

Review

The adequacy of alfalfa crops as an agri-environmental scheme: A review of agronomic benefits and effects on biodiversity

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ABSTRACT

The agriculture intensification required to provide enough food commodities for humans has negative impacts on the environment. To reduce these drawbacks Agri-Environmental Schemes (AES) have been implemented in Europe since the last decade of the twentieth century. One of the measures included in these schemes was the introduction of alfalfas in crop rotation systems. In order to evaluate their suitability as an AES, we synthesize knowledge on the agronomical benefits of alfalfa cultivations, as well as on the relationships of alfalfa crops with biodiversity at three taxonomic levels: vascular plants, arthropods, and vertebrates. Based on the articles reviewed, alfalfas can help restoring native grassland communities due to the nutrient enrichment they provide. Moreover, this legume crop usually ensures food resources not only for invertebrates, but also for vertebrates. Alfalfas tend to harbour a stable arthropod community that benefits surrounding crops by improving ecological processes (pollination, pest predation) and reducing the need to use agrochemicals. At the same time, arthropod abundance attracts vertebrates, especially birds, which supports the role of alfalfa as a conservation tool to favour endangered farmland birds. Additionally, alfalfa crops may function as a reservoir habitat for voles, which are a preferred food resource for farmland-foraging raptors, many of them endangered. On the other hand, birds nesting in alfalfa crops may suffer higher nest destruction rates due to frequent cuts, and voles using alfalfa crops may also create agricultural damage in surrounding crops in certain cases. The review also highlights that negative ecological relationships of alfalfa crops with biodiversity can be minimized, and positive effects may also be maximized under the appropriate management of this crop. Examples of such management actions include cut delays or higher cuts to avoid nest destruction, the use of grazing cattle to reduce the impacts of rodent pests, reduced frequency of cutting or maintaining unharvested strips in the field to maximize positive effects on predatory arthropods and vole availability to raptors. We conclude that alfalfa crops can be considered globally beneficial for farmland biodiversity and a useful management tool for conservation in agricultural landscapes, for example as an AES, but that management should be adapted to particular taxonomical or functional groups.

1. Introduction

Due to the continuous human population growth and the increasing demand of food commodities resulting therefrom, agriculture has been intensified to the detriment of biodiversity (Krebs et al., 1999). Changes in agriculture management to promote this intensification included the use of agrochemicals (fertilizers and pesticides), high-tech machinery, increased sowing densities, changes in the timing of mowing or harvesting, increased plot sizes (to allow working with larger machinery

and removal of non-cultivated landscape elements (Emmerson et al., 2016). All these practices have environmental consequences from small to large scale, including landscape simplification and homogenization, depletion of soil, air and water resources, and biodiversity loss (Stoate et al., 2001; Flohre et al., 2011). The associated erosion of biodiversity has been studied for birds (Fuller et al., 1995; Chamberlain et al., 2000; Guerrero et al., 2010; Voříšek et al., 2010; Flohre et al., 2011; Traba & Morales 2019), mammals (Sotherton & Self, 2000; Fischer et al. 2011), insects (Benton et al., 2003; Goulson, 2003; Guerrero et al. 2010,

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Cameron et al., 2011; Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2019) and plants (Guerrero et al., 2010; José-María et al., 2010; Flohre et al., 2011; Carmona et al., 2020).

The European Union's (EU) Common Agricultural Policy (CAP) was born after the Second World War to ensure enough food resources for the European population. Therefore, one of its main goals was to increase farmland productivity (Oñate, 2005; Emmerson et al., 2016). However, to mitigate the adverse effects of agricultural intensification on the environment, Agri-Environmental Schemes (AES) were created in Europe in 1992 (Stoate et al., 2009), consisting in voluntary contracts with farmers that adopt green measures to benefit biodiversity and the environment (Oñate, 2005; Concepción & Díaz, 2019) and, since 2014, to mitigate climate change (Science for Environment Policy, 2017; Pe'er et al., 2020). AES are highly varied, as they should be appropriate for a wide range of purposes and conditions (Peach et al., 2001; Perkins et al., 2011).

Given their cost (7% of the whole CAP budget in 2014–2020), it is paramount to assess the effectiveness of AES in attaining their environmental objectives, which may be a challenge. Studies have shown both positive and negative results of AES, depending on the target taxa (e.g. Kleijn & Sutherland, 2003; Berendse et al., 2004; Kleijn et al., 2004, 2006; Ponce et al., 2014). For example, a review by Kleijn & Sutherland (2003) showed that plant diversity was difficult to enhance with the AES applied so far, while arthropods seemed easier to favour, and effects on birds were positive or negative depending on the scale of AES application in the landscape, as well as overall landscape complexity in relation to structure and composition (Tscharntke et al., 2005; Concepción et al., 2008; 2012). In addition, AES tend to be more efficient when they are designed for specific species or ecosystems (Ekroos et al., 2014, see recent review in Pe'er et al., 2022).

In Europe, legumes (i.e., crops from the Fabaceae family) are usually found as part of traditional crop rotations. Introducing legumes in crop rotations is considered an optimal management practice against soil degradation, pests, and plant diseases (Cook et al., 2013; Garrison et al., 2014; Reckling et al., 2016), especially because the latter two are not shared between legumes and cereal crops (Zander et al., 2016). The sowing of legumes has thus been frequently proposed as an AES within CAP and management programs for biodiversity conservation (Díaz et al. 2021, Sanz-Pérez et al. 2019). Species used include annual legumes such as pea (*Pisum sativum*), lupin (*Lupinus* spp.) and vetch (*Vicia sativa*),

as well as multiannual legumes such as alfalfa (*Medicago sativa*) and red clover (*Trifolium pratense*) (e.g. Giralt et al. 2018). Legume crops can be used to generate a heterogeneous farm landscape and have been shown to increase biodiversity (improving pest control processes), improve soil fertility, modulate the nitrogen and carbon cycles, and reduce greenhouse gas emissions (Baumgärtner, 2007; Milcu et al., 2008; van Eekeren et al., 2009; Crotty et al., 2015; Zander et al., 2016; Murphy-Bokern et al., 2017; Peoples et al., 2019).

Among legumes, alfalfa crops have been particularly used as AES. About 30% of the surface occupied by legume forage crops in the world is dedicated to alfalfa (Peoples et al., 2019), which has favoured a wealth of technical knowledge on its biology and thus its management is well known (e.g. Fuerst et al., 2009; Undersander & Cosgrove, 2011; Fernández et al., 2019). As in other legumes, alfalfa green parts are rich in proteins, which, in addition to this crop's capacity to fix atmospheric nitrogen, makes alfalfa an interesting crop from a production and conservation point of view (Murphy-Bokern et al., 2017). Because it is pluriannual, it is also associated with lower soil disturbance than other crops, allowing, for instance, many arthropods to complete their biological cycle when part of it takes place in the soil (Soroka & Otani, 2011). However, as with other crops, in recent years alfalfa management is being increasingly intensified to meet market demands (Luque-Larena et al., 2018), which may have negative environmental effects. Therefore, when used as an AES, it is also important to adapt management practices in alfalfa crops to make them more biodiversity friendly, e.g. reducing agrochemical inputs (pesticides and fertilizers) and adapting the number of cuts per year to biodiversity conservation targets (Graham, 2005; Syswerda & Robertson, 2014; Caro et al., 2016; di Lascio et al., 2016). Additionally, the benefits of alfalfa cultivation on biodiversity may differ between taxa. For example, in the case of pollinators, alfalfa does not necessarily fulfil nutritional requirements of all species due to their differences in foraging efficiency in relation to floral morphology (Rollin et al., 2013), which has been suggested to lead to more homogeneous insect communities (Forister, 2009). Similarly, alfalfa crops have been described to become ecological traps for certain species (Bretagnolle et al., 2011; Schlaich et al., 2015), or have negative agronomic effects due to increased likelihood of rodent pests (Luque-Larena et al., 2018) if they are not adequately managed.

Yet, no thorough assessment of the effects of alfalfa cultivation on biodiversity and how they vary in relation to taxon or environmental

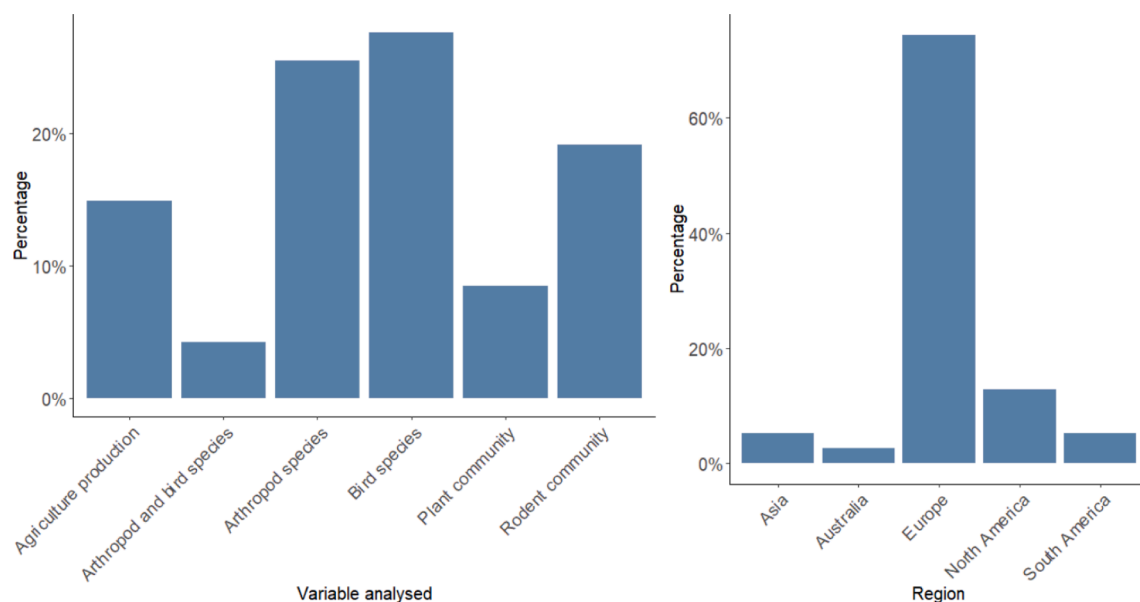


Fig. 1. Percentages of studies reviewed focused on agriculture production and the different taxa considered (left), and carried out in different regions of the world (right).

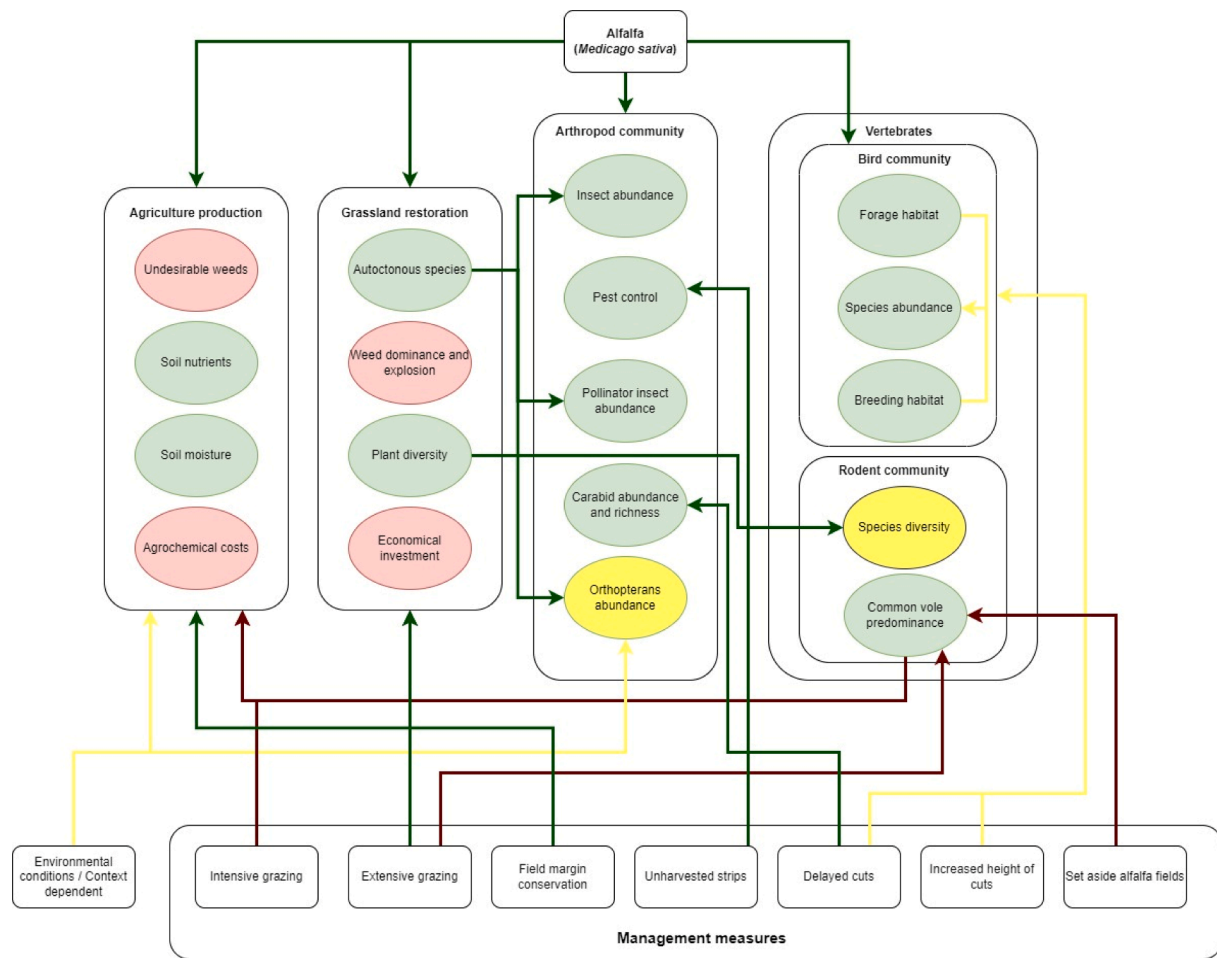


Fig. 2. Synthesis of relationships of alfalfa cultivation (and the main management measures involved) with agriculture production and biodiversity found in the literature, based on evidence reviewed (see Table A1). Green ellipses represent those aspects positively affected by (i.e. that benefit from) alfalfas, while the red ones represent the aspects negatively affected (e.g., the red ellipse around “undesirable weeds” indicates that those weeds are less common in alfalfa crops). Arrows represent relationships (green when positive and red when negative). The yellow ellipses and arrows mean that the relationship could be either positive or negative. When an arrow ends outside a box, the effect applies to all the elements inside.

context has been made so far. The aim of this systematic literature review is therefore to synthesize the information available about the agronomical benefits of alfalfa cultivation, as well as about the effects of alfalfa crops on biodiversity, with a focus on vascular plants, arthropods and vertebrates, and the factors regulating them, in order to evaluate their suitability as AES.

2. Methods

We followed the systematic review approach described in Pullin & Stewart (2006) in order to assess the suitability of alfalfa crops as AES. We searched for articles about the relationship of alfalfas with agriculture management and biodiversity published up to February 2021. We carried out a thorough search on Google Scholar and Web of Science (WOS) using the following keywords (and their combination): AES, agricultural intensification, agriculture, agri-environmental measures / policy / schemes / programmes, alfalfa, arthropods, biodiversity, birds, climate change, common agricultural / agriculture policy, conservation, conservation measures, fallow management, farmland biodiversity, forage crops, grassland, grassland management, habitat loss, insects, legume crops, lucerne, mammals, meadows, *Medicago sativa*, plant community, weed community, and wildlife. We used information in abstracts as a second filter to discard those articles not reporting any effect of alfalfa or its management (or differences between alfalfa and other crops) on biodiversity. In case of doubt, a full and careful read of

the paper was done. Finally, we also used the reference lists of the papers selected to check for other relevant literature that had not been previously identified with the web search.

3. Search results

Out of all the articles found in the literature research ($n = 101$), only 46 articles dealt specifically with alfalfa crops and their effects on agriculture or any of the three focal biological groups; all of them are detailed in table A1. Three other papers (Pimentel & Wheeler, 1973; Soroka & Otani, 2011; Augul & Al-Saffar, 2016), described the arthropod community associated to alfalfa crops; however, as they did not analyse any specific effect of alfalfa or its management, nor differences in their arthropod communities with other crops, they were not included in our final study subset (table A1).

The rest of discarded studies ($n = 52$) either analysed the effects of agriculture intensification on the environment or the effectiveness of AES measures, but without a focus on alfalfa crops. The issues discussed were more related to management regimes, policy implementation and suggestions to improve the AES measures rather than the habitat per se.

A high proportion of the studies about the effects of alfalfa focused on vertebrates: 15 (32.6%) related to steppe birds (two of them dealt with birds and arthropods in their analyses) and 9 (19.6%) to rodent communities. The second most analysed group was arthropods with 12 studies (26.1%), followed by plant communities 4 (8.7%) and

agriculture production with 6 (13%) studies (Fig. 1). However, only in 13 of these studies alfalfas were part of AES programmes to mitigate the negative consequences of agriculture intensification. These studies, as well as the main effect detected, are compiled in table A1.

From a geographical point of view, most of the studies compiled were carried out in Europe ($n = 34$), followed by North America ($n = 5$), South America and Asia ($n = 2$ in each area) and Australia ($n = 1$). Two of them were reviews not focused on a specific region (Fig. 1). We specify and discuss below the results of these papers grouped in four topics: the agronomical benefits of alfalfa cultivation; the role of alfalfa crops in restoring grassland plant communities; the relationship between alfalfa crops and arthropod communities; and the relationship of alfalfa cultivation with farmland vertebrates.

4. The agronomical benefits of alfalfa cultivation

Several studies have highlighted the benefits of alfalfa crops on agriculture production (e.g. Wiens et al., 2006; Li et al., 2015). One benefit arises from its use as green manure in the form of mulch: fields where alfalfa mulch was applied had more soil nutrients (Fribourg & Bartholomew, 1956), less undesirable weeds (Teasdale et al., 1991) and maintained soil moisture (Yunusa et al., 1994); overall, these effects increase with higher mulch applications (Wiens et al., 2006). Despite these positive effects on the application plot, the mulch itself may not be produced under a green management scheme, so that net conservation benefits of the whole production system (including mulch origin) are not assured.

Alfalfa in crop rotations provide several benefits in subsequent crops. Although it is not disease-free and some agrochemical treatment is usually required (Undersander & Cosgrove, 2011), the agronomical benefits of alfalfa cultivation also include the reduction of fertilizer and biocide costs (Fig. 2). Moreover, alfalfa crops reduce the presence of some plant species considered as detrimental for annual crops (Meiss et al., 2010a) and they present higher weed seed predation compared to other crops (Meiss et al., 2010c) which is beneficial to agriculture production. At the same time, alfalfa favours the presence of perennial broad-leaved species maintaining a considerable arable plant diversity useful for the ecosystem (Meiss et al., 2010b). Furthermore, sowing alfalfa modifies soil structure (Fuerst et al., 2009) and composition due to its ability to fix nitrogen and carbon from the atmosphere (Mortenson & Ingram, 2004; Syswerda & Robertson, 2014). In terms of production, cereals grown after alfalfa yield more per hectare due to alfalfa's capacity, shared with all legume crops, to enrich the soil with inorganic nitrogen (Li et al., 2015), which may imply a significant reduction of fertilizer application. The increase in cereal production after sowing a leguminous crop is significant after several years (Forster, 1999). In general, however, the effects of leguminous crops on subsequent ones vary according to local environmental conditions and the particular crop management applied (Kirkegaard et al., 2008). Climate constraints the benefits of alfalfa for cereal rotations: the positive effects are smaller in semiarid regions and in drier seasons (Kirkegaard et al., 2001; Gan et al., 2003); for example, in semiarid landscapes of central Spain it was considerably weaker than in other sites (López-Fando & Almendros, 1995).

Regarding climate, interannual weather variability combined with livestock pressure may affect the nutritional quality of alfalfa fields and other grasslands (Faria, 2019; Faria & Morales, 2020). Some alfalfa varieties, which are grazing-tolerant, can obtain benefits from livestock grazing; for example, it has been proved that winter grazing increases crop quality, reducing undesirable weeds and increasing protein content in the long term (Fig. 2; Chocarro et al., 2001). Also, sheep grazing can help controlling alfalfa weevil (*Hypera postica*) pests (Goosey, 2012), reducing the use of agrochemicals. On the other hand, the intensity of livestock grazing must be taken into account: researchers from Australia found that alfalfa plants cannot survive under intensive grazing management (Lodge, 1991), which prevents root carbohydrate storage

(Smith, 1962). In summary, extensive livestock grazing on alfalfa can be positive, from a production point of view, but also for the conservation of endangered species using this crop as foraging or breeding habitat such as little bustards (Faria et al., 2012).

5. Effects of alfalfas on grassland plant community restoration

Grassland plant communities have been eroded by agricultural intensification (Andreasen et al., 1996; José-María et al., 2010), with negative implications on their ecological and agronomic services (Clergue et al., 2009; Carmona et al. 2020). For this reason, grassland reestablishment is one of the main goals of AES to restore biodiversity and ecological processes (European Commission, 2017; Díaz et al., 2021). This restoration can follow technical land reclamation or spontaneous succession (Prach & Hobbs, 2008). The latter approach promotes higher natural values in the restored fields (Hodačová & Prach, 2003), favouring the colonization by species that are better adapted to local conditions (Vander Mijnsbrugge et al., 2010), as well as shelter for native animal species (Tropek et al., 2010), with lower investment than in technical restoration (Prach & Hobbs, 2008). On the other hand, it has some disadvantages due to its low predictability and the length of the process (Ruprecht, 2006; Prach & Hobbs, 2008). In this context, Török et al. (2011) found that sowing alfalfas after intensive management was a good option for grassland restoration in Hungary. Their results suggest that 10 years after sowing the alfalfa, the field was transformed into a grassland dominated by native perennial plants. Similar results have been found in China, where the sowing of alfalfa at the first stages of grassland restoration reduced weed dominance, and, ultimately, shortened the restoration process (Li et al., 2007). In the same area Zhou et al. (2019) found that alfalfas only increased plant diversity if combined with P (phosphorus) amendment and periodical mowing.

The use of legume mixtures for grassland plant community restorations has several advantages: the increase of available soil nitrogen resulting from the sowing of legumes (Li et al., 2015) increases plant diversity (Baer et al., 2003) and avoids the weed explosions associated to the use of nitrogen fertilisers (Graham, 2005). Beyhaut et al. (2014) found that the sowing of legumes (combined with rhizobia inoculation) during the first stages of plant restoration led to more diverse communities. In fact, the grassland plant community resulting from the inclusion of alfalfas in the restoration process tend to be dominated by biennial and perennial species, which are typical of later successional stages (Meiss et al., 2010b).

Li et al. (2015) analysed the potential effect of grass-legume combination (including *Medicago* sp.) on the amount of soil N, species recruitment and grassland productivity in Eurasian steppe grasslands. They found that the best results were obtained with a mixture of alfalfa (*Medicago sativa*) and a native species typical of steppe grasslands, false wheatgrass (*Leymus chinensis*), and that the introduction of both plants in semi-arid steppe grassland had ecological and economic advantages as an alternative to chemical fertilization.

The effectiveness of grassland plant community restoration may be improved if the use of alfalfa crops is combined with other management measures (Fig. 2). For example, field margins act as refuges and seed-banks for natural species that may eventually colonise alfalfa fields, so it is also crucial to protect these natural corridors (José-María et al., 2010). Likewise, moderate, and locally adapted livestock grazing may benefit plant diversity in alfalfa and other leguminous grasslands (Faria, 2019).

6. Alfalfa and arthropod communities

The decline of farmland arthropods has been related to direct effects of intensive agricultural practices at the field and landscape levels and indirect effects related to the simplification of plant communities associated with farmland intensification (Morris, 2000; Woodcock et al., 2013). Intensive management implies the use of agrochemicals such as pesticides and fertilizers. Pesticides (including insecticides) are

incompatible with high arthropod diversity, and fertilizers tend to generate a dense canopy unsuitable for some arthropod taxa (Marini et al., 2008). Moreover, Cizek et al. (2012) analysed the effects of different mowing regimes on the arthropod community along an intensification gradient. They found that butterflies, ground beetles, grasshoppers and spiders avoid those areas completely mown associated to intensive management. According to their conclusions, this effect is not only due to the direct mortality associated with harvest, but also to the low habitat suitability for these taxa of mown areas. This effect can be compensated by sowing improved crops that ensure green food resources for arthropods (Fig. 2; Morris, 2000; Littlewood et al., 2012).

Numerous studies have assessed the relationship between alfalfa and arthropod richness. For example, between 250 and 1,000 arthropod species have been found to be associated with alfalfa around the world, of which only 10–150 can cause damages to this crop, and few of them can be considered as pests (Pimentel & Wheeler, 1973; Alsuhaibani, 1996; Flanders and Radcliffe, 2013). Clemente-Orta et al. (2020) found that alfalfas in North-eastern Spain were positively correlated with higher insect abundance, especially aphids, their predators and herbivorous thrips during summer. Pons et al. (2005) showed that most aphidophagous predators in alfalfa crops of the same region were generalist rather than specialist predators. Forister (2009) found similar results in North America: the abundance of insects was considerably higher in alfalfas than in uncultivated fields with autochthonous vegetation, although diversity was similar in both habitat types. Increased presence of aphid predators in alfalfa was also useful to prevent pests in the surrounding fields (Clemente-Orta et al., 2020; Madeira et al., 2014; Núñez, 2002; Pons et al., 2005), but their mobility was found to be correlated with regular cutting of the alfalfas (Madeira et al., 2014; Madeira & Pons, 2015; di Lascio et al., 2016). Therefore, to control aphid outbreaks, it is necessary not only to sow alfalfa crops, but also to manage them with the appropriate cutting regime.

Among arthropods, insect pollinators are particularly relevant, as their services include not only benefits for wild plants, but also for agriculture production: 75% of crop species are pollinated by animals, primarily insects (e.g. Klein et al., 2007; Gallai et al., 2009; Catarino et al., 2019). Due to the global economic and environmental impact of pollinator declines, there are some AES specifically designed to favour their populations, focused on their habitat and resource requirements (Dicks et al., 2010). The latter are based on increasing availability of the flowers they feed on, including alfalfa or other legumes (Dicks et al., 2010). Rollin et al. (2013) found a significant preference for alfalfas in bumble bees, honeybees and wild bees over other agricultural and seminatural habitats in France. Further, these authors show that alfalfa crops outperform other crops such as sunflower as a means to favour farmland pollinators. However, they also emphasized that alfalfa flowers are not well suited for all bee species, as some species cannot forage on them depending on their tongue length, which constrains their ability to forage on corolla flowers (Michener, 2007; Kirk & Howes, 2012). Thus, only 30% of the genera of wild bees was reported on alfalfa crops (Rollin et al. 2013). For that reason, alfalfas are not always the optimal habitat for all bee species and AES should include both the sowing of alfalfa crops and the restoration of natural areas nearby to provide high floristic diversity in order to further increase pollinator richness (Rollin et al., 2013). In conclusion, the restoration of natural areas could be considered as an efficient AES since it helps wild plants (herbaceous and woody vegetation) as well as pollinators insects (Rollin et al., 2013), which would attract higher trophic-level taxa.

Carabids play a key role in agriculture ecosystems as they are natural pest enemies, as well as food for higher trophic levels (Thiele, 2012), and thus their presence implies higher ecosystem resilience (Hooper et al., 2005). Alfalfas are important for them, especially as overwintering habitats (Marrec et al., 2014), and their abundance and richness increase when alfalfas are managed under AES with delayed cuts (Caro et al., 2016). Another relevant group for farmland ecosystems is grasshoppers, especially as prey for birds (Barker, 2004), including species of

high conservation concern. For example, González del Portillo et al. (2021) found that both biomass and abundance of orthopterans was significantly higher in areas used by the rapidly declining little bustard (*Tetrax tetrax*) during the chick rearing period than in non-used areas, which indicates the importance of these insects for that species' reproductive performance. Some of the measures proposed to conserve orthopterans are the creation of new habitats to colonize or improve quality and connectivity between the potential habitats (Tscharntke & Brandl, 2004). In France, Badenhauer & Cordeau (2012) found that grasshoppers (Acrididae) prefer grass-dominated habitats rather than alfalfa crops. In fact, high densities of some legume species (including *M. sativa*) had a negative effect on these arthropods (Badenhauer et al., 2015). However, in north-western Spain, overall orthopteran (including grasshoppers but also crickets, Gryllidae) abundance tended to be higher in alfalfa fields than in other crops (González del Portillo et al., 2021), which suggests a context-dependent relationship between orthopterans and alfalfa, but also taxon-specific responses.

Overall, the dynamics of arthropod populations and, therefore, the possibility to become a pest, depend on the degree of specialization, dispersal abilities and trophic relationships of each species (Chaplin-Kramer et al., 2011). Biological pest control has shown ecological and economic advantages over chemical management: lower presence of resistance forms, better control of thrip pests, maintenance of harvest periods, lesser environmental impact, and smaller labour demand (van Lenteren, 2000), although traditional pest control is still widespread due to its more predictable cost/benefit ratio (Bán et al., 2010). Among the arthropod taxa found in Hungarian alfalfa fields (Bán et al., 2010), there were effective pest controllers according to literature: hemipterans of genus *Orius* (Rutledge & O'Neil, 2005), ladybugs (Grez et al., 2008), carabids (Grez et al., 2008) and spiders (Sunderland, 1999), which supports the integration of alfalfa crops in more sustainable pest control strategies.

Periodic harvesting has negative impacts in the pest control capacity of alfalfas due to direct mortality of predators (Casagrande & Stehr, 1973; Bishop & McKenzie, 1986), decreased prey densities and habitat quality (van den Bosch et al., 1966), as well as movement of individuals to more stable areas (Schaber et al., 1990). On the contrary, maintaining unharvested strips has positive effects against crop pests because it concentrates pest insects (Fig. 2; Hossain et al., 2000a) and it increases predator densities reducing the impact in harvested zones (Hossain et al., 2000b, 2001). Hossain et al. (2002) found that unharvested strips in alfalfa fields were considerably beneficial for crop pest control as they act as reservoirs of natural enemies. Similar conclusions were reached by Grez et al. (2008), showing that leaving unharvested alfalfa patches favoured greater densities of aphidophagous predators. Coccinellids and carabids, which are efficient aphid predators, can survive in small patches without interfering in their pest control capacity (Grez et al., 2007), so maintaining small uncut alfalfa areas in the landscape is a good alternative against the use of pesticides, and a good mechanism to maintain good abundances of these insects.

7. Alfalfa and vertebrates

Alfalfa crops may harbour a wide variety of vertebrates. Putnam et al. (2001) found 182 species of amphibians, birds, mammals, and reptiles that used this crop regularly in California, which means 27% of the vertebrate species in that State. The most abundant group was birds, followed by mammals. However, during the survey only one amphibian species and six reptile species were found. This bias is also represented in our results since all the studies found reported on birds or rodents (Fig. 1).

7.1. Birds

Several studies have shown the importance of alfalfa for birds due to the food resources they provide and as habitat for cover and nesting. A

study in Californian crops showed that only rice crops harboured more bird species than alfalfa crops (Hartman & Kyle, 2010). In Europe, many species such as skylark (*Alauda arvensis*), corn bunting (*Emberiza calandra*), whinchat (*Saxicola rubetra*) and quail (*Coturnix coturnix*) prefer alfalfa crops to breed over other agricultural habitats (Fischer et al., 2006; Stein-Bachinger & Fuchs, 2012). However, not all farmland bird species seem to benefit from alfalfa crops, which depends on their foraging and breeding requirements. In North America, densities of some grassland passerines like lark bunting (*Calamospiza melanocorys*), grasshopper sparrow (*Ammodramus savannarum*), savannah sparrow (*Passerculus sandwichensis*), brown-headed cowbird (*Molothrus ater*) and western meadowlark (*Sturnella neglecta*) declined with increasing legume cover, while abundance of clay-coloured sparrow (*Spizella pallida*) was positively correlated with legume availability (mainly *M. sativa* and *Melilotus* spp as a minor crop; Johnson & Schwartz, 1993).

These differences may be related to the different resources sought by birds within alfalfas, and the mechanism by which they are influenced by those resources. The occupation of a particular habitat by a particular species does not usually depend on the habitat *per se*, but may be mainly related to the amount and quality of resources it harbours (Butler & Norris, 2013; Ponce et al., 2014). The combination of alfalfa with other agricultural habitats in the landscape may contribute to enhance resource availability for birds through their influence on plants or insects (Fig. 2). Thus, measures focused on the improvement of arthropod populations are expected to benefit farmland birds, as most of them need invertebrates to rear their chicks (Connelly et al., 2000; Holland et al., 2006). For example, the sage grouse (*Centrocercus urophasianus*) in North America uses alfalfa crops to rear their chicks due to the high abundance of insects (Connelly et al., 2000). Similar results were found by Ursúa et al. (2005) in irrigated alfalfas; their results showed that lesser kestrels (*Falco naumanni*) used this crop after harvest as foraging habitat during the chick-rearing period. Similarly, the link between alfalfas and vole abundance (see also below) implies that alfalfas are a good foraging habitat for many vole-eating birds such as Montagu's harrier (*Circus pygargus*) or marsh harriers (*C. aeruginosus*, Cardador & Mañosa 2011; Schlaich et al., 2015). In any case, a study about the efficiency of alfalfa crops as AES for Montagu's harrier conservation in the Netherlands (Schlaich et al., 2015) showed that harriers preferred harvested crops over others with higher prey (mainly voles) density, concluding that prey availability (favoured by cleared vegetation) is more important than abundance and that AES based on alfalfa crops should include specific harvest schemes in order to obtain the most positive results.

On the other hand, alfalfa fields can turn into ecological traps for farmland birds nesting within the plots if their mowing regime is not adapted to their breeding phenology (Stein-Bachinger & Fuchs, 2012; Bretagnolle et al., 2018). Therefore, AES based on alfalfa crops should include an appropriate management with measures such as non-inversion tillage (with positive effects on bird food chain; Cunningham et al., 2004) or the timing of harvests (Bretagnolle et al., 2018) to reduce nest destruction and improve chick's survival. In this context, Stein-Bachinger & Fuchs (2012) demonstrated that by modifying harvesting methodologies (delaying or increasing the height of cuts) few skylark nests in alfalfa crops were affected by mowing; however, a delayed first cut will not be suitable for all species. In the same study, yellow wagtail (*Motacilla flava*), whinchat (*Saxicola rubetra*) and corn bunting (*Miliaria calandra*) did not benefit from a later cut, but for these species an average cut height of 14 cm would be more beneficial.

Alfalfa and other leguminous crops have been used in different European countries as AES to improve the status of endangered farmland birds. This strategy has been successful in the case of bustards in France and Spain (Llusia & Oñate, 2005; Bretagnolle et al., 2011). The growth of great bustard (*Otis tarda*) populations in the Northern Spanish Plateau from 1998 to 2008 was positively correlated with the increase in the extent of land dedicated to rain-fed legumes, including alfalfa (Martín et al., 2012). Bretagnolle et al. (2011) studied the effects of AES (20% of which were alfalfas) on little bustards (*Tetrax tetrax*) and found that

weed richness and grasshopper abundance were higher in those alfalfas sown and maintained by AES, which was reflected in little bustard population growth. However, Concepción & Díaz (2019) found that AES linked to legumes (grain and forage species) were not always beneficial to farmland birds, requiring a regional focus on specific targets. Similarly, Sanz-Pérez et al. (2019) proved that the best landscape for steppe birds is a mosaic, in which fallows are specifically managed in order to cover the requirements of most bird species in the community. Their results showed that little bustards, stone curlew (*Burhinus oedicnemus*) and calandra lark (*Melanocorypha calandra*) benefit the most from fallow shallow tillage and vegetation cutting at low height, while the presence of alfalfa in areas where high quality fallows occur had little positive additive, or even negative effects on these species abundance in the breeding season. These different results highlight the importance of designing measures according to each site's conditions and population requirements.

7.2. Mammals

One mammal group closely linked to farmland systems is rodents, also affected by agriculture intensification, whose abundance, species richness and diversity increase in heterogeneous landscapes (Fischer et al., 2011; Janova et al., 2011). Small mammal communities are composed of multiple rodent species, but their relative abundance depends on the crops analysed and their surrounding habitats. For example, in Europe, crops characterized by high green biomass production, such as alfalfa, are dominated by common voles (*Microtus arvalis*), while those rich in seed food are more suitable for mice (genera *Apodemus* and *Mus*, Heroldová et al., 2005).

Predominance in the rodent community depends on the crop analysed. Common voles are far more abundant in alfalfa fields, whereas wood mice (*Apodemus sylvaticus*) do not show a strong preference for one particular crop and use all habitats available more uniformly (Heroldová et al., 2005; Heroldová et al., 2007; Santamaría et al., 2019). In the latter species, space use is more related to the vegetation phenology rather than habitat *per se* (Janova & Heroldová, 2016). Some studies have pointed out alfalfas as the optimal habitat for common voles (Janova et al., 2011; Jacob et al., 2014; Jareño et al., 2015; Rodríguez-Pastor et al., 2016). In fact, its range expansion in the Iberian Peninsula is associated to the increase of alfalfas and other irrigating crops (Jareño et al., 2015). Regarding community diversity, studies found low diversity levels in alfalfas due to vole dominance (Heroldová et al., 2007), although these values were higher than in other crops due to the long-lasting vegetation cover (Heroldová et al., 2005; Janova & Heroldová, 2016).

Like for birds, the rodent community composition in alfalfas is strongly influenced by management (Fig. 2). For example, when alfalfa fields in the Czech Republic were abandoned to succession, the dominance of common voles weakened due to increasing resource abundance and diversity, and other species increased their relative abundance (Heroldová et al., 2005). A similar study in Romania found that rodent communities in alfalfas were more similar to those of grasslands formed by annual crops (Benedek and Sirbu, 2018).

The relationship between alfalfas and rodents has influence on vole-eating predators (as mentioned above), but also influences the farmland environment. Rodents are the most important vertebrate farmland pests, causing considerable economic, environmental and health impacts (Singleton et al., 2010; Gebhardt et al., 2011). In the case of common voles, the dominant rodent species in alfalfas, outbreaks occur cyclically every 3–5 years (Cornulier et al., 2013). Their impact on alfalfa crops under outbreaks is well-documented (Tertil, 1977), causing an average reduction of 51% in field productivity (Fig. 2). Overall, vole outbreaks produce damages in millions of farmland hectares (under different crops) in the European Union (Luque-Larena et al., 2013). On the other hand, rodent population growth is limited by livestock grazing (Torre et al., 2007) and natural predators like Montagu's harrier (Koks et al.,

Table A1

Summary of the articles about alfalfa crops (or legumes if alfalfas were included among them) and their relationship with biodiversity. Each article's main focus (e.g. agriculture production, particular taxon or taxa) is described. Agri: if any effect was detected on agriculture production (Yes or blank); Plants: if any effect was detected on plant community (Yes or blank); Arthr: if any effect was detected on arthropods community (Yes or blank); Vert: if any effect was detected on vertebrates (Yes or blank); AES: whether or not the alfalfa crops were under agri-environmental schemes (Yes or blank).

N°	Reference	Country	Focus	Agri	Plants	Arthr	Vert	AES	Main effect detected
1	Peoples et al., (2019)	–	Agriculture and biodiversity	Yes		Yes	Yes		The inclusion of legume crops in agriculture rotations implies a reduction in the use of agrochemicals and non-renewable energy resources, greenhouse gases production and the increase of soil organic C.
2	Lloveras, (1999)	–	Alfalfa crops	Yes					A review about the effects of alfalfa crop on the environment, with a focus on agriculture.
3	Pearson et al. (2008)	United States of America	Arthropod community	Yes		Yes			Fertilizer implementations on alfalfa crops have positive effects on plant quality and abundance, leading to a more diverse and abundant community of herbivore and predator insects.
4	Greze et al. (2004)	Chile	Coleopterans			Yes			Beetle abundance was higher (although not significant) in fragmented than in non-fragmented alfalfa crops. Fragmentation had not a negative impact <i>per se</i> but depended on the landscape and the taxa analysed.
5	Meiss et al. (2010a, b and c)	France	Weed community	Yes	Yes				Alfalfa can be used to reduce herbicides, due to its ability to suppress some plant species (considered as problematic for agriculture) and favours the presence of perennial broad-leaved species. Alfalfas present higher weed seed predation.
6	Török et al., (2011)	Hungary	Grassland in loess		Yes				Alfalfas can be used to accelerate grassland restoration with a lower budget than technical reclamation.
7	Wiens et al., (2006)	Canada	Wheat	Yes					Alfalfa mulch has overall positive effects in wheat crops: weed suppression, moisture conservation, increased yield, N and protein concentration in grains.
8	Zhou et al., (2019)	China	Grassland	Yes	Yes				Seeding alfalfas under the appropriated management of Phosphorus amendments and mowing improve both forage production and plant community restoration.
9	Clemente-Orta et al., (2020)	Spain	Insects			Yes			Alfalfa fields increase abundance of aphids, aphid predators and herbivore thrips in maize crops.
10	Rollin et al., (2013)	France	Hymenopteran (Honeybees, bumble bees and wild bees)			Yes		Yes	The groups analysed showed a preference for alfalfa, despite the crop not being the most suited for their nutritional requirements.
11	Caro et al., (2016)	France	Carabids			Yes		Yes	Among the different AES applied in alfalfa crops, only delayed cuts have positive effects in carabids communities.
12	Marrec et al. (2014)	France	Carabids (<i>Poecilus cupreus</i> and <i>Brachinus sclopeta</i>)			Yes			Alfalfas are important as wintering habitat for <i>Poecilus cupreus</i> , but not for <i>Brachinus sclopeta</i> .
13	Badenhausser & Cordeau, (2012), Badenhausser et al., (2012)	France	Grasshoppers (Orthoptera)			Yes			Gomphocerinae are more abundant in grass-dominant mixtures than in mixtures with legumes.
14	Hossain et al., (2002)	Australia	Insects (pests and their natural enemies)			Yes			Unharvested alfalfa strips act as refuge for pest predators. The most appropriate management to potentiate pest predator community is dividing alfalfa crops into two halves with different growth stages.
15	Bán et al., (2010)	Hungary	Insects (pest predators)			Yes			Mowing alfalfa and nettle patches are the cheapest and simplest way to fight against crop pests.
16	Greze et al., (2008)	Chile	Coccinellids Carabids			Yes			In general, coccinellid and carabid species analysed are not affected by habitat loss nor fragmentation. Their densities increased if unharvested blocks were maintained in alfalfa fields.
17	Forister, (2009)	North America	Insect communities			Yes			Arthropod richness and abundance are higher in alfalfas than in native habitats. However, communities are more homogeneous in alfalfas.
18	Pons et al., (2005)	Spain	Aphidofagous insects			Yes			The aphidofagous community is dominated by generalist predators that move between different crops looking for aphids.
19	Bretagnolle et al., (2011)	France	Little bustard (<i>Tetrax tetrax</i>)			Yes	Yes	Yes	Alfalfa crops under AES management, which have higher weed diversity and grasshopper abundance, increase little bustard productivity.
20	Hartman & Kyle, (2010)	California	Bird species				Yes		Alfalfas are crucial as food reservoirs to maintain bird wildlife due to the loss of the native wetlands.
21	Wood et al., (2013)	England	Pollinators and gamebirds			Yes	Yes	Yes	Legume mixed crops harbour more pollinator abundance and diversity than surrounding habitats.

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Table A1 (continued)

N°	Reference	Country	Focus	Agric	Plants	Arthr	Vert	AES	Main effect detected
22	Stein-Bachinger & Fuchs, (2012)	Germany	Passerines				Yes	Yes	However, it is necessary to reduce their height and density to make these food resources available for birds. Legume crops are an attractive habitat for birds, but due to their agriculture management can become an ecological trap. Modifying the production regime (timing of cuts, height of cuts and unmown strips) can increase their breeding success.
23	Johnson & Schwartz, (1993)	North America	Grassland birds				Yes	Yes	Each species responded differently according to the conservation reserve program. Some species appear to be positively correlated to legume crops, while others show the opposite trend.
24	Ponce et al., (2014)	Spain	Steppe birds		Yes	Yes	Yes	Yes	AES efficiency relies on the amount of food resources available more than on the habitat <i>per se</i> and should be seasonally focused according to bird phenology.
25	Cardador et al., (2015)	Spain	Little bustard (<i>Tetrax tetrax</i>) Stone curlew (<i>Burhinus oedipnemus</i>) Calandra lark (<i>Melanocorypha calandra</i>)				Yes		Between different future scenarios of land use change, the increase of grain legume crops, could increase habitat sustainability, specially for calandra lark and little bustard.
26	Rodríguez-Pastor et al., (2016)	Spain	Common vole (<i>Microtus arvalis</i>)				Yes		Field margins and alfalfas harbour most common vole populations due to the stability and food resources provided.
27	Jareño et al., (2015)	Spain	Common vole (<i>Microtus arvalis</i>)				Yes		Alfalfa has played a key role in common vole expansion in Iberian Peninsula because this habitat provides voles with refuge, food, and stability.
28	Li et al. (2007)	China	Plant community		Yes				<i>Medicago sativa</i> increase the amount of soil C and N. Its presence avoids weed dominance at the first stages of grassland restoration and shortens the process.
29	Ursúa et al., (2005)	Spain	Lesser kestrel (<i>Falco naumanni</i>)				Yes		Irrigated alfalfa crops offer the suitable forage habitat for lesser kestrel, being highly selected once harvested.
30	Bretagnolle et al., (2018)	France	Little bustard (<i>Tetrax tetrax</i>)				Yes	Yes	In intensive farmland, little bustard females choose alfalfas as breeding habitat, which can become an ecological trap due to harvest timing.
31	Martín et al., (2012)	Spain	Great bustard (<i>Otis tarda</i>)				Yes	Yes	The increase in great bustard populations is linked to the spread of unirrigated leguminous (alfalfa among them), which are, at least partly, maintained by AES.
32	Tryjanowski, (2000)	Poland	Passerines				Yes		Blackbird (<i>Turdus merula</i>) and white wagtail (<i>Motacilla alba</i>) decrease is related to the structure of crops. They are affected by the reduction of alfalfa fields which they use as forage habitat.
33	Barreiro-Hurlé et al., (2010)	Spain	AES contracts					Yes	Alfalfas (irrigated or not) decrease profit loss when are sown as AES.
34	Sanz-Pérez et al., (2019)	Spain	Steppe birds				Yes	Yes	Alfalfa crops had a small positive effect on stone curlew (<i>Burhinus oedipnemus</i>) occurrence and negative effect on little bustards (<i>Tetrax tetrax</i>) and calandra lark (<i>Melanocorypha calandra</i>).
35	Concepción & Díaz, (2019)	Spain	Bird abundance and richness				Yes	Yes	In spring, legumes show overall positive relationship with bird communities. However, in winter their positive effect was only detected for open land species.
36	Schlaich et al., (2015)	Netherlands	Montagu's harriers (<i>Circus pygargus</i>)				Yes	Yes	Alfalfa strips provide more food resources to Montagu's harriers than other crops and were highly selected after harvest.
37	González del Portillo et al., (2021)	Spain	Arthropods and little bustard (<i>Tetrax tetrax</i>)			Yes	Yes		Alfalfa fields harbour high densities of arthropods, so they play a crucial role during little bustard breeding period.
38	Heroldová et al., (2007)	Czech Republic	Small mammal community				Yes		Rodent community were less diverse in alfalfas than in other crops.
39	Benedek & Sîrbu, (2018)	Romania	Small mammal community				Yes		Rodent assemblages of alfalfas were the most similar to those of grassland communities.
40	Heroldová et al., (2005)	Czech Republic	Rodent community				Yes		Alfalfa rodent communities change when the field is set-aside, due a change in the food resources available.
41	Janova & Heroldová, (2016)	Czech Republic	Rodent community				Yes		Multiannual crops show higher diversity than annual ones. Alfalfas were dominated by common voles.
42	Santamaría et al., (2019)	Spain	Common vole (<i>Microtus arvalis</i>)				Yes		

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Table A1 (continued)

N°	Reference	Country	Focus	Agric	Plants	Arthr	Vert	AES	Main effect detected
43	Tertil, (1977)	Poland	Common voles (<i>Microtus arvalis</i>)	Yes			Yes		Common voles were more abundant, and their populations showed less fluctuations in alfalfa crops.
44	Janova et al., (2011)	Czech Republic	Rodent community				Yes		Alfalfa and winter wheat productivity were reduced by high abundance of common vole populations. Alfalfas were dominated by common voles, especially during autumn. This result contrasts with the low abundances found in spring for the rest of species.

2007). For example, cattle have been shown to modify vegetation structure with impact on small mammals due to the reduction of food available and the compaction of soil (Torre et al., 2007). Taking this into account, the inclusion of grazing livestock as a green measure in extensive regime could help reduce the agronomic impacts of common vole outbreaks.

8. Conclusions and perspectives

At the global level, the amount of land devoted to alfalfa is increasing year by year, as well its yield. This crop may provide many ecosystem services (Syswerda & Robertson, 2014; Fernández et al., 2019): provisioning (crop production) and regulating (related with environmental stability and quality), as well as supporting (responsible for the ecosystem functional capacities) and cultural (related with human aesthetic appreciation and conservation of flagstaff endangered species). As depicted in Fig. 2, these service categories are not independent of one another; in fact, one of the challenges of current agriculture is optimizing the trade-off between provisioning and the rest of services (Power, 2010). Nevertheless, as pointed out by different authors, a win-win scenario is possible, in which a biodiversity-friendly management of agroecosystems can maintain their services (regulating, supporting and cultural) without a significant reduction of yield (Catarino et al., 2019; Tarjuelo et al., 2020).

In relation to the capacity of alfalfas to support wildlife, the information found showed an overall positive relationship for most of the groups analysed. This leguminous crop has proved useful for plant community restoration, due to its lower need of agrochemicals (Graham, 2005), and the increase of native species abundance (Wilson & Gerry, 1995) and diversity (Baer et al., 2003). These effects have positive impacts for upper trophic levels. In fact, under an extensive management arthropods and vertebrates increased (Morris, 2000; Stein-Bachinger & Fuchs, 2012; Woodcock et al., 2013). Although generalizations should be made with caution, our review highlights that the implementation of AES on alfalfa crops could benefit endangered species such as the little bustard or Montagu's harrier but only if harvest operations take breeding periods into account, and management of tilling is also organized spatially so that the availability of prey (insects or voles) is optimized.

However, due to its high nutritional values, and considering that the establishment and growth of wildlife populations is more related to the trophic offer than habitat *per se* (Butler & Norris, 2013; Schlaich et al., 2015), alfalfa crops are susceptible to harbour pests (Gebhardt et al., 2011; Flanders & Radcliffe, 2013). The inclusion of livestock grazing in agricultural systems can be an appropriate measure to limit rodent demographic explosions (Torre et al., 2007), at least combined with other measures. However little is known about its effect on other groups. In any case, it is crucial to combine conservation measures with monitoring programs to ensure the green goals that AESs should reach (Kleijn & Sutherland, 2003; Pe'er et al., 2020).

Although we may have not found all existing studies about the relationship between alfalfas and biodiversity (particularly those included in grey literature), we consider our review to be reasonably representative of the evidence available. However, the unequal

geographical distribution of available studies (Fig. 1) implies that the conclusions obtained in the present review are constrained by this bias. Our review also highlights knowledge gaps about the potential effect of alfalfas on farmland biodiversity, and more studies targeting amphibians and reptiles, as well as non-rodent mammals are needed. Another promising approach would be the analysis of relationships with alfalfa across trophic levels or high-level taxonomical categories, found in only two publications (see Appendix Table 1). Finally, deepening our knowledge on the ecosystem services associated to alfalfa crops in interaction with the effects of climate change should be encouraged.

In synthesis, alfalfas can be of high value for biodiversity conservation in farmland and considered as a restoration tool for areas degraded by agricultural intensification. These features plus the increase in agriculture production that alfalfas imply (Fig. 2), make them an appropriate AES. On the other hand, our review also highlights that the management of this crop may have both positive and negative effects on various taxa, as depicted in Fig. 2. More studies are necessary about the relationship between the management of alfalfa as AES and biodiversity. For example, few studies analysed the influence of alfalfa grazing regimes, especially on arthropods and birds. From a geographical point of view, the vast majority of the studies found were developed in Europe, whereas few of them were conducted in Asia, Africa or South America (Fig. 1). This would have to be taken into consideration when using published results for designing conservation measures in understudied areas. Table A1.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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