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Wild herbaceous vegetation in agroforestry systems: an asset that should not be overlooked

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Herbaceous vegetation grows spontaneously at the foot of woody plants and becomes omnipresent in the absence of soil tillage. From alley-cropping agroforestry to bocage landscapes, these 'little' plants are proving to be a major asset for the agroecological transition. Through the presentation of key results, this article explains how to take advantage of the wild herbaceous vegetation in agroforestry systems, in order to conserve biodiversity and promote sustainable agricultural production.

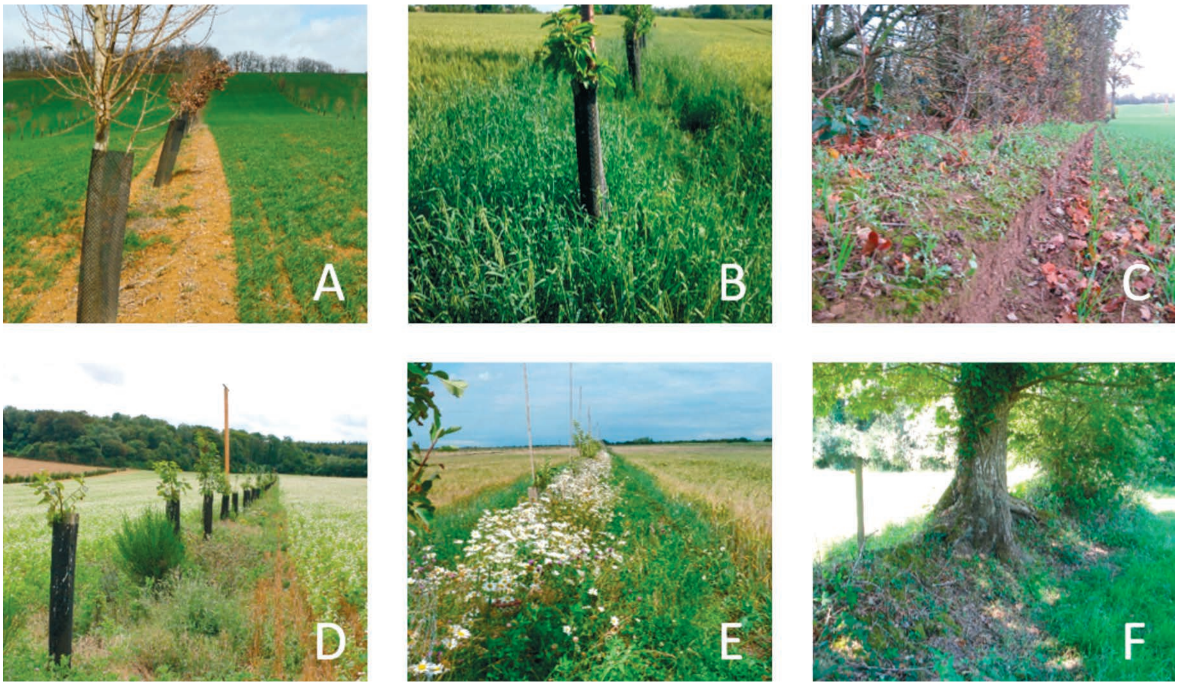
What is agroforestry? Why associate trees with arable crops?

With the rise of intensive and chemical-based agriculture, the following paradigm has emerged: forests on one side, arable fields on the other. However, in many parts of the world, humans historically used trees in agriculture. Agroforestry, which is a land use management system associating trees and shrubs with arable crops or pastures, has experienced a strong revival of interest over the past two decades (Dupraz and Liagre, 2011; Castle *et al.*, 2022). Agroforestry allows for diversification of production, through fruits and timber or fuelwood for example. Trees and shrubs also provide many ecosystem services: soil and water protection (reducing erosion and runoff), shade for livestock, carbon sequestration, and biodiversity conservation, including ecosystem-service providers (pollinators, natural enemies of pests, decomposers of organic matter). Agroforestry systems also provide important cultural services: aesthetics, inspiration, education and leisure (walks, nature observation, etc.). Finally, agroforestry could enhance resistance and/or resilience of agroecosystems to climate change, extreme climatic events (drought, storms), biological invasions and pest outbreaks. Trees and shrubs are the main focus in agroforestry systems, but it is likely that wild herbaceous vegetation also plays an important role in the provision of ecosystem services, provided that good management practices are adopted (Figure 1). In this article, we focus on the role of wild herbaceous vegetation in the preservation of invertebrates, including ecosystem-service providers.

Wild herbaceous vegetation of hedgerows in bocage landscapes

Hedgerows are among the most stable refugia for biodiversity in agricultural landscapes, providing habitats and food resources for many living organisms. Unfortunately, the intensification of agriculture has led to a massive removal of hedgerows, perceived as constraints or even threats to agricultural production. In Brittany, 50% of hedgerows disappeared between 1960 and 1983, and 12% more between 1996 and 2008. Since 1950, 750 000 kilometres of hedgerows have been removed in France due to land consolidation and the decline of livestock farming, according to the French Office of Biodiversity (OFB). The destruction of habitats was associated with massive use of pesticides and chemical fertilizers, drifting from arable fields and undermining the environmental quality of remaining hedgerows. Recent European studies have reported an increase in competitive and nitrophilous plant species in hedgerows in the last decades, presumably due to eutrophication and lack of hedgerow management. In addition, farmers sometimes cover the ground with

Figure ❶ – Wild herbaceous vegetation in agroforestry systems can take on many forms, and much depends on management practices. (A) An understory vegetation strip sprayed with herbicides, to which only a few weedy species can survive. (B) A vegetation strip colonized by wild oats (*Avena fatua*) and cleavers (*Galium aparine*), which benefit from soil eutrophication due to chemical fertilizer drift. (C) A hedgerow whose width is restricted to the maximum by soil tillage, which promotes the establishment of weeds over more disturbance-sensitive species. (D) A fairly wide vegetation strip (about 4 m) harbouring high plant diversity. (E) A vegetation strip harbouring a mixture of wild and sown plants that provides floral resources for ecosystem service providers. (F) A hedgerow planted on a bank that provides habitats for forest plant species and wildlife.
Photo credits: (A) J. Poulmarc'h, (B) D. Mézière, (C) S. Boinot, (D) L. Vervuut, (E) J. Smith, (F) A. Alignier.



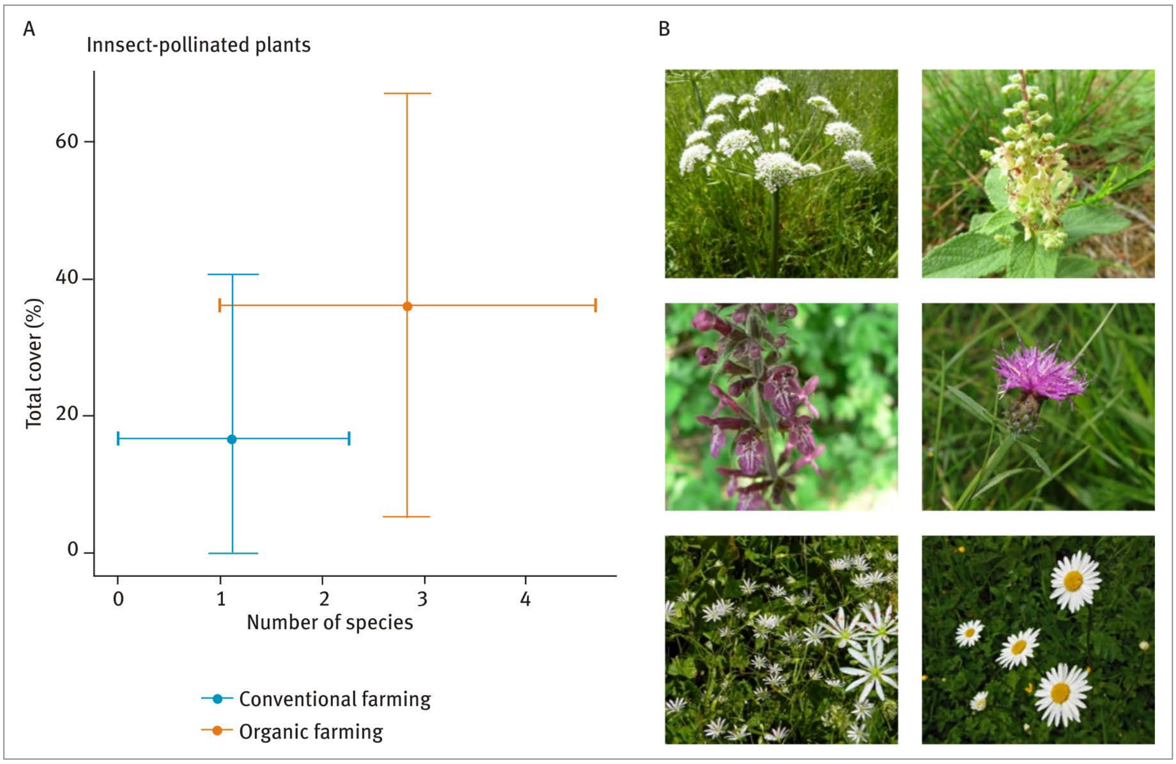
plastic tarps or spray herbicides directly at the base of the hedge to prevent herbaceous flora from growing, as they fear hedgerows can harbour troublesome weeds. Not only the destruction but also the alteration of the herbaceous vegetation of hedgerows undermine their potential to preserve biodiversity. A study conducted by the French research unit "Biodiversity, Agroecology and Landscape Management" of INRAE Rennes (Brittany) has highlighted local and landscape-scale drivers that promote plant diversity in hedgerows and prevent their colonization by troublesome weeds (Boinot and Alignier, 2022). Vegetation surveys were conducted in 40 hedgerows in the "Zone Atelier Armorique", south of Rennes. Hedgerows were adjoining conventional or organic fields (n = 20 hedgerows per farming system). In addition, hedgerows were located along two independent landscape gradients of organic farming and wooded elements cover. The relative effects of hedgerow features (e.g. height, width, tree cover), adjacent farming practices (conventional vs. organic farming) and landscape context were quantified. Among all the factors considered, organic farming at local scale was the main driver for preserving hedgerow plant diversity. Notably, the abundance of insect-pollinated plants doubled and their number of species tripled in hedgerows adjoining organic fields (Figure ❷).

Agrochemical drift in hedgerows adjoining conventional fields favours nitrophilous and competitive grasses such as sterile brome (*Anisantha sterilis*) and wild oats (*Avena fatua*). In addition, previous studies showed that organic farming favours the preservation of pollinators, through the absence of pesticide treatments, but also more complex crop rotations and more diverse weed communities providing abundant and diverse floral resources. Pollinators ensure the reproduction of most plant species, and would thus contribute to the maintenance of plant diversity in hedgerows adjoining organic fields. Consequently, hedgerows adjoining organic fields probably harbour a higher diversity of ecosystem service providers (e.g. wild bees, hoverflies, ladybugs, parasitoid wasps, etc.) which benefit from abundant and diversified floral resources.

Wild herbaceous vegetation of understory vegetation strips and associated invertebrates in alley cropping agroforestry fields

Much has been written about the massive decline of insects in recent years. Agricultural intensification is one of the main causes, through the drastic reduction of crop diversity, the massive use of agrochemicals and the destruction of semi-natural habitats such as hedgerows. Semi-natural habitats are particularly important for invertebrates; they provide refugia from agricultural disturbances and perennial sites for feeding, reproducing and overwintering. In this regard, the success of the overwintering determines the abundance and diversity of invertebrates in arable fields in spring, with strong implications for the biological control of pests (an abun-

**Figure ❷ – A) Insect-pollinated plants are on average twice as abundant and three times as diverse in hedgerows adjoining organic fields, compared with hedgerows adjoining conventional fields. (B) Examples of plant species that benefit from the absence of chemical disturbances, and presumably from better pollinator preservation in organic fields (from left to right and top to bottom): *Oenanthe crocata*, *Teucrium scorodonia*, *Stachys sylvatica*, *Centaurea nigra*, *Stellaria graminea* and *Leucanthemum vulgare*. These species provide a diversity of floral resources that favour ecosystem service providers such as pollinators, but also many natural enemies of pests and decomposers of organic matter, which feed on pollen and/or nectar at some point in their life cycle.
Photo credits: M. Menand, P. Guillaumeau, M. Menand, J.-L. Gorremans, J.-L. Cheype, G. Lecq (licence CC BY-SA *via* Tela Botanica). Data source: Boinot and Alignier (2022).**

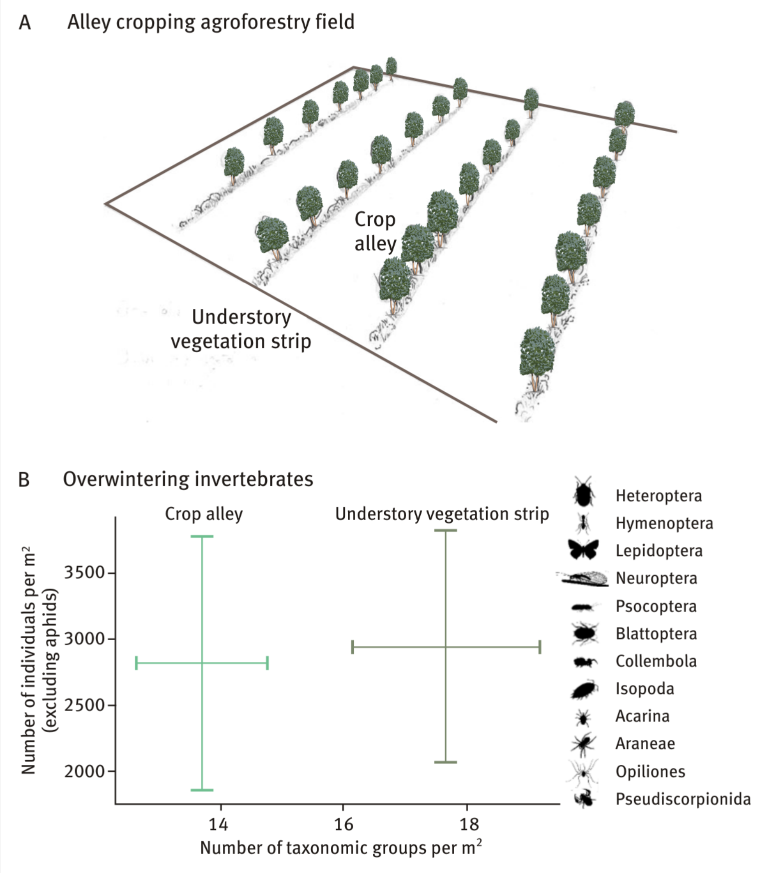


dant and diversified community of predators will have a stronger impact on a wide range of pests). Alley cropping agroforestry is a great opportunity for the reintegration of semi-natural habitats in arable fields. In the absence of soil tillage and crop sowing under the trees, herbaceous vegetation grows and forms understory strips. A study conducted by the French research unit "Agrosystèmes Biodiversifiés" of INRAE Montpellier on seven agroforestry fields in the Restinclières Estate (Hérault) assessed the importance of understory vegetation strips for invertebrate overwintering, compared with crop alleys that are frequently disturbed by soil tillage. Emergence traps were set up in the agroforestry fields to sample invertebrates overwintering in the soil or the vegetation. The study revealed that understory vegetation strips are major overwintering sites for invertebrates (Figure ❸).

Indeed, 55% of the taxonomic groups observed (n = 12 / 22) were significantly more abundant in the understory vegetation strips than in the crop alleys, often with very high differences in abundance. These groups include decomposers of organic matter (cockroaches, springtails, and woodlice), predators or parasitoids of pests (neuropterans, hymenoptera, spiders, opiliones). Other groups have ambivalent functions, containing both pests and pollinators or predators (e.g. bugs, butterflies, mites). In contrast, only 14% of the groups (beetles, homoptera, and myriapods) were more abundant in crop alleys. More detailed identification of invertebrates within each group shows that the dominant crop pests (aphids, slugs and wireworms) overwintered mostly in crop alleys, suggesting that understory vegetation strips do not promote the overwintering of pests and the colonization of cropland in spring.

A second study conducted by the same team highlighted the importance of understory vegetation strips in promoting the spring activity of generalist predators (i.e., consuming a diversity of prey). Carabids and cursorial spiders were sampled in winter cereals (six pairs of agroforestry and pure crop fields, half under conventional farming and half under organic farming) in the Gers department. Paired fields (agroforestry vs. pure crop control) were located within the same perimeter, similar in terms of pedo-climatic conditions and surrounding land use. Each pair of fields was cultivated by the same farmer, with similar crop management over the three years preceding the survey. The study revealed that the effect of understory vegetation strips on generalist predator communities differed depending on the farming system. In organic fields, understory vegetation strips strongly favoured the activity and diversity of granivorous and omnivorous carabids in crop alleys (Figure ❹), which contribute to the biological control of pests, especially weeds. In

Figure ❸ – (A) In agroforestry fields under conventional farming, understory vegetation strips are relatively stable and undisturbed habitats compared with crop alleys. (B) Understory vegetation strips are major overwintering sites for invertebrates (taxonomic groups that are more abundant in understory vegetation strips are listed on the right side of the graph). The total number of individuals per square meter is calculated excluding aphids, which reach overwhelming proportions under emergence traps in crop alleys. Data source: Boinot *et al.* (2019).



contrast, in conventional fields, understory vegetation strips reduced the activity of predators in crop alleys, which can be explained by two main mechanisms. First, understory vegetation strips may hamper the movement of dominant predators that overwinter and forage in disturbed and open environments. This is the case for small and carnivorous carabids (e.g., Anchomenus dorsalis and Trechus spp.), whose abundance was reduced by 50% in crop alleys compared with pure crop controls. Second, seed-eating carabids and cursorial spiders, which overwinter mostly in semi-natural habitats, probably foraged in understory vegetation strips where plant and invertebrate resources are more abundant and diversified than in crop alleys, resulting in a “retention” effect.

These results show that trees and associated herbaceous vegetation are sometimes insufficient to promote the activity of generalist arthropod predators in cropland. In this case, crop habitats themselves must be diversified, either by preserving weed diversity or by using crop mixtures.

How to take advantage of wild herbaceous vegetation in agroforestry?

This article shows that organic farmers greatly benefit from the presence of semi-natural habitats around or within arable fields. Indeed, on the one hand, the wild herbaceous vegetation of linear habitats (hedgerows and tree rows) provides abundant and diversified floral resources for ecosystem service providers, whether pollinators or natural enemies of pests. On the other hand, the dispersal of ecosystem service providers in arable fields is promoted by the absence of chemical disturbances and the presence of abundant and diversified resources (e.g. weed flora and associated insects). Conversely, under conventional farming, linear habitats can harbour potentially troublesome weeds, and exert a "retention" effect on ecosystem service providers, which have little interest in dispersing from semi-natural habitats to intensively-managed crop habitats. Nevertheless, several levers can be used to take full advantage of the agroecological potential of linear habitats and associated herbaceous vegetation, including: (1) widening linear woody habitats, and (2) partially mowing the vegetation. These levers would be particularly beneficial in conventional farming systems, but could also be used in organic farming systems.

Widening linear woody habitats

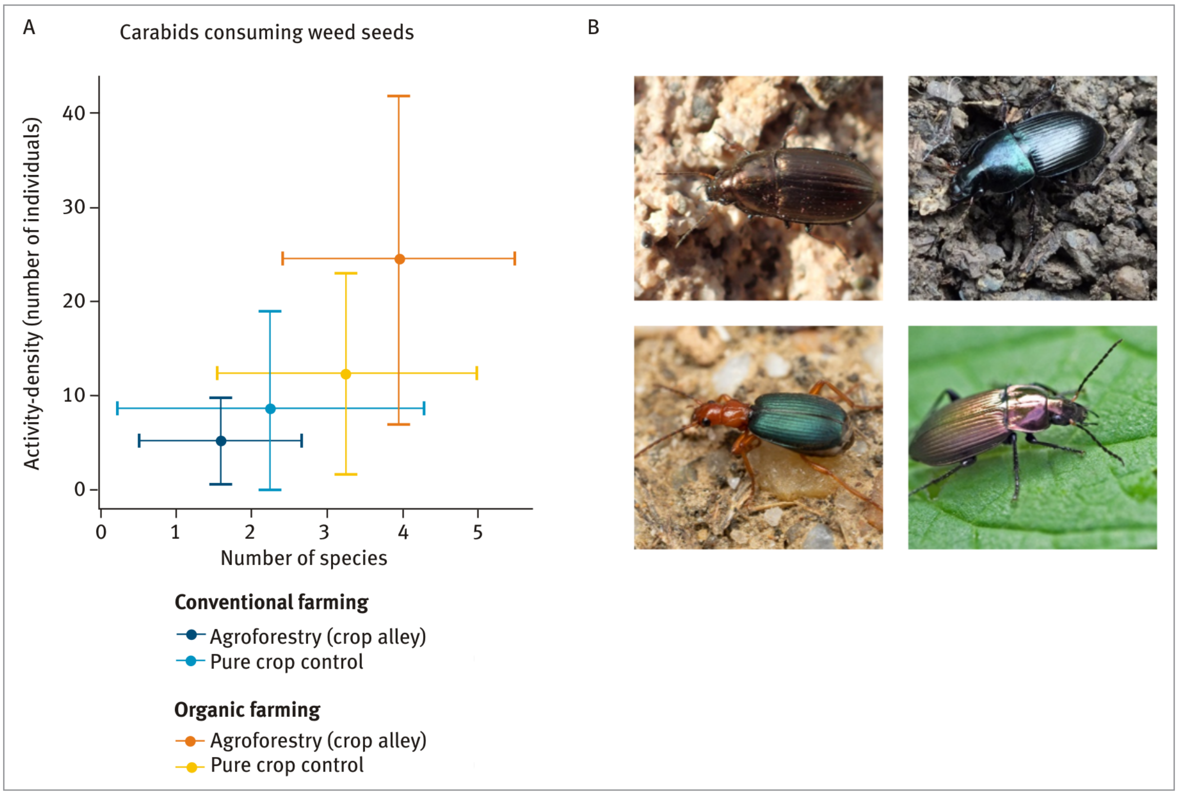
One of the most simple and cost-effective ways to promote ecosystem service delivery from wild herbaceous vegetation in agroforestry systems could well be widening linear woody habitats, up to 5-6 m for example. Widening linear woody habitats decreases the area available for agricultural production but can improve ecosystem service provision. First, it has been shown that widening linear habitats increases plant diversity and favours non-ruderal species over common arable weeds. This is due to the reduction of soil eutrophication in the wider linear habitats, in turn reducing the dominance of fast-growing and competitive grasses, and favouring the establishment of melliferous plants and associated ecosystem service providers. Second, an increased area of semi-natural habitats around or within fields would directly enhance resource availability and provide additional refugia from agricultural disturbances for sensitive species, including many ecosystem service providers. For example, Pywell *et al.* (2015) showed that despite the resulting loss of cropped area (3 or 8 % in their study), the expansion and diversification of semi-natural field boundaries enhances ecosystem service flows in crops by supporting pollinators and natural enemies of pests, leading to even higher crop production than in absence of such habitats (+ 0 to + 35%).

Finally, given the competition between trees and crops and the resulting yield losses, it is more relevant to use the area adjoining woody habitats for biodiversity conservation (and associated ecosystem services) rather than for agricultural production. This area could be occupied by wild herbaceous vegetation or by sown wildflower and grass strips, for example..

Partially mowing wild herbaceous vegetation

In eutrophic habitats, mowing the vegetation helps reduce the dominance of fast-growing, tall and competitive plant species, thereby increasing plant diversity

Figure ❹ – (A) Alley cropping agroforestry combined with organic farming strongly increases the activity and diversity of seed-eating carabids in crop alleys. (B) Species that benefit from understory vegetation strips and the absence of chemical disturbances include (from left to right and top to bottom): *Amara aenea*, *Harpalus dimidatus*, *Brachinus crepitans*, and *Peocilus cupreus*. These species are particularly interesting for farmers because they contribute to the biological control of weeds. Photo credits: C. Reymonet, N. Alric, J. Joachim, E. Vandebeulque (licence CC BY-NC *via* Galerie du Monde des insectes). Data source: Boinot *et al.* (2020).



and the provision of floral resources for ecosystem service providers (Kirmer *et al.*, 2018). Many dicotyledonous species are indeed able to regenerate quickly after mowing, extending the provision of floral resources into early fall. However, mowing should be coupled with biomass removal to (1) enhance plant diversity, because a high amount of litter hinders seedling germination and establishment, and (2) prevent the return of nutrients to the soil, which creates unfavourable conditions for less nitrophilous species. Finally, the use of flail mowers leads to homogeneous habitat structure, temporarily depleting resources, affecting micro-climate conditions and causing direct animal mortality. For this reason, it is best to use hand tools as much as possible, to target the areas that really need intervention. Overall, mowing once or twice a year maximum, with biomass removal, seems to be an intermediate disturbance regime that maintains high plant and insect diversity. In addition, mowing in early mornings should be avoided as many invertebrates are still inactive and hidden in the vegetation by that time of the day. It is also recommended to preserve unmown refuge zones, in the form of patches or strips, and to move these zones from year to year to prevent competitive grasses from taking over. Notably, these refuge zones help maintain the vegetation structures (e.g., hollow stems) that provide overwintering sites for many insects. In short, partial mowing is a good way to maintain a diversity of habitats - with their own flora and fauna - within each field, farm or landscape..

Conclusion

In many cases, we are not taking full advantage of the potential of agroforestry systems. At present, the focus is obviously on tree-crop interactions, which play a central role in the functioning of agroforestry systems. Nevertheless, wild herbaceous vegetation certainly plays an important role in the provision of ecosystem services. This article provides some suggestions for managing linear habitats and associated herbaceous vegetation to improve biodiversity conservation and associated ecosystem services, such as pollination and biological control of pests. However, the list is far from exhaustive. Both farmers and researchers still have a lot to learn about the functioning of agroforestry systems, a lot of experimentation to conduct and a lot of new ideas to find.

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