & Abenavoli, M. R. (2012). Screening of Mediterranean wild plant species for allelopathic activity and their use as bio-herbicides. *Allelopathy Journal, 29*(1), 107–124.

Banda, L. J., & Tanganyika, J. (2021). Livestock provide more than food in smallholder production systems of developing countries. *Animal Frontiers, 11*(2), 7–14. https://doi.org/10.1093/af/vfab001

Bandopadhyay, S., Martin-Closas, L., Pelacho, A. M., & DeBruyn, J. M. (2018). Biodegradable plastic mulch films: Impacts on soil microbial communities and ecosystem functions. *Frontiers in Microbiology, 9*, 819. https://doi.org/10.3389/fmicb.2018.00819

Baraibar, B., Hunter, M. C., Schipanski, M. E., Hamilton, A., & Mortensen, D. A. (2018). Weed suppression in cover crop monocultures and mixtures. *Weed Science, 66*, 121–133. https://doi.org/10.1017/wsc.2017.59

Barilli, E., Jeuffroy, M. H., Gall, J., De Tourdonnet, S., & Mediene, S. (2017). Weed response and crop growth in winter wheat–lucerne intercropping: A comparison of conventional and reduced soil-tillage conditions in northern France. *Crop and Pasture Science, 68*(11), 1070–1079. https://doi.org/10.1071/CP16459

Barot, S., Porcher, E., Mckey, D., & Lavigne, C. (2021). Apports de l'écologie à l'agroécologie. La transition agroécologique. Quelles perspectives en France et ailleurs dans le monde ?, I, Presses des Mines, pp. 211–227.

Baucom, R. S. (2019). Evolutionary and ecological insights from herbicide-resistant weeds: What have we learned about plant adaptation, and what is left to uncover? *New Phytologist, 223*(1), 68–82. https://doi.org/10.1111/nph.15723

Bayyinah, L. N., & Pratama, R. A. (2022). Analisis Vegetasi Gulma pada Lahan Budidaya Jagung di Arcawinangun, Purwokerto Timur Banyumas. *AGROSCRIPT: Journal of Applied Agricultural Sciences, 4*(2), 75–82. https://doi.org/10.36423/agroscript.v4i2.1120

Beckie, H. J., Ashworth, M. B., & Flower, K. C. (2019). Herbicide resistance management: Recent developments and trends. *Plants, 8*(6), 161. https://doi.org/10.3390/plants8060161

Beillouin, D., Ben-Ari, T., Malézieux, E., Seufert, V., & Makowski, D. (2021). Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Global Change Biology, 27*(19), 4697–4710. https://doi.org/10.1111/gcb.15747

Benchaa, S., Hazzit, M., Zermane, N., & Abdelkrim, H. (2019). Chemical composition and herbicidal activity of essential oils from two Labiatae species from Algeria. *Journal of Essential Oil Research, 31*(4), 335–346. https://doi.org/10.1080/10412905.2019.1567400

Benmeddour, T., & Fenni, M. (2018). Phytotoxicité des extraits de trois espèces végétales sur le blé dur et sur *kochia scoparia*: Adventice envahissante des périmètres agricoles dans la wilaya de biskra. *Courrier Du Savoir, 25*, 173–178.

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

Berquer, A., Bretagnolle, V., Martin, O., & Gaba, S. (2023). Disentangling the effect of nitrogen input and weed control on crop–weed competition suggests a potential agronomic trap in conventional farming. *Agriculture, Ecosystems & Environment, 345*, 108232. https://doi.org/10.1016/j.agee.2022.108232

Blessing, D. J., Gu, Y., Cao, M., Cui, Y., Wang, X., & Asante-Badu, B. (2022). Overview of the advantages and limitations of maize-soybean intercropping in sustainable agriculture and future prospects: A review. *Chilean Journal of Agricultural Research, 82*(1), 177–188. https://doi.org/10.4067/S0718-58392022000100177

Bobadilla, L. K., & Tranel, P. J. (2023). Predicting the unpredictable: The regulatory nature and promiscuity of herbicide cross resistance. *Pest Management Science*. https://doi.org/10.1002/ps.7728

Boulet, A. K., Alarcão, C., Ferreira, C., Kalantari, Z., Veiga, A., Campos, L., ... & Hessel, R. (2021). Agro-ecological services delivered by legume cover crops grown in succession with grain corn crops in the Mediterranean region. *Open Agriculture, 6*(1), 609–626. https://doi.org/10.1515/opag-2021-0041
Boutagayout, A., Belmalha, S., Nassiri, L., El Alami, N., Jiang, Y., Lahlali, R., & Bouiamrine, E. H. (2023b). Weed competition, land equivalent ratio and yield potential of faba bean (*Vicia faba* L.)-cereals (*Triticum aestivum* L. and/or *Avena sativa* L.) intercropping under low-input conditions in Meknes region, Morocco. *Vegetos*, 1–14. https://doi.org/10.1007/s42535-023-00592-7
Boutagayout, A., Belmalha, S., Rehali, M., Nassiri, L., & Bouiamrine, E. H. (2023b). Agroecology as agricultural practices for sustainable management in North African Countries. *International Journal of Plant Production*. https://doi.org/10.1007/s42106-023-00251-6
Boutagayout, A., Bouiamrine, E. H., Nassiri, L., Rhioui, W., Bouabid, R., & Belmalha, S. (2023c). Integrated agroecological practices for sustaining weed management and improving faba bean (*Vicia faba* var. minor) productivity under low-input farming. *International Journal of Pest Management*. https://doi.org/10.1080/09670874.2023.2240275
Boutagayout, A., Bouiamrine, E., Adiba, A., Yahbi, M., Nassiri, L., & Belmalha, S. (2023d). Reduced Corum herbicide dose with allelopathic crop water extract for weed control in faba bean. *Journal of Plant Protection Research, 63*(2), 1–14. https://doi.org/10.24425/jppr.2023.145756
Boutagayout, A., Nassiri, L., Bouiamrine, E. H., & Belmalha, S. (2020). Mulching effect on weed control and faba bean (*Vicia faba* L. Minor) yield in Meknes region, Morocco. In *E3S web of conferences. EDP Sciences*. Vol. 183, p. 04002. https://doi.org/10.1051/e3sconf/202018304002
Brar, A. S., & Gill, H. K. (2021). Role of planting pattern and weed control methods on growth and yield of mustard: A review. *The Pharma Innovation Journal, 10*(4), 880–883.
Brown, B., Karki, E., Sharma, A., Suri, B., & Chaudhary, A. (2021). Herbicides and zero tillage in South Asia: Are we creating a gendered problem? *Outlook on Agriculture, 50*(3), 238–246. https://doi.org/10.1177/00307270211013823
Brozović, B., Jug, I., Jug, D., Stipešević, B., Ravlić, M., & Đurđević, B. (2021). Biochar and fertilization effects on weed incidence in winter wheat. *Agronomy, 11*(10), 2028. https://doi.org/10.3390/agronomy11102028
Brühl, C. A., & Zaller, J. G. (2019). Biodiversity decline as a consequence of an inappropriate environmental risk assessment of pesticides. *Frontiers in Environmental Science*. https://doi.org/10.3389/fenvs.2019.00177
Bulut, S., Özturk, A., Yıldız, N., & Karaoğlu, M. M. (2022). Mineral composition of bread wheat cultivars as influenced by different fertilizer sources and weed management practices. *Gesunde Pflanzen, 74*(4), 1087–1098. https://doi.org/10.1007/s10343-022-00671-w
Burgess, A. J., Cano, M. E. C., & Parkes, B. (2022). The deployment of intercropping and agroforestry as adaptation to climate change. *Crop and Environment*. https://doi.org/10.1016/j.crope.2022.05.001
Cabrera-Pérez, C., Llorens, J., Escolà, A., Royo-Esnal, A., & Recasens, J. (2023). Organic mulches as an alternative for under-vine weed management in Mediterranean irrigated vineyards: Impact on agronomic performance. *European Journal of Agronomy, 145*, 126798. https://doi.org/10.1016/j.eja.2023.126798
Calha, IM, Montull, J, Jesenko, T, Omon, B, Chachalis, D. (2019). Cropping system design for non-chemical weed management. EIP-AGRI Focus Group, pp. 1–19.
Campbell, L. G., Snow, A. A., Sweeney, P. M., & Ketner, J. M. (2009). Rapid evolution in crop-weed hybrids under artificial selection for divergent life histories. *Evolutionary Applications, 2*(2), 172–186. https://doi.org/10.1111/j.1752-4571.2008.00051.x
Carton, N., Naudin, C., Piva, G., & Corre-Hellou, G. (2020). Intercropping winter lupin and triticale increases weed suppression and total yield. *Agriculture, 10*(8), 316. https://doi.org/10.3390/agriculture10080316
Catarino, R., Gaba, S., & Bretagnolle, V. (2019). Experimental and empirical evidence shows that reducing weed control in winter cereal fields is a viable strategy for farmers. *Scientific Reports, 9*(1), 1–10. https://doi.org/10.1038/s41598-019-45315-8
Chauhan, B. S. (2020). Grand challenges in weed management. *Frontiers in Agronomy, 1*, 3. https://doi.org/10.3389/fagro.2019.00003
Chaves Lobón, N., González Félix, M., & Alías Gallego, J. C. (2023). Comparison of the allelopathic potential of non-native and native species of mediterranean ecosystems. *Plants, 12*(4), 972. https://doi.org/10.3390/plants12040972
Chemouri, S., & Belmir, M. (2014). *Contribution à l'étude de la flore adventice dans quelques agrumeraies du bassin agricole de Tlemcen* (p. 94). Université Abou bekr belkaid-Tlemcen.
Chopra, M., & Koul, B. (2020). Comparative assessment of different types of mulching in various crops: A review. *Plant Arch, 20*, 1620–1626.

Codina-Pascual, N., Torra, J., Baraibar, B., & Royo-Esnal, A. (2022). Weed suppression capacity of camelina (*Camelina sativa*) against winter weeds: The example of corn-poppy (*Papaver rhoeas*). *Industrial Crops and Products, 184*, 115063. https://doi.org/10.1016/j.indcrop.2022.115063
Cordeau S., Dessaint F., Deneuil C., Bonin L., Vuillemin F., Delattre M., & Chauvel B. (2016). La nuisibilité directe des adventices en grandes cultures : quelles réponses nous apportent les essais désherbages ? In *23. Conférence du COLUMA-Journées Internationales sur la Lutte contre les Mauvaises Herbes*. AFPP-Association Française de Protection des Plantes, pp. 11–22.
Cordeau, S. (2022). Conservation agriculture and agroecological weed management. *Agronomy, 12*(4), 867. https://doi.org/10.3390/agronomy12040867
Cusworth, G., Garnett, T., & Lorimer, J. (2021). Agroecological break out: Legumes, crop diversification and the regenerative futures of UK agriculture. *Journal of Rural Studies, 88*, 126–137. https://doi.org/10.1016/j.jrurstud.2021.10.005
D'Amico, M. B., Chantre, G. R., Calandrini, G. L., & González-Andújar, J. L. (2021). Effect of barley sowing density on the integrated weed management of Lolium rigidum (*Annual ryegrass*) in mediterranean dryland: A modeling approach. *Agronomy, 11*(8), 1565. https://doi.org/10.3390/agronomy11081565
Dara, D., & Drabovich, A. P. (2022). Assessment of risks, implications, and opportunities of waterborne neurotoxic pesticides. *Journal of Environmental Sciences*. https://doi.org/10.1016/j.jes.2022.03.033
Daramola, O. S., Adeyemi, O. R., Adigun, J. A., & Adejuyigbe, C. O. (2021). Influence of row spacing and weed control methods on weed population dynamics in soybean (*Glycine max* L.). *International Journal of Pest Management, 68*(1), 43–58. https://doi.org/10.1080/09670874.2020.1795300
Dayoub, E., Piva, G., Shirtliffe, S. J., Fustec, J., Corre-Hellou, G., & Naudin, C. (2022). Species choice influences weed suppression, N sharing and crop productivity in oilseed rape-legume intercrops. *Agronomy, 12*(9), 2187. https://doi.org/10.3390/agronomy12092187
De Vita, P., Colecchia, S. A., Pecorella, I., & Saia, S. (2017). Reduced inter-row distance improves yield and competition against weeds in a semi-dwarf durum wheat variety. *European Journal of Agronomy, 85*, 69–77. https://doi.org/10.1016/j.eja.2017.02.003
Detrey, J. (2021). Pratiques agroécologiques en micro-fermes maraîchères: Influence de la culture sur butte et de l'association de cultures sur les performances végétales de la tomate et des nématodes bioindicateurs du fonctionnement du sol (Doctoral dissertation, Université de Poitiers).
Dhillon, B. S., Bansal, T., Kumar, V., Bhullar, M. S., & Singh, S. (2021). Weed competitive cultivars as a component of integrated weed management in direct-seeded rice: A review. *Indian Journal of Weed Science, 53*(3), 230–237. https://doi.org/10.5958/0974-8164.2021.00043.5
Dhima, K., & Eleftherohorinos, I. (2005). Wild mustard (*Sinapis arvensis* L.) competition with three winter cereals as affected by nitrogen supply. *Journal of Agronomy and Crop Science, 191*, 241–248. https://doi.org/10.1111/j.1439-037X.2005.00152.x
Ditzler, L., & Driessen, C. (2022). Automating agroecology: How to design a farming robot without a monocultural mindset? *Journal of Agricultural and Environmental Ethics, 35*(1), 1–31. https://doi.org/10.1007/s10806-021-09876-x
Dmitrović, S., Simonović, A., Mitić, N., Savić, J., Cingel, A., Filipović, B., & Ninković, S. (2015). Hairy root exudates of allelopathic weed *Chenopodium murale* L. induce oxidative stress and down-regulate core cell cycle genes in Arabidopsis and wheat seedlings. *Plant Growth Regulation, 75*(1), 365–382. https://doi.org/10.1007/s10725-014-9959-z
Dong, H., Huang, Y., & Wang, K. (2021). The development of herbicide resistance crop plants using CRISPR/Cas9-mediated gene editing. *Genes, 12*(6), 912. https://doi.org/10.3390/genes12060912
Einbinder, N., Morales, H., Mier y Terán Giménez Cacho, M., Ferguson, B. G., Aldasoro, M., & Nigh, R. (2022). Agroecology from the ground up: a critical analysis of sustainable soil management in the highlands of Guatemala. *Agriculture and Human Values*, 1–18.
Ekwealor, K. U., Echereme, C. B., Ofobeze, T. N., & Okereke, C. N. (2019). Economic importance of weeds: A review. *Asian Journal of Plant Science, 3*, 1–11.
El-Metwally, I., & Shalaby, S. (2019). Herbicidal efficacy of some natural products and mulching compared to herbicides for weed control in onion fields. *Journal of Plant Protection Research*. https://doi.org/10.24425/jppr.2019.131266
El-Metwally, I. M., Saudy, H. S., & Elewa, T. A. (2022). Natural plant by-products and mulching materials to suppress weeds and improve sugar beet (*Beta vulgaris* L.) yield and quality. *Journal of Soil Science and Plant Nutrition, 22*(4), 5217–5230. https://doi.org/10.1007/s42729-022-00997-4
Ennami, M., Briache, F. Z., Gaboun, F., Abdelwahd, R., Ghaouti, L., Belqadi, L., ... & Mentag, R. (2017). Host differentiation and variability of Orobanche crenata populations from legume species in Morocco as revealed by cross-infestation and molecular analysis. *Pest Management Science*, *73*(8), 1753–1763. DOI: https://doi.org/10.1002/ps.4536

Esposito, M., Crimaldi, M., Cirillo, V., Fabrizio, S., & Albino, M. (2021). Drone and sensor technology for sustainable weed management: A review. *Chemical and Biological Technologies in Agriculture, 8*, 18. https://doi.org/10.1186/s40538-021-00217-8

FAO. (2017). The future of food and agriculture-trends and challenges. Food and Agriculture Organization, 163. Retrieved from. http://www.fao.org/3/a-i6583e.pdf

FAO. (2023). NSP-Database of weed species in crops and countries. Data stored from 69 developing countries and regularly updated. https://urlz.fr/oorn. Accessed November 28, 2023.

FAOSTAT. (2023). The Food and Agriculture Organization. https://www.fao.org/faostat/en/#compare Accessed April 28, 2023

Farooq, N., Abbas, T., Tanveer, A., & Jabran, K. (2020). Allelopathy for weed management. Co-evolution of secondary metabolites, pp. 505–519. https://doi.org/10.1007/978-3-319-96397-6_16

Fennimore, S. A., & Cutulle, M. (2019). Robotic weeders can improve weed control options for specialty crops. *Pest Management Science, 75*(7), 1767–1774. https://doi.org/10.1002/ps.5337

Fernández-Aparicio, M., Delavault, P., & Timko, M. P. (2020). Management of infection by parasitic weeds: A review. *Plants, 9*(9), 1184. https://doi.org/10.3390/plants9091184

Fernando, M., & Shrestha, A. (2023). The potential of cover crops for weed management: A sole tool or component of an integrated weed management system? *Plants, 12*(4), 752. https://doi.org/10.3390/plants12040752

Franco-Ortega, S., Goldberg-Cavalleri, A., Walker, A., Brazier-Hicks, M., Onkokesung, N., & Edwards, R. (2021). Non-target site herbicide resistance is conferred by two distinct mechanisms in black-grass (*Alopecurus myosuroides*). *Frontiers in Plant Science, 12*, 636652. https://doi.org/10.3389/fpls.2021.636652

Fried, G., Chauvel, B., Munoz, F., & Reboud, X. (2019). Which traits make weeds more successful in maize crops? Insights from a three-decade monitoring in France. *Plants, 9*(1), 40. https://doi.org/10.3390/plants9010040

Gaba, S., Cheviron, N., Perrot, T., Piutti, S., Gautier, J. L., & Bretagnolle, V. (2020). Weeds enhance multifunctionality in arable lands in south-west of France. *Frontiers in Sustainable Food Systems, 4*, 71. https://doi.org/10.3389/fsufs.2020.00071

Gaba, S., Chauvel, B., Dessaint, F., Bretagnolle, V., & Petit, S. (2010). Weed species richness in winter wheat increases with landscape heterogeneity. *Agriculture, Ecosystems & Environment, 138*(3–4), 318–323. https://doi.org/10.1016/j.agee.2010.06.005

Gaba, S., Fried, G., Kazakou, E., Chauvel, B., & Navas, M. L. (2014). Agroecological weed control using a functional approach: A review of cropping systems diversity. *Agronomy for Sustainable Development, 34*, 103–119. https://doi.org/10.1007/s13593-013-0166-5

Gaba, S., Reboud, X., & Fried, G. (2016). Agroecology and conservation of weed diversity in agricultural lands. *Botany Letters, 163*(4), 351–354. https://doi.org/10.1080/23818107.2016.1236290

Gaines, T. A., Duke, S. O., Morran, S., Rigon, C. A., Tranel, P. J., Küpper, A., & Dayan, F. E. (2020). Mechanisms of evolved herbicide resistance. *Journal of Biological Chemistry, 295*(30), 10307–10330. https://doi.org/10.1074/jbc.REV120.013572

García, A. L., Royo-Esnal, A., Torra, J., Cantero-Martinez, C., & Recasens, J. (2014). Integrated management of Bromus diandrus in dryland cereal fields under no-till. *Weed Research, 54*(4), 408–417. https://doi.org/10.1111/wre.12088

Gardarin, A., Celette, F., Naudin, C., Piva, G., Valantin-Morison, M., Vrignon-Brenas, S., ... & Medience, S. (2022). Intercropping with service crops provides multiple services in temperate arable systems: a review. *Agronomy for Sustainable Development, 42*(3), 39. https://doi.org/10.1007/s13593-022-00771-x

Gargouri-Kammoun, L., Ghanmi, A., & Khammassi, M. (2019). Affect of sowing dates and of herbicides on weeds and yield of two varieties of canola (Trapper et Pr 73). In *Annales de l'INRAT. Institut National de la Recherche Agronomique de Tunisie (INRAT)* (pp. 97–111).

Garibaldi, L. A., Goldenberg, M. G., Burian, A., Santibañez, F., Satorre, E. H., Martini, G. D., & Seppelt, R. (2023). Smaller agricultural fields, more edges, and natural habitats reduce herbicide-resistant weeds. *Agriculture, Ecosystems & Environment, 342*, 108260. https://doi.org/10.1016/j.agee.2022.108260

Gazoulis, I., Kanatas, P., Antonopoulos, N., Tataridas, A., & Travlos, I. (2022). Narrow row spacing and cover crops to suppress weeds and improve sulla (*Hedysarum coronarium* L.) biomass production. *Energies, 15*(19), 7425. https://doi.org/10.3390/en15197425

Gazoulis, I., Kanatas, P., Antonopoulos, N., Tataridas, A., & Travlos, I. (2023). False seedbed for agroecological weed management in forage cereal-legume intercrops and monocultures in Greece. *Agronomy, 13*(1), 123. https://doi.org/10.3390/agronomy13010123

Gerhards, R., Andujar Sanchez, D., Hamouz, P., Peteinatos, G. G., Christensen, S., & Fernandez-Quintanilla, C. (2022). Advances in site-specific weed management in agriculture-A review. *Weed Research, 62*(2), 123–133. https://doi.org/10.1111/wre.12526

Ghanizadeh, H., & Harrington, K. C. (2017). Non-target site mechanisms of resistance to herbicides. *Critical Reviews in Plant Sciences, 36*(1), 24–34. https://doi.org/10.1080/07352689.2017.1316134

Ghanizadeh, H., & Harrington, K. C. (2021). Herbicide resistant weeds in New Zealand: State of knowledge. *New Zealand Journal of Agricultural Research, 64*(4), 471–482. https://doi.org/10.1080/00288233.2019.1705863

Gherekhloo, J., Hassanpour-Bourkheili, S., Hejazirad, P., Golmohammadzadeh, S., Vazquez-Garcia, J. G., & De Prado, R. (2021). Herbicide resistance in Phalaris species: A review. *Plants, 10*(11), 2248. https://doi.org/10.3390/plants10112248

Ghosh, D., Brahmachari, K., Brestic, M., Ondrisik, P., Hossain, A., Skalicky, M., ... & Bell, R. W. (2020). Integrated weed and nutrient management improve yield, nutrient uptake and economics of maize in the rice-maize cropping system of Eastern India. *Agronomy*, *10*(12), 1906. https://doi.org/10.3390/agronomy10121906

Ghosh, D., Brahmachari, K., Skalický, M., Roy, D., Das, A., Sarkar, S., ... & Hossain, A. (2022). The combination of organic and inorganic fertilizers influence the weed growth, productivity and soil fertility of monsoon rice. *PLoS ONE, 17*(1), e0262586. https://doi.org/10.1371/journal.pone.0262586

Giambalvo, D., Ruisi, P., Saia, S., Di Miceli, G., Frenda, A. S., & Amato, G. (2012). Faba bean grain yield, N_2 fixation, and weed infestation in a long-term tillage experiment under rainfed Mediterranean conditions. *Plant and Soil, 360*, 215–227. https://doi.org/10.1007/s11104-012-1224-5

Gualbert Gbèhounou. (2010). NSP - Weeds most difficult to control. FAO survey report. https://urlz.fr/oorh. Accessed November 11, 2023.

Guerra, J. G., Cabello, F., Fernández-Quintanilla, C., Peña, J. M., & Dorado, J. (2022). How weed management influence plant community composition, taxonomic diversity and crop yield: A long-term study in a Mediterranean vineyard. *Agriculture, Ecosystems & Environment, 326*, 107816. https://doi.org/10.1016/j.agee.2021.107816

Gullino, M. L., & Tavella, L. (2020). Chemical and natural pesticides in IPM: side-effects and application. *Integrated Pest and Disease maNagement in Greenhouse Crops*. https://doi.org/10.1007/978-3-030-22304-5_15

Haider, F. U., Cheema, S. A., & Farooq, M. (2019). Impact of cover crops in improving agro-ecosytems including sustainable weed suppression—a review. *Pakistan Journal of Weed Science Research, 25*(1), 47–62. https://doi.org/10.28941/25-1(2019)-5

Hall, L. M., Holtum, J. A., & Powles, S. B. (2018). Mechanisms responsible for cross resistance and multiple resistance. In *Herbicide resistance in plants* (pp. 243–262). CRC Press.

Hanif, K., Zubair, M., Hussain, D., Ali, S., Saleem, M., Khan, H. A. A., & Nazir, T. (2022). Biopesticides and insect pest management. *International Journal of Tropical Insect Science*. https://doi.org/10.1007/s42690-022-00898-0

Hannachi A. (2010). Étude des mauvaises herbes des cultures de la région de Batna: Systématique, Biologie et Écologie. Mémoire de Magister. Amélioration de la production végétale. Université Farhet Abbès. Sétif.

Hartwig, N. L., & Ammon, H. U. (2002). Cover crops and living mulches. *Weed Science, 50*(6), 688–699. https://doi.org/10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2

Hawkins, N. J., Bass, C., Dixon, A., & Neve, P. (2019). The evolutionary origins of pesticide resistance. *Biological Reviews, 94*(1), 135–155. https://doi.org/10.1016/bs.agron.2021.10.004

Heap I. (2023). The International Herbicide-Resistant Weed Database. http://www.weedscience.org/Home.aspx. Accessed April 28, 2023.

Hu, L., Wang, J., Yang, C., Islam, F., Bouwmeester, H. J., Muños, S., & Zhou, W. (2020). The effect of virulence and resistance mechanisms on the interactions between parasitic plants and their hosts. *International Journal of Molecular Sciences, 21*(23), 9013. https://doi.org/10.3390/ijms21239013

Hussain, M., Abbas Shah, S. N., Naeem, M., Farooq, S., Jabran, K., & Alfarraj, S. (2022). Impact of different mulching treatments on weed flora and productivity of maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.). *PLoS ONE, 17*(4), e0266756. https://doi.org/10.1371/journal.pone.0266756

Hussen, A. (2021). Effect of critical period of weed competition and its management option in sweet corn [*Zea mays* (L.) var saccharata strut] production: A review. *Agricultural Reviews, 42*(3), 308–314. https://doi.org/10.18805/ag.R-189

Ingraffia, R., Amato, G., Ruisi, P., Giambalvo, D., & Frenda, A. S. (2022). Early sowing can boost grain production by reducing weed infestation in organic no-till wheat. *Journal of the Science of Food and Agriculture, 102*(14), 6246–6254. https://doi.org/10.1002/jsfa.11973

Iqbal, N., Manalil, S., Chauhan, B. S., & Adkins, S. W. (2022). Effect of narrow row-spacing and weed crop competition duration on cotton productivity. *Archives of Agronomy and Soil Science, 68*(3), 355–367. https://doi.org/10.1080/03650340.2020.1836344

Izquierdo, J., Blanco-Moreno, J. M., Chamorro, L., Gonzalez-Andujar, J. L., & Sans, F. X. (2009). Spatial distribution of weed diversity within a cereal field. *Agronomy for Sustainable Development, 29*, 491–496. https://doi.org/10.1051/agro/2009009

Jabran, K. (2019). Mulches for weed control. In*: Role of mulching in pest management and agricultural sustainability*. Springer Briefs in Plant Science (pp. 15–25). Springer. https://doi.org/10.1007/978-3-030-22301-4_2

Jabran, K., & Chauhan, B. S. (2018). Weed control using ground cover systems. In *Non-chemical weed control* (pp. 61–71). Academic Press. https://doi.org/10.1016/B978-0-12-809881-3.00004-8

Jabran, K., Mahajan, G., Sardana, V., & Chauhan, B. S. (2015). Allelopathy for weed control in agricultural systems. *Crop Protection., 72*, 57–65. https://doi.org/10.1016/j.cropro.2015.03.004

Jatoi, M. T., Ahmed, S. R., Lahori, A. H., Sydorenko, V., Afzal, A., Kandhro, M. N., ... & Pruskyi, A. (2022). Allelopathic effects of sunflower water extract integrated with affinity herbicide on weed control and wheat yield. *Ecological Questions, 33*(4), 1–17. https://doi.org/10.12775/EQ.2022.031

Jauzein, P. (1995). *Flore des champs cultives [Flora of cultivated fields]*. Sopra-INRA.

Javanmard, A., et al. (2020). Intercropping of maize with legumes: A cleaner strategy for improving the quantity and quality of forage. *Cleaner Engineering and Technology., 1*, 100003. https://doi.org/10.1016/j.clet.2020.100003

Jha, P., Kumar, V., Godara, R. K., & Chauhan, B. S. (2017). Weed management using crop competition in the United States: A review. *Crop Protection, 95*, 31–37. https://doi.org/10.1016/j.cropro.2016.06.021

Jordan, N., & Vatovec, C. (2004). Agroecological benefits from weeds. *Weed Biology and Management*. https://doi.org/10.1007/978-94-017-0552-3_6

José-María, L., Armengot, L., Blanco-Moreno, J. M., Bassa, M., & Sans, F. X. (2010). Effects of agricultural intensification on plant diversity in Mediterranean dryland cereal fields. *Journal of Applied Ecology, 47*(4), 832–840. https://doi.org/10.1111/j.1365-2664.2010.01822.x

Kaab, S. B., Rebey, I. B., Hanafi, M., Hammi, K. M., Smaoui, A., Fauconnier, M. L., ... & Ksouri, R. (2020). Screening of Tunisian plant extracts for herbicidal activity and formulation of a bioherbicide based on *Cynara cardunculus*. *South African Journal of Botany, 128*, 67–76. https://doi.org/10.1016/j.sajb.2019.10.018

Kader, M. A., Singha, A., Begum, M. A., Jewel, A., Khan, F. H., & Khan, N. I. (2019). Mulching as water-saving technique in dryland agriculture. *Bulletin of the National Research Centre, 43*(1), 1–6. https://doi.org/10.1186/s42269-019-0186-7

Kanatas, P. (2020). Mini-review: The role of crop rotation, intercropping, sowing dates and increased crop density towards a sustainable crop and weed management in arable crops. *Journal of Agricultural Science, 1*, 22–27. https://doi.org/10.15159/jas.20.11

Kanatas, P. J., & Gazoulis, I. (2022). The integration of increased seeding rates, mechanical weed control and herbicide application for weed management in chickpea (*Cicer arietinum* L.). *Phytoparasitica, 50*(1), 255–267. https://doi.org/10.1007/s12600-021-00955-3

Kanatas, P., Travlos, I., Papastylianou, P., Gazoulis, I., Kakabouki, I., & Tsekoura, A. (2020a). Yield, quality and weed control in soybean crop as affected by several cultural and weed management practices. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 48*(1), 329–341. https://doi.org/10.15835/nbha48111823

Kanatas, P. J., Travlos, I. S., Gazoulis, J., Antonopoulos, N., Tsekoura, A., Tataridas, A., & Zannopoulos, S. (2020b). The combined effects of false seedbed technique, post-emergence chemical control and cultivar on weed management and yield of barley in Greece. *Phytoparasitica, 48*, 131–143. https://doi.org/10.1007/s12600-020-00783-x

Kaptymer, B. L., Ute, J. A., & Hule, M. N. (2019). Climate smart agriculture and its implementation challenges in Africa. *Curr. J. Appl. Sci. Technol, 38*, 1–13. https://doi.org/10.9734/CJAST/2019/v38i430371

Karkanis, A., Angou, A., Athanasiadou, D., Giannoulis, K. D., Askianaki, R., Kousi, N., ... & Karamoutis, C. (2022). Using post-emergence herbicides in combination with the sowing date to suppress *Sinapis arvensis* and *Silybum marianum* in Durum wheat. *Agronomy, 12*(10), 2583. https://doi.org/10.3390/agronomy12102583

Karkanis, A., Ntatsi, G., Kontopoulou, C. K., Pristeri, A., Bilalis, D., and Savvas, D. (2016a). Field pea in European cropping systems: adaptability, biological nitrogen fixation and cultivation practices. *Not. Bot. Horti Agrobot. Cluj Napoca. 44*, 325–336. https://doi.org/10.15835/nbha44210618

Karkanis, A., Ntatsi, G., Lepse, L., Fernández, J. A., Vågen, I. M., Rewald, B., ... & Savvas, D. (2018). Faba bean cultivation–revealing novel managing practices for more sustainable and competitive European cropping systems. *Frontiers in Plant Science*, *1115*. https://doi.org/10.3389/fpls.2018.01115

Karkanis, A., Travlos, I. S., Bilalis, D., & Tabaxi, E. I. (2016b). Integrated weed management in winter cereals in Southern Europe. In S. Travlos, D. J. Bilalis, & D. Chachalis (Eds.), *Weed and Pest Control: Molecular Biology* (pp. 1–15). Practices and Environmental Impact: Nova Science Publishers Inc.

Kato-Noguchi, H. (2021). Phytotoxic substances involved in teak allelopathy and agroforestry. *Applied Sciences, 11*(8), 3314. https://doi.org/10.3390/app11083314

Katre, A., Bertossi, T., Clarke-Sather, A., & Parsatoon, M. (2022). Agroecological transition: A territorial examination of the simultaneity of limited farmer livelihoods and food insecurity. *Sustainability, 14*(6), 3160. https://doi.org/10.3390/su14063160

Kaur, S., Dhanda, S., Yadav, A., Sagwal, P., Yadav, D. B., & Chauhan, B. S. (2022). Current status of herbicide-resistant weeds and their management in the rice-wheat cropping system of South Asia. *Advances in Agronomy, 172*, 307–354. https://doi.org/10.1111/brv.12440

Kaur, S., Kaur, R., & Chauhan, B. S. (2018). Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems. *Crop Protection, 103*, 65–72. https://doi.org/10.1016/j.cropro.2017.09.011

Kordali, S., Kabaagac, G., Sen, İ, Yilmaz, F., & Najda, A. (2022). Phytotoxic effects of three origanum species extracts and essential oil on seed germinations and seedling growths of four weed species. *Agronomy, 12*(10), 2581. https://doi.org/10.3390/agronomy12102581

Korres, N. E. (2018). Agronomic weed control: a trustworthy approach for sustainable weed management. In *Non-chemical weed control* (pp. 97–114). Academic Press. https://doi.org/10.1016/B978-0-12-809881-3.00006-1

Kumar, S., Bhowmick, M. K., & Ray, P. (2021a). *Weeds as Alternate and Alternative Hosts of Crop Pests.* https://doi.org/10.5958/0974-8164.2021.00002.2

Kumar, V., Bana, R. S., Singh, T., & Ganpat, L. (2021b). Ecological weed management approaches for wheat under rice–wheat cropping system. *Environmental Sustainability, 4*, 51–61. https://doi.org/10.1007/s42398-020-00157-3

Kumar, V., Obour, A., Jha, P., Liu, R., Manuchehri, M.R., Dille, J.A., ... & Stahlman, P.W. (2020). Integrating cover crops for weed management in the semiarid US Great Plains: Opportunities and challenges. *Weed Science, 68*(4), 311–323. https://doi.org/10.1017/wsc.2020.29

Kurtenbach, M. E., Johnson, E. N., Gulden, R. H., Duguid, S., Dyck, M. F., & Willenborg, C. J. (2019). Integrating cultural practices with herbicides augments weed management in flax. *Agronomy Journal, 111*(4), 1904–1912. https://doi.org/10.2134/agronj2018.09.0593

Las Casas, G., Ciaccia, C., Iovino, V., Ferlito, F., Torrisi, B., Lodolini, E.M., ... & Bella, S. (2022). Effects of Different inter-row soil management and intra-row living mulch on spontaneous flora, beneficial insects, and growth of young Olive Trees in Southern Italy. *Plants, 11*(4), 545. https://doi.org/10.3390/plants11040545

Lazzaro, M., Costanzo, A., Farag, D. H., & Bàrberi, P. (2017). Grain yield and competitive ability against weeds in modern and heritage common wheat cultivars are differently influenced by sowing density. *Italian Journal of Agronomy*. https://doi.org/10.4081/ija.2017.901

Le Bellec, F., Damas, O., Boullenger, G., Vannière, H., Lesueur Jannoyer, M., Tournebize, R., & Ozier Lafontaine, H. (2012). Weed control with a cover crop (*Neonotonia wightii*) in mandarin orchards in Guadeloupe (FWI). *Acta Horticulturae, 928*, 359–366.

LeBuhn, G., & Luna, J. V. (2021). Pollinator decline: What do we know about the drivers of solitary bee declines? *Current Opinion in Insect Science, 46*, 106–111. https://doi.org/10.1016/j.cois.2021.05.004

Lechenet, M., Dessaint, F., Py, G., Makowski, D., & Munier-Jolain, N. (2017). Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants, 3*(3), 1–6. https://doi.org/10.1038/nplants.2017.8

Lee, N., & Thierfelder, C. (2017). Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. *Agronomy for Sustainable Development, 37*(5), 1–25. https://doi.org/10.1007/s13593-017-0453-7

Leoni, F., Lazzaro, M., Ruggeri, M., Carlesi, S., Meriggi, P., & Moonen, A. C. (2022). Relay intercropping can efficiently support weed management in cereal-based cropping systems when appropriate legume species are chosen. *Agronomy for Sustainable Development, 42*(4), 75. https://doi.org/10.1007/s13593-022-00787-3

Li, R., Li, Q., & Pan, L. (2021). Review of organic mulching effects on soil and water loss. *Archives of Agronomy and Soil Science, 67*(1), 136–151. https://doi.org/10.1080/03650340.2020.1718111

Li, Z. R., Amist, N., & Bai, L. Y. (2019). Allelopathy in sustainable weeds management. *Allelopathy J, 48*, 109–138. https://doi.org/10.26651/2019-48-2-1249

Lionello, P., Abrantes, F., Gacic, M., Planton, S., Trigo, R., & Ulbrich, U. (2014). The climate of the Mediterranean region: Research progress and climate change impacts. *Regional Environmental Change, 14*, 1679–1684. https://doi.org/10.1007/s10113-014-0666-0

Little, N. G., DiTommaso, A., Westbrook, A. S., Ketterings, Q. M., & Mohler, C. L. (2021). Effects of fertility amendments on weed growth and weed–crop competition: A review. *Weed Science, 69*(2), 132–146. https://doi.org/10.1017/wsc.2021.1

Long, R. L., Gorecki, M. J., Renton, M., Scott, J. K., Colville, L., Goggin, D. E., ... & Finch-Savage, W. E. (2015). The ecophysiology of seed persistence: a mechanistic view of the journey to germination or demise. *Biological Reviews, 90*(1), 31–59. https://doi.org/10.1111/brv.12095

Lu, H., Liu, Y., Bu, D., Yang, F., Zhang, Z., & Qiang, S. (2023). A double mutation in the ALS gene confers a high level of resistance to mesosulfuron-methyl in Shepherd's-purse. *Plants, 12*(14), 2730. https://doi.org/10.3390/plants12142730

Lykogianni, M., Bempelou, E., Karamaouna, F., & Aliferis, K. A. (2021). Do pesticides promote or hinder sustainability in agriculture? The challenge of sustainable use of pesticides in modern agriculture. *Science of the Total Environment, 795*, 148625. https://doi.org/10.1016/j.scitotenv.2021.148625

Macías, F. A., Mejías, F. J., & Molinillo, J. M. (2019). Recent advances in allelopathy for weed control: From knowledge to applications. *Pest Management Science, 75*(9), 2413–2436. https://doi.org/10.1002/ps.5355

MacLaren, C., Storkey, J., Menegat, A., Metcalfe, H., & Dehnen-Schmutz, K. (2020). An ecological future for weed science to sustain crop production and the environment. A review. *Agronomy for Sustainable Development, 40*(4), 1–29. https://doi.org/10.1007/s13593-020-00631-6

MacLaren, C., Storkey, J., Strauss, J., Swanepoel, P., & Dehnen-Schmutz, K. (2019). Livestock in diverse cropping systems improve weed management and sustain yields whilst reducing inputs. *Journal of Applied Ecology, 56*(1), 144–156. https://doi.org/10.1111/1365-2664.13239

Mahajan, G., & Brar, L. S. (2002). Integrated management of Phalaris minor in wheat: Rationale and approaches-a review. *Agricultural Reviews, 23*(4), 241–251.

Maitra, S., Shankar, T., & Banerjee, P. (2020). Potential and advantages of maize-legume intercropping system. *Maize-Production and Use*, 1–14.

Manisankar, G., Ghosh, P., Malik, G. C., & Banerjee, M. (2022). Recent trends in chemical weed management: A review. *The Pharma Innovation, 11*(4), 745–753.

Marí, A. I., Pardo, G., Aibar, J., & Cirujeda, A. (2020). Purple nutsedge (*Cyperus rotundus* L.) control with biodegradable mulches and its effect on fresh pepper production. *Scientia Horticulturae, 263*, 109111. https://doi.org/10.1016/j.scienta.2019.109111

Marín, C., & Weiner, J. (2014). Effects of density and sowing pattern on weed suppression and grain yield in three varieties of maize under high weed pressure. *Weed Research, 54*(5), 467–474. https://doi.org/10.1111/wre.12101

Marques, E., Kur, A., Bueno, E., & von Wettberg, E. (2020). Defining and improving the rotational and intercropping value of a crop using a plant–soil feedbacks approach. *Crop Science, 60*(5), 2195–2203. https://doi.org/10.1002/csc2.20200

Marsala, R., Capri, E., Russo, E., Bisagni, M., Colla, R., Lucini, L., ... & Suciu, N.A. (2020). First evaluation of pesticides occurrence in groundwater of Tidone Valley, an area with intensive viticulture. *Science of the Total Environment, 736*, 139730. https://doi.org/10.1016/j.scitotenv.2020.139730

Martins, S. A., dos Santos, R. C., de Rezende Ramos, A., Figueiredo, P. L. B., da Silva, C. R. C., & da Silva, J. K. R. (2021). Allelopathic potential and phytochemical screening of Piper divaricatum extracts on germination and growth of indicator plant (*Lactuca sativa*). *South African Journal of Botany, 138*, 495–499. https://doi.org/10.1016/j.sajb.2021.01.014

Mas, M. T., Poggio, S. L., & Verdú, A. M. (2007). Weed community structure of mandarin orchards under conventional and integrated management in northern Spain. *Agriculture, Ecosystems & Environment, 119*(3–4), 305–310. https://doi.org/10.1016/j.agee.2006.07.016

Masteling, R., Lombard, L., De Boer, W., Raaijmakers, J. M., & Dini-Andreote, F. (2019). Harnessing the microbiome to control plant parasitic weeds. *Current Opinion in Microbiology, 49*, 26–33. https://doi.org/10.1016/j.mib.2019.09.006

Melakhessou, Z. (2020). Etude de l'effet des mauvaises herbes sur les caractéristiques morphologiques, agronomiques, et leurs pouvoirs allélopathiques sur blé dur (*Triticum durum* Desf.). Doctoral dissertation, Université Mohamed Khider de Biskra (pp. 1–123).

Mennan, H., Jabran, K., Zandstra, B. H., & Pala, F. (2020). Non-chemical weed management in vegetables by using cover crops: A review. *Agronomy, 10*(2), 257. https://doi.org/10.3390/agronomy10020257

Merfield, C.N. (2019). Integrated weed management in organic farming. In *Organic farming* (pp. 117–180). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-813272-2.00005-7

Merotto, A., Jr., Goulart, I. C., Nunes, A. L., Kalsing, A., Markus, C., Menezes, V. G., & Wander, A. E. (2016). Evolutionary and social consequences of introgression of nontransgenic herbicide resistance from rice to weedy rice in Brazil. *Evolutionary Applications, 9*(7), 837–846. https://doi.org/10.1111/eva.12387

Mohler, C. L., & Johnson, S. E. (2009). The role of crop rotation in weed management. Crop Rotation on Organic Farms: A Planning Manual. Natural Resources, Agriculture, and Engineering Service (NRAES) (pp. 44–46).

Möller, G., Keasar, T., Shapira, I., Möller, D., Ferrante, M., & Segoli, M. (2020). Effect of weed management on the parasitoid community in Mediterranean vineyards. *Biology, 10*(1), 7. https://doi.org/10.3390/biology10010007

Monteiro, A., & Santos, S. (2022). Sustainable approach to weed management: The role of precision weed management. *Agronomy, 12*(1), 118. https://doi.org/10.3390/agronomy12010118

Muhammad, Z., Inayat, N., Majeed, A., Ali, H., & Ullah, K. (2019). Allelopathy and agricultural sustainability: Implication in weed management and crop protection-an overview. *European Journal of Ecology, 5*(2), 54–61. https://doi.org/10.2478//eje-2019-0014

Muñoz, M., Torres-Pagán, N., Jouini, A., Araniti, F., Sánchez-Moreiras, A. M., & Verdeguer, M. (2022). Control of problematic weeds in mediterranean vineyards with the bioherbicide pelargonic acid. *Agronomy, 12*(10), 2476. https://doi.org/10.3390/agronomy12102476

Naeem, M., Farooq, S., & Hussain, M. (2022). The impact of different weed management systems on weed flora and dry biomass production of barley grown under various barley-based cropping systems. *Plants, 11*(6), 718. https://doi.org/10.3390/plants11060718

Nandula, V. K., Riechers, D. E., Ferhatoglu, Y., Barrett, M., Duke, S. O., Dayan, F. E., ... & Ma, R. (2019). Herbicide metabolism: crop selectivity, bioactivation, weed resistance, and regulation. *Weed Science, 67*(2), 149–175. https://doi.org/10.1017/wsc.2018.88

Negewo, T., Ahmed, S., Tessema, T., & Tana, T. (2022). Biological characteristics, impacts, and management of crenate broomrape (*Orobanche crenata*) in faba bean (*Vicia faba*): A Review. *Frontiers in Agronomy, 4*, 708187. https://doi.org/10.3389/fagro.2022.708187

Ngosong, C., Okolle, J. N., & Tening, A. S. (2019). Mulching: A sustainable option to improve soil health. *Soil Fertility Management for Sustainable Development*. https://doi.org/10.1007/978-981-13-5904-0_11

Nicolétis, É., Caron, P., El Solh, M., Cole, M., Fresco, L. O., Godoy-Faúndez, A., ... & Zurayk, R. (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 1–162.

Ntatsi, G., Karkanis, A., Yfantopoulos, D., Olle, M., Travlos, I., Thanopoulos, R., ... & Savvas, D. (2018). Impact of variety and farming practices on growth, yield, weed flora and symbiotic nitrogen fixation in faba bean cultivated for fresh seed production. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *68*(7), 619–630. https://doi.org/10.1080/09064710.2018.1452286

Osadebe, V. O., Dauda, N., Ede, A. E., Chimdi, G. O., & Echezona, B. C. (2021). The use of bioherbicides in weed control: Constraints and prospects. *African Scholar Publications & Research International, 21*(1), 37–54.

Osipitan, O. A., Dille, J. A., Assefa, Y., Radicetti, E., Ayeni, A., & Knezevic, S. Z. (2019). Impact of cover crop management on level of weed suppression: A meta-analysis. *Crop Science, 59*(3), 833–842. https://doi.org/10.2135/cropsci2018.09.0589

Page, K. L., Dang, Y. P., & Dalal, R. C. (2020). The ability of conservation agriculture to conserve soil organic carbon and the subsequent impact on soil physical, chemical, and biological properties and yield. *Frontiers in Sustainable Food Systems, 4*, 31. https://doi.org/10.3389/fsufs.2020.00031

Papamichael, I., Voukkali, I., & Zorpas, A. A. (2022). Mediterranean: Main environmental issues and concerns. *Euro-Mediterranean Journal for Environmental Integration, 7*, 477–481. https://doi.org/10.1007/s41207-022-00336-0

Parrón, T., Requena, M., Hernández, A. F., & Alarcón, R. (2011). Association between environmental exposure to pesticides and neurodegenerative diseases. *Toxicology and Applied Pharmacology, 256*(3), 379–385.

Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment, 19*(7), 387–395. https://doi.org/10.1002/fee.2359

Pavlović, D., Vrbničanin, S., Anđelković, A., Božić, D., Rajković, M., & Malidža, G. (2022). Non-chemical weed control for plant health and environment: Ecological integrated weed management (EIWM). *Agronomy, 12*(5), 1091. https://doi.org/10.3390/agronomy12051091

Pedda Ghouse Peera, S. K., P. G. P., Debnath, S., & Maitra, S. (2020). Mulching: Materials, advantages and crop production. In Maitra, S., Gaikwad, D. J., Tanmoy, S. (Eds.) Protected cultivation and smart agriculture (pp. 55–66). https://doi.org/10.30954/NDP-PCSA.2020.6

Peerzada, A. M., Bukhari, S. A. H., Dawood, M., Nawaz, A., Ahmad, S., & Adkins, S. (2019). Weed management for healthy crop production. Agronomic Crops: Volume 2: Management Practices, 225–256. https://doi.org/10.1007/978-981-32-9783-8_13

Pelzer, E., Bedoussac, L., Corre-Hellou, G., Jeuffroy, M. H., Métivier, T., & Naudin, C. (2014). Association de cultures annuelles combinant une légumineuse et une céréale: Retours d'expériences d'agriculteurs et analyse. *Innovations Agronomiques, 40*, 73–91.

Perotti, V. E., Larran, A. S., Palmieri, V. E., Martinatto, A. K., & Permingeat, H. R. (2020). Herbicide resistant weeds: A call to integrate conventional agricultural practices, molecular biology knowledge and new technologies. *Plant Science, 290*, 110255. https://doi.org/10.1016/j.plantsci.2019.110255

Peterson, M. A., Collavo, A., Ovejero, R., Shivrain, V., & Walsh, M. J. (2018). The challenge of herbicide resistance around the world: A current summary. *Pest Management Science, 74*(10), 2246–2259. https://doi.org/10.1002/ps.4821

Petit, S., Cordeau, S., Chauvel, B., Bohan, D., Guillemin, J. P., & Steinberg, C. (2018). Biodiversity-based options for arable weed management. A review. *Agronomy for Sustainable Development, 38*(5), 1–21. https://doi.org/10.1007/s13593-018-0525-3

Ponce, R., & Santin, I. (2001). Competitive ability of wheat cultivars with wild oats depending on nitrogen fertilization. *Agronomie, 21*, 119–125. https://doi.org/10.1051/agro:2001112

Pradhan, G., Meena, R. S., Kumar, S., Jhariya, M. K., Khan, N., Shukla, U. N., ... & Sheoran, S. (2022). Legumes for eco-friendly weed management in agroecosystem. In Advances in legumes for sustainable intensification (pp. 133–154). Academic Press. https://doi.org/10.1016/B978-0-323-85797-0.00033-1

Puig, C. G., Revilla, P., Barreal, M. E., Reigosa, M. J., & Pedrol, N. (2019). On the suitability of *Eucalyptus globulus* green manure for field weed control. *Crop Protection, 121*, 57–65. https://doi.org/10.1016/j.cropro.2019.03.016

Punyalue, A., Jamjod, S., & Rerkasem, B. (2018). Intercropping maize with legumes for sustainable highland maize production. *Mountain Research and Development, 38*(1), 35–44. https://doi.org/10.1659/MRD-JOURNAL-D-17-00048.1

Radhakrishnan, R., Alqarawi, A. A., & Abd_Allah, E. F. (2018). Bioherbicides: Current knowledge on weed control mechanism. *Ecotoxicology and Environmental Safety, 158*, 131–138. https://doi.org/10.1016/j.ecoenv.2018.04.018

Radi, A. (2007). Conventional and biotechnological approaches for control of parasitic weeds. *In Vitro Cell Development Biological Plant, 2007*(43), 304–317. https://doi.org/10.1007/s11627-007-9054-5

Radicetti, E., & Mancinelli, R. (2021). Sustainable weed control in the agro-ecosystems. *Sustainability, 13*(15), 8639. https://doi.org/10.3390/su13158639

Radicetti, E., Baresel, J. P., El-Haddoury, E. J., Finckh, M. R., Mancinelli, R., Schmidt, J. H., ... & Campiglia, E. (2018). Wheat performance with subclover living mulch in different agro-environmental conditions depends on crop management. *European Journal of Agronomy, 94*, 36–45. https://doi.org/10.1016/j.eja.2018.01.011

Ranaldo, M., Carlesi, S., Costanzo, A., & Bàrberi, P. (2020). Functional diversity of cover crop mixtures enhances biomass yield and weed suppression in a Mediterranean agroecosystem. *Weed Research, 60*(1), 96–108. https://doi.org/10.1111/wre.12388

Ranjan P., Patle G. T., Prem M., & Solanke K. R. (2017). Organic mulching-a water saving technique to increase the production of fruits and vegetables. *Current Agriculture Research Journal, 5*(3), 371–380. https://doi.org/10.12944/CARJ.5.3.17

Rathika, S., Ramesh, T., & Shanmugapriya, P. (2020). Weed management in direct seeded rice: A review. *International Journal of Chemical Studies, 8*(4), 925–933. https://doi.org/10.22271/chemi.2020.v8.i4f.9723

Renton, M., & Chauhan, B. S. (2017). Modelling crop-weed competition: Why, what, how and what lies ahead? *Crop Protection, 95*, 101–108. https://doi.org/10.1016/j.cropro.2016.09.003

Restuccia, A., Scavo, A., Lombardo, S., Pandino, G., Fontanazza, S., Anastasi, U., ... & Mauromicale, G. (2020). Long-term effect of cover crops on species abundance and diversity of weed flora. *Plants, 9*(11), 1506. https://doi.org/10.3390/plants9111506

Rezendes, I., Baseggio, E. R., Galon, L., Brandler, D., Forte, C. T., Aspiazú, I., ... & da Silva, A. F. (2020). Allelopathy of weeds on the growth of vegetables. *Communications in Plant Sciences, 10*, 8–17. https://doi.org/10.26814/cps2020002

Rivera-Ferre, M. G., Gallar, D., Calle-Collado, Á., & Pimentel, V. (2021). Agroecological education for food sovereignty: Insights from formal and non-formal spheres in Brazil and Spain. *Journal of Rural Studies, 88*, 138–148. https://doi.org/10.1016/j.jrurstud.2021.10.003

Robert, L. Z. (2018a). Chapter 10 - Methods of Weed Management. Fundamentals of Weed Science (Fifth Edition), Editor(s): Robert L. Zimdahl, Academic Press, ISBN 9780128111437, 271–335. DOI: https://doi.org/10.1016/B978-0-12-811143-7.00010-X

Robert, L.Z. (2018b). Chapter 22 - Weed-Management Systems. Fundamentals of Weed Science (Fifth Edition), Editor(s): Robert L. Zimdahl, Academic Press, ISBN 9780128111437, 609–649. DOI: https://doi.org/10.1016/B978-0-12-811143-7.00022-6

Rodenburg, J., Demont, M., Zwart, S. J., & Bastiaans, L. (2016). Parasitic weed incidence and related economic losses in rice in Africa. *Agriculture, Ecosystems & Environment, 235*, 306–317. https://doi.org/10.1016/j.agee.2016.10.020

Romero, A., Chamorro, L., & Sans, F. X. (2008). Weed diversity in crop edges and inner fields of organic and conventional dryland winter cereal crops in NE Spain. *Agriculture, Ecosystems & Environment, 124*(1–2), 97–104. https://doi.org/10.1016/j.agee.2007.08.002

Rosati, A., Borek, R., & Canali, S. (2021). Agroforestry and organic agriculture. *Agroforestry Systems, 95*(5), 805–821. https://doi.org/10.1007/s10457-020-00559-6

Rosculete, C. A., Bonciu, E., Rosculete, E., & Olaru, L. A. (2019). Determination of the environmental pollution potential of some herbicides by the assessment of cytotoxic and genotoxic effects on *Allium cepa*. *International Journal of Environmental Research and Public Health, 16*(1), 75. https://doi.org/10.3390/ijerph16010075

Royo-Esnal, A., & Valencia-Gredilla, F. (2018). Camelina as a rotation crop for weed control in organic farming in a semiarid Mediterranean climate. *Agriculture, 8*(10), 156. https://doi.org/10.3390/agriculture8100156

Rubiales, D., Moral, A., & Flores, F. (2022). Agronomic performance of broomrape resistant and susceptible faba bean accession. *Agronomy, 12*(6), 1421. https://doi.org/10.3390/agronomy12061421

Rubiales, D., Rojas-Molina, M. M., & Sillero, J. C. (2016). Characterization of resistance mechanisms in faba bean (*Vicia faba*) against broomrape species (Orobanche and Phelipanche spp.). *Frontiers in Plant Science, 7*, 1747. https://doi.org/10.3389/fpls.2016.01747

Ruggeri, R., Provenzano, M. E., & Rossini, F. (2016). Effect of mulch on initial coverage of four groundcover species for low input landscaping in a Mediterranean climate. *Urban Forestry & Urban Greening, 19*, 176–183. https://doi.org/10.1016/j.ufug.2016.06.029

Saha, D., Marble, S. C., & Pearson, B. J. (2018). Allelopathic effects of common landscape and nursery mulch materials on weed control. *Frontiers in Plant Science, 9*, 733. https://doi.org/10.3389/fpls.2018.00733

Saini, S., & Saini, K. (2020). *Chenopodium album* Linn: An outlook on weed cum nutritional vegetable along with medicinal properties. *Emergent Life Science Research, 6*, 28–33. https://doi.org/10.31783/elsr.2020.612833

San Martín, C., Andújar, D., Fernández-Quintanilla, C., & Dorado, J. (2015). Spatial distribution patterns of weed communities in corn fields of central Spain. *Weed Science, 63*(4), 936–945. https://doi.org/10.1614/WS-D-15-00031.1

Sánchez-Bayo, F., & Wyckhuys, K. A. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation, 232*, 8–27. https://doi.org/10.1016/j.biocon.2019.01.020

Sansinenea, E. (2021). Application of biofertilizers: Current worldwide status. *Biofertilizers, Woodhead Publishing., 1*, 183–190. https://doi.org/10.1016/B978-0-12-821667-5.00004-X

Scavo, A., & Mauromicale, G. (2020). Integrated weed management in herbaceous field crops. *Agronomy, 10*(4), 466. https://doi.org/10.3390/agronomy10040466

Scavo, A., Fontanazza, S., Restuccia, A., Pesce, G. R., Abbate, C., & Mauromicale, G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development, 42*(5), 93. https://doi.org/10.1007/s13593-022-00825-0

Scavo, A., Pandino, G., Restuccia, A., & Mauromicale, G. (2020). Leaf extracts of cultivated cardoon as potential bioherbicide. *Scientia Horticulturae, 261*, 109024. https://doi.org/10.1016/j.scienta.2019.109024

Scavo, A., Restuccia, A., Abbate, C., & Mauromicale, G. (2019). Seeming field allelopathic activity of *Cynara cardunculus* L. reduces the soil weed seed bank. *Agronomy for Sustainable Development, 39*, 1–12. https://doi.org/10.1007/s13593-019-0580-4

Scavo, A., Restuccia, A., Pandino, G., Onofri, A., & Mauromicale, G. (2018). Allelopathic effects of *Cynara cardunculus* L. leaf aqueous extracts on seed germination of some Mediterranean weed species. *Italian Journal of Agronomy, 13*(2), 119–125. https://doi.org/10.4081/ija.2018.1021

Schaffner, U., Hill, M., Dudley, T., & D'Antonio, C. (2020). Post-release monitoring in classical biological control of weeds: Assessing impact and testing pre-release hypotheses. *Current Opinion in Insect Science, 38*, 99–106. https://doi.org/10.1016/j.cois.2020.02.008

Scott, D., & Freckleton, R. P. (2022). Crop diversification and parasitic weed abundance: A global meta-analysis. *Scientific Reports, 12*(1), 19413. https://doi.org/10.1038/s41598-022-24047-2

Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., ... & Scholten, T. (2019). Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development, 39*, 1–10. https://doi.org/10.1007/s13593-018-0545-z

Selim, M. (2019). A review of advantages, disadvantages and challenges of crop rotations. *Egyptian Journal of Agronomy, 41*(1), 1–10. https://doi.org/10.21608/agro.2019.6606.1139

Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified crop rotation: An approach for sustainable agriculture production. *Advances in Agriculture, 2021*, 1–9. https://doi.org/10.1155/2021/8924087

Shah, S. T., Ullah, I., Basit, A., Sajid, M., Arif, M., & Mohamad, H. I. (2022). Mulching is a mechanism to reduce environmental stresses in plants. In *Mulching in agroecosystems: Plants, soil & environment* (pp. 353–376). Springer Nature. https://doi.org/10.1007/978-981-19-6410-7_20

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., ... & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences, 1*(11), 1–16. https://doi.org/10.1007/s42452-019-1485-1

Sharma, G., Shrestha, S., Kunwar, S., & Tseng, T. M. (2021). Crop diversification for improved weed management: A review. *Agriculture, 11*(5), 461. https://doi.org/10.3390/agriculture11050461

Sharma, M., & Gupta, B. B. (2020). Role of wild relatives for development of climate-resilient varieties. *Rediscovery of Genetic and Genomic Resources for Future Food Security*. https://doi.org/10.1007/978-981-15-0156-2_11

Shaw, R. H., Ellison, C. A., Marchante, H., Pratt, C. F., Schaffner, U., Sforza, R. F., & Deltoro, V. (2018). Weed biological control in the European Union: From serendipity to strategy. *BioControl, 63*, 333–347. https://doi.org/10.1007/s10526-017-9844-6

Sheppard, A. W., Shaw, R. H., & Sforza, R. (2006). Top 20 environmental weeds for classical biological control in Europe: A review of opportunities, regulations and other barriers to adoption. *Weed Research, 46*(2), 93–117. https://doi.org/10.1111/j.1365-3180.2006.00497.x

Silberg, T. R., Chimonyo, V. G. P., Richardson, R. B., Snapp, S. S., & Renner, K. (2019). Legume diversification and weed management in African cereal-based systems. *Agricultural Systems, 174*, 83–94. https://doi.org/10.1016/j.agsy.2019.05.004

Singh, M., Kukal, M. S., Irmak, S., & Jhala, A. J. (2022). Water use characteristics of weeds: A global review, best practices, and future directions. *Frontiers in Plant Science, 12*, 794090. https://doi.org/10.3389/fpls.2021.794090

Singh, S., Kumar, V., Dhanjal, D. S., & Singh, J. (2020). Biological control agents: Diversity, ecological significances, and biotechnological applications. *Natural Bioactive Products in Sustainable Agriculture*. https://doi.org/10.1007/978-981-15-3024-1_3

Singh, V., Bagavathiannan, M., Chauhan, B. S., & Singh, S. (2019). Evaluation of current policies on the use of unmanned aerial vehicles in Indian agriculture. *Current Science, 117*, 25–29. https://doi.org/10.18520/cs/v117/i1/25-29

Smith, B. M., Aebischer, N. J., Ewald, J., Moreby, S., Potter, C., & Holland, J. M. (2020). The potential of arable weeds to reverse invertebrate declines and associated ecosystem services in cereal crops. *Frontiers in Sustainable Food Systems, 3*, 118. https://doi.org/10.3389/fsufs.2019.00118

Sollen-Norrlin, M., Ghaley, B. B., & Rintoul, N. L. J. (2020). Agroforestry benefits and challenges for adoption in Europe and beyond. *Sustainability, 12*(17), 7001. https://doi.org/10.3390/su12177001

Soltani, N., Dille, J. A., Gulden, R. H., Sprague, C. L., Zollinger, R. K., Morishita, D. W., ... & Sikkema, P. H. (2018). Potential yield loss in dry bean crops due to weeds in the United States and Canada. *Weed Technology, 32*(3), 342–346. https://doi.org/10.1017/wet.2017.116

Sponsler, D. B., Grozinger, C. M., Hitaj, C., Rundlöf, M., Botías, C., Code, A., ... & Douglas, M. R. (2019). Pesticides and pollinators: A socioecological synthesis. *Science of the Total Environment, 662*, 1012–1027. https://doi.org/10.1016/j.scitotenv.2019.01.016

Tataridas, A., Kanatas, P., Chatzigeorgiou, A., Zannopoulos, S., & Travlos, I. (2022). Sustainable crop and weed management in the era of the EU Green Deal: A survival guide. *Agronomy, 12*(3), 589. https://doi.org/10.3390/agronomy12030589

Telkar S.G., Singh A. K., Kant K., Solanki S. P. S. & Kumar D., (2017). Types of Mulching and their uses for dryland condition. Biomolecule Reports Ed.

Telkar, S. G., Gurjar, G. N., Dey, J. K., Kant, K., & Solanki, S. P. S. (2015). Biological weed control for sustainable agriculture. *International Journal of Economic Plants, 2*(4), 181–183.

Testani, E., Montemurro, F., Ciaccia, C., & Diacono, M. (2020). Agroecological practices for organic lettuce: Effects on yield, nitrogen status and nitrogen utilisation efficiency. *Biological Agriculture & Horticulture, 36*(2), 84–95. https://doi.org/10.1080/01448765.2019.1689531

Thanou, Z. N., Kontogiannis, E. G., & Tsagkarakis, A. E. (2021). Impact of weeds on Auchenorrhyncha incidence and species richness in citrus orchards. *Phytoparasitica, 49*, 333–347. https://doi.org/10.1007/s12600-020-00857-w

Thomine, E. (2019). Effet de la diversification spatiale et temporelle des cultures à l'échelle du paysage agricole sur le biocontrôle et les ravageurs de culture (Doctoral dissertation, COMUE Université Côte d'Azur. Français.

Tiwari, R., Reinhardt Piskáčková, T. A., Devkota, P., Mulvaney, M. J., Ferrell, J. A., & Leon, R. G. (2021). Growing winter Brassica carinata as part of a diversified crop rotation for integrated weed management. *GCB Bioenergy, 13*(3), 425–435. https://doi.org/10.1111/gcbb.12799

Tlemcani, S., Lahkimi, A., Eloutassi, N., Bendaoud, A., Hmamou, A., & Bekkari, H. (2023). Ethnobotanical study of medicinal plants in the Fez-Meknes Region of Morocco. *Journal of Pharmacy Research, 11*, 137–159. https://doi.org/10.14421/biomedich.2023.121.133-141

Torra, J., Montull, J. M., Calha, I. M., Osuna, M. D., Portugal, J., & de Prado, R. (2022). Current status of herbicide resistance in the Iberian Peninsula: Future trends and challenges. *Agronomy, 12*(4), 929. https://doi.org/10.3390/agronomy12040929

Tournebize, R., Uneau, Y., & Roggy, J. C. (2018). Peut-on gérer la flore adventice sans recours aux herbicides de synthèse dans les systèmes de cultures amazoniens? Sensibilisation aux apports et intérêts des principes agroécologiques. *Innovations Agronomiques, 64*, 11–18.

Travlos, I. S., Montull, J. M., Kukorelli, G., Malidza, G., Dogan, M. N., Cheimona, N., ... & Peteinatos, G. (2019). Key aspects on the biology, ecology and impacts of Johnsongrass [*Sorghum halepense* (L.) Pers] and the role of glyphosate and non-chemical alternative practices for the management of this weed in Europe. *Agronomy, 9*(11), 717. https://doi.org/10.3390/agronomy9110717

Travlos, I. (2012). Reduced herbicide rates for an effective weed control in competitive wheat cultivars. *International Journal of Plant Production, 6*, 1–14.

Travlos, I., de Prado, R., Chachalis, D., & Bilalis, D. J. (2020). Herbicide resistance in weeds: Early detection, mechanisms, dispersal, new insights and management issues. *Frontiers in Ecology and Evolution, 8*, 213. https://doi.org/10.3389/fevo.2020.00213

Trinchera, A., Testani, E., Ciaccia, C., Tittarelli, F., & Canali, S. (2014). May barley and rye extracts have an allelopathic inhibition effect on weed seedling root development by suppressing mycorrhization?. In *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014)* (Vol. 1105, pp. 261–67).

Tu, M., Hurd, C., & Randall, J. M. (2001). Weed control methods handbook: tools & techniques for use in natural areas. *All U.S. Government Documents (Utah Regional Depository)*, 1–533. https://digitalcommons.usu.edu/govdocs/533

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., ... & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International Journal of Environmental Research and Public Health, 18*(3), 1112. https://doi.org/10.3390/ijerph18031112

Tuneu-Corral, C., Puig-Montserrat, X., Riba-Bertolín, D., Russo, D., Rebelo, H., Cabeza, M., & López-Baucells, A. (2023). Pest suppression by bats and management strategies to favour it: A global review. *Biological Reviews*. https://doi.org/10.1111/brv.12967

Tursun, N., Işık, D., Demir, Z., & Jabran, K. (2018). Use of living, mowed, and soil-incorporated cover crops for weed control in apricot orchards. *Agronomy, 8*(8), 150. https://doi.org/10.3390/agronomy8080150

Ulbrich, U., Lionello, P., Belušić, D., Jacobeit, J., Knippertz, P., Kuglitsch, F. G., ... & Ziv, B. (2012). Climate of the Mediterranean: synoptic patterns, temperature, precipitation, winds, and their extremes.https://doi.org/10.1016/B978-0-12-416042-2.00005-7

Uludag, A., Uremis, I., & Arslan, M. (2018). Biological weed control. In *Non-chemical weed control* (pp. 115–132). Academic Press. https://doi.org/10.1016/B978-0-12-809881-3.00007-3

Uremis, I., Uludag, A., Ulger, A., & Cakir, B. (2009). Determination of critical period for weed control in the second crop corn under Mediterranean conditions. *African Journal of Biotechnology, 8*(18).

Vencill, W. K., Nichols, R. L., Webster, T. M., Soteres, J. K., Mallory-Smith, C., Burgos, N. R., ... & McClelland, M. R. (2012). Herbicide resistance: toward an understanding of resistance development and the impact of herbicide-resistant crops. *Weed Science, 60*(SP1), 2–30. https://doi.org/10.1614/WS-D-11-00206.1

Verdú, A. M., & Mas, M. T. (2007). Mulching as an alternative technique for weed management in mandarin orchard tree rows. *Agronomy for Sustainable Development, 27*, 367–375. https://doi.org/10.1051/agro:2007028

Vlahova, V. (2022). Intercropping-An opportunity for sustainable farming systems. A review. *Sci. Pap. Ser. A Agron, 65*, 728–740.
Wang, G., Shi, R., Mi, L., & Hu, J. (2022). Agricultural eco-efficiency: Challenges and progress. *Sustainability, 14*(3), 1051. https://doi.org/10.3390/su14031051
Wang, L., Gruber, S., & Claupein, W. (2013). Effect of sowing date and variety on yield and weed populations in a lentil–barley mixture. *The Journal of Agricultural Science, 151*(5), 672–681. https://doi.org/10.1017/S0021859612000895
Weerarathne, L. V. Y., Marambe, B., & Chauhan, B. S. (2017). Intercropping as an effective component of integrated weed management in tropical root and tuber crops: A review. *Crop Protection, 95*, 89–100. https://doi.org/10.1016/j.cropro.2016.08.010
Weisberger, D., Nichols, V., & Liebman, M. (2019). Does diversifying crop rotations suppress weeds? A meta-analysis. *PLoS ONE, 14*(7), e0219847. https://doi.org/10.1371/journal.pone.0219847
Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. *A Review. Agronomy for Sustainable Development, 40*(6), 1–13. https://doi.org/10.1007/s13593-020-00646-z
Xiang, H., Ni, L. A. N., Fugang, W. A. N. G., Benliang, Z. H. A. O., Hui, W. E. I., & Zhang, J. (2022). An effective planting model to decrease cadmium accumulation in rice grain and plant: Intercropping rice with wetland plants. *Pedosphere*. https://doi.org/10.1016/j.pedsph.2022.06.054
Yigezu, Y. A., El-Shater, T., Boughlala, M., Bishaw, Z., Niane, A. A., Maalouf, F., ... & Aw-Hassan, A. (2019). Legume-based rotations have clear economic advantages over cereal monocropping in dry areas. *Agronomy for Sustainable Development, 39*(6), 58. https://doi.org/10.1007/s13593-019-0602-2
Zeder, M. A. (2008). Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences, 105*(33), 11597–11604. https://doi.org/10.1073/pnas.0801317105
Zhang, H., Miles, C., Gerdeman, B., LaHue, D. G., & DeVetter, L. (2021). Plastic mulch use in perennial fruit cropping systems—A review. *Scientia Horticulturae, 281*, 109975. https://doi.org/10.1016/j.scienta.2021.109975
Zhao, J., Yang, Y., Zhang, K., Jeong, J., Zeng, Z., & Zang, H. (2020). Does crop rotation yield more in China? A meta-analysis. *Field Crops Research, 245*, 107659. https://doi.org/10.1016/j.fcr.2019.107659
Zohaib, A., Abbas, T., & Tabassum, T. (2016). Weeds cause losses in field crops through allelopathy. *Notulae Scientia Biologicae, 8*(1), 47–56. https://doi.org/10.15835/nsb819752

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