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Weed Management: Its Significance for Holistic Pest Management

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Abstract

Holistic Pest Management (HPM) is a recent approach that starts with the producer's own social, economic, and environmental context and builds decisions around it. Its goal is sustainability at the regional scale, pursued by diversifying agroecosystems through a mix of ecological and productive practices. Fewer pest outbreaks are one result; better well-being for the people who farm is another. HPM draws on agroecology, which leans on a farm's internal resources instead of external inputs and lets the synergies among the system's components do part of the pest control. People, crops, soil, and livestock are analyzed together, and vegetation management is the main way to bring natural pest control back. The logic is simple: a more diverse system offers habitat and food to beneficial organisms. These regulate pest populations through biological control and make production systems more stable and more resilient to disturbance. Weeds matter here. Usually treated as a nuisance, they also protect soil and its fertility, add to biodiversity, and shelter the natural enemies of pests. What must be managed, then, is not the weeds themselves but their abundance, their diversity, and how they interact with the rest of the agroecosystem. Done well, this lets farmers withstand the agricultural pressures they face today.

Keywords

Agroecology, Holistic Pest Management, Human Resilience, Weeds, Weed Management

1. Introduction

Holistic Pest Management (HPM), as a new paradigm for protecting plants, animals, and humans, considers the economic, environmental, and social contexts of producers and farmers, placing them at the center of the system as its articulating

axis (Barrera, 2006, 2020). Through pest management and ecological diversification, HPM attempts to contribute to regional sustainability. By combining pest management with ecological diversification, HPM aims to contribute to regional sustainability and, through it, to human well-being (Barrera, 2006, 2020). HPM rests on five principles. One of them, the agroecological principle, proposes the efficient use of internal inputs and the reduction of external inputs to establish synergies between the processes and components of agroecosystems, thereby preventing the emergence of pests (Barrera, 2006, 2020).

Altieri (1987) describes agroecology as a broader way of understanding agricultural processes, built around the interactions among people, crops, soil, and livestock. From this view, managing vegetation and diversifying the agroecosystem can strengthen the ecological processes that keep pest populations in check, since plants provide natural enemies with food, shelter, and alternative resources. Biological control may increase as a result, and the need for external input may fall. How much of this benefit is realized depends on the identity and diversity of the plant species present, their abundance and spatial arrangement, and the way the vegetation in and around the crop is managed (Altieri & Letourneau, 1982; Altieri & Nicholls, 2004; Nicholls & Altieri, 2018). Vegetation management allows plant diversification, which provides habitats and resources for a varied beneficial fauna and thereby favors pest regulation and biological control (Nicholls & Altieri, 2018). Agroecosystems designed in this way can work in harmony with their environmental and socioeconomic conditions, gaining ecological sustainability and, with it, stability and resilience (Altieri et al., 2007; Nuñez Espinoza et al., 2022).

From an agronomic perspective, plant diversity can be incorporated into agroecosystem design in several ways. One of them is the selective management of weeds: the composition, abundance, species identity, spatial distribution, and phenology of weed communities can influence insect population dynamics, crop-insect interactions, and the activity of natural enemies. The effect of weeds depends on the species and the situation. Some provide beneficial invertebrates with food, shelter, or alternative resources; others compete with the crop or host herbivorous pests and pathogens. Decisions therefore have to be made case by case, depending on the species, its abundance and location in the field, the growth stage of the crop, and the likely effect of the weed on yield and pest regulation (Altieri & Letourneau, 1982; Nicholls et al., 2015; Barbercheck & Wallace, 2021). Here we review the costs and benefits of weeds in agroecosystems and the ways they are managed. Using examples, we then show how selective management can protect soil and biodiversity without sacrificing yield, and how that relates to biological control and resilience within HPM.

This mini review is based on a targeted search of Scopus, Web of Science, Google Scholar, and the FAO and IPBES institutional repositories. The search terms were “weed management”, “integrated weed management”, “Holistic Pest Management”, “agroecology”, “cover crops”, “ecosystem services”, “herbicide resistance”, and “agroecosystem resilience”, combined with Boolean operators

where appropriate. We included peer-reviewed reviews, meta-analyses, primary studies, and institutional reports in English or Spanish that dealt with weed ecology, weed-management practices, agroecological processes, biological control, ecosystem services, or herbicide resistance. 2022-2026 period applies to recent examples and data; older references were kept when they supplied definitions, foundational concepts, or historical context. We selected examples that directly illustrate ecological benefits, management tactics, trade-offs, or the contribution of weed management to HPM, and organized the literature by theme: weed impacts, management methods, ecological services, and contribution to HPM.

2. Definition of the Term "Weed"

Weeds go by many names in the literature, among them scrub, vines, adventitious plants, invasive herbs, and underbrush, and all of them refer to non-cultivated plants (Acuña, 1974; Blanco & Leyva, 2007; Baptiste & Cárdenas-Toro, 2015; Leopardi-Verde et al., 2022). Definitions of weeds vary with the perspective from which they are made. Some describe them as higher plants that grow where they are not wanted, whether in natural, semi-natural, or cultivated habitats (Baker, 1974; Tawfeeq & Ali, 2024). Others point out that weeds do well in human-altered habitats and can have environmental, economic, or public health impacts (Baptiste & Cárdenas-Toro, 2015; Leopardi-Verde et al., 2022). In crops, weeds interfere with plant development, lower yield or quality, and raise production costs (Harlan, 1982; Poreja, 1988; Akobundu, 1996; Berti et al., 1996; Leguizamón, 2024). The Spanish word "maleza" derives from the Latin *malitia* ("evil"); the General Etymological Dictionary of the Spanish Language defines it as an outdated form of "wickedness" and as an abundance of weeds that harm crops (Barcia, 1902). Yet the same species can be helpful in one situation and undesirable in another (Baker, 1974; MacLaren et al., 2020), so the term describes what a plant does in each place more than what it is.

The literature often uses "weed", "non-crop plant", "invasive species", and "exotic species" interchangeably (Baker, 1974; Heywood, 1989; Holm et al., 1997; Randall, 1997; Westbrooks, 1998; Myers & Bazely, 2003; Brancatelli et al., 2024), but the four terms rest on different criteria and only partly overlap. "Non-crop plant" is the broadest: it says only that a plant is not the one being cultivated, and many non-crop plants are harmless or beneficial (Araj & Wratten, 2015; Merfield, 2019; Merfield, 2022). "Weed" adds a judgment of value, since a plant is a weed when it interferes with human objectives in each place and time, whatever its origin (Baker, 1974; MacLaren et al., 2020). "Exotic species" (also called non-native or alien) is defined by geographic origin, meaning a species introduced beyond its natural range; it says nothing about harm, and many exotic species are neither weeds nor invasive (Richardson et al., 2000; Pyšek et al., 2004; Blackburn et al., 2011). "Invasive species" is defined by ecological behavior, meaning an exotic species that establishes, spreads, and causes impacts in its new range (Mack & Lonsdale, 2001; Sakai et al., 2001). A plant can therefore be a native weed, a

harmless exotic, or an invasive species in a natural area that never affects a crop (Richardson et al., 2000; Pyšek et al., 2004; Blackburn et al., 2011). Here we use "weed" for non-crop plants that interfere with crop production or management objectives (Schonbeck, 2009), and "invasive weed" for exotic weeds that spread aggressively (Reichard & White, 2001).

3. Economic Impacts Caused by Weeds

Weeds impose economic, social, and medical costs on human society in several ways. They compete with valuable plants (food and fiber crops, ornamentals, and timber) for nutrients and light, and can reduce crop yields, in part through allelopathy (Westbrooks, 1998). They also raise production costs because of the mechanical and chemical controls applied against them, increase crop protection costs by harboring other pests (arthropods, nematodes, and plant pathogens), and lower the quality of agricultural products when weed seeds contaminate crop seed (Zimdahl, 1999; Mullin et al., 2000). They reduce the area of usable forage in rangelands, interfere with water management by infesting irrigation ditches and other waterways, endanger human health and reduce labor productivity through allergies and poisoning, reduce income from recreational hunting, fishing, and tourism, restrict access to foreign markets, and lower land values (Westbrooks, 1998; Zimdahl, 1999; Mullin et al., 2000; Monaco et al., 2002).

For example, invasive species (plants, animals and microbes) have been estimated to cost about US$314 billion per year (around 1998, US$) across six countries covered by Pimentel et al. (2001): United States (~US$116 - 120 billion), India (~US$116 billion), Brazil (~US$50 billion), Australia (~US$13 billion), United Kingdom (~US$12 billion), and South Africa (~US$7 billion); Pimentel et al. (2005) later updated the U.S. figure to ~US$120 billion per year (around 2003, US$). Separate studies report about US$7 billion per year in damages plus US$1.2 billion in control costs for South Africa (van Wilgen et al., 2001), about AU$4.0 billion per year (≈US$3 billion; 1997/98-2001/02, AUD) for Australia (Sinden et al., 2004), and about NZ$100 million per year (early 2000s, NZD) for New Zealand (Williams & Timmins, 2002). According to Claudi (2002) and subsequent national syntheses, Canada loses on the order of tens of millions of Canadian dollars annually (≈CAD 38 million) due to the invasion of four weed species: *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), *Centaurea diffusa* (white knapweed), and *C. maculosa* (spotted knapweed). The estimated costs imposed by invasive aquatic weeds in the United States alone range from US$900 million to US$14 billion annually (Rockwell, 2003). Australia's weed caused a serious degradation of more than 15 million hectares of rangeland and natural ecosystems (Glanznig, 2003) like in South Africa they have invaded about 10 million hectares (van Wilgen et al., 2001). In natural ecosystems invasive weeds decrease biodiversity and change ecosystem functioning (Ehrenfeld, 2010; Liu et al., 2025; Negesse et al., 2025). The control costs also reach the wider economy, since weeds raise prices in agriculture and burden other sectors, which can slow economic growth

(Culliney, 2005; Weidlich et al., 2020).

4. Methods of Weed Control or Management

Because of the losses that weeds cause, strategies based on prevention, eradication, and control or management have been developed (Mack et al., 2000; Monaco et al., 2002; Bàrberi, 2004; Mascorro-de Loera et al., 2024). Prevention often involves legislation that prohibits the entry of weeds and other pests into a country or restricts their movement (Culliney, 2005). Eliminating weeds is difficult once they have formed dense, widespread infestations in agricultural fields, and at that stage complete eradication becomes practically and economically impossible (Culliney, 2005).

Control measures are applied to minimize the economic and environmental impacts of weeds where prevention and eradication fail. Weed management in production systems relies on five approaches that differ in what they act on: cultural, mechanical, chemical, biological, and integrated (Bàrberi, 2004; Culliney, 2005; Wittenberg & Cock, 2001; Manning & Miller, 2011). Cultural methods modify the crop environment so that weeds are less able to establish; mechanical methods physically remove or damage weeds; chemical methods use herbicides; biological methods use natural enemies; and integrated management combines two or more of these according to the crop, the weed community, and the management goals. Because weed management is closely tied to crop management, practices applied before planting and direct methods applied during the crop cycle are usually combined (Bàrberi, 2004).

Cultural methods act on the crop environment to reduce the ability of weeds to establish and proliferate, and many are applied before planting. They include crop rotation, cover crops (used as green manure, dead cover, or living cover), tillage systems, seedbed preparation, soil solarization, drainage management, irrigation systems, crop residue management, planting time, spatial arrangement, choice of crop genotype, intercropping, and fertilization (Bàrberi, 2004; Gómez-Gómez, 2024).

Mechanical control is accurate and only impacts the target species, but it is very labor intensive (Wittenberg & Cock, 2001; Manning & Miller, 2011). Methods consist of uprooting, cutting, cutting at ground level, plowing, burning, and pruning, whether by hand or with tools (Wittenberg & Cock, 2001). Their effect lasts only until the next germination, so they must be repeated every year (Kettenring & Adams, 2011).

Chemical control, such as herbicides, can provide effective short-term weed control, but their use may also have ecological consequences, particularly when these compounds affect organisms in soil and aquatic environments (IUCN, 2006; Freytez et al., 2025). Herbicide resistance should be considered separately, as it reflects management practices rather than a direct ecological cost of herbicide application. When the same active ingredient is used repeatedly, selection pressure can favor resistant weed biotypes, ultimately reducing treatment effectiveness

over time (Moreno-Serrano, 2025).

Natural enemies used for biological control are especially suitable for nature reserves, conservation areas, and invasive exotic species because of their environmentally friendly approach (Wittenberg & Cock, 2001; Manning & Miller, 2011). The agents are typically host-specific insects, together with parasitic fungi and pathogenic organisms (Taylor & Hastings, 2004; IUCN, 2006).

Integrated weed management combines cultural, mechanical, chemical, and biological methods to keep weed populations below damaging levels while relying less on any single tactic and lowering the risk of herbicide resistance (Melander et al., 2005; Culliney, 2005; Beckie, 2006). Most of these methods aim to reduce or eliminate weeds. The next section considers approaches that also consider what weeds contribute to the agroecosystem.

5. Weed Management in Agroecosystems

Many weeds occupy agroecosystems through ecological succession, a frequent process that contributes to numerous agronomic problems. A plant community first shifts when disturbance opens resources such as water, nutrients, and light, and species that can exploit these openings, weeds among them, move in and colonize (Paleologos & Sarandón, 2014; Paleologos et al., 2017). Despite all that is known about weed management, agroecologists and specialists acknowledge the limitations of control strategies. They have focused on understanding weeds' role in agroecosystems (Jordan & Vatovec, 2004; Clements et al., 2004). This knowledge has led to a reassessment of the paradigm on weeds and their impact on agroecosystems. Weeds have traditionally been assumed to reduce crop yield and therefore to require elimination (Timmons, 1970; Horvath et al., 2023). However, recent studies and document reviews show that weeds can provide ecosystem services and benefits in agroecosystems, i.e., biological pest control, pollination, soil property improvement, and nutrient cycling (Rollin et al., 2016; Blaix et al., 2018; Gazoulis et al., 2024; Osu et al., 2026).

Weeds affect cropping systems ecologically in more than one way. They affect soil quality and fertility, shape interactions between herbivorous arthropods and their natural enemies, and can function as cover crops (Jordan & Vatovec, 2004; MacLaren et al., 2020). Benefits for the soil include less erosion, slower nutrient loss, more organic matter, better nitrogen levels, and better water conservation (Moreau et al., 2020; Travlos et al., 2025). Associations with beneficial soil organisms are also important (Wardle, 1992; Trognitz et al., 2016), as they establish symbioses with arbuscular mycorrhizal fungi and serve as hosts for them (Jordan et al., 2000; Trognitz et al., 2016). They increase plant community diversity and can offset the low species diversity typical of cropping systems (De Ruiter et al., 1995; Trognitz et al., 2016). Soil arthropod abundance also increases with weed abundance (Wardle, 1995; Jordan & Vatovec, 2004; Navntoft et al., 2016).

Many weeds are important elements of agroecosystems because they favor the biology and dynamics of beneficial insects by supplying resources that weed-free

monocultures lack (alternative prey or hosts, pollen or nectar, and microhabitats) (Landis et al., 2000; Marshall et al., 2003; Navas, 2012) and help maintain viable populations of natural enemies (Evans, 2005). Fields with dense plant biodiversity of weeds harbor more predatory arthropods than those free of such plants (Landis et al., 2000; Kleiman et al., 2021). Parasitoid establishment generally depends on weeds that provide nectar to adult female wasps (Evans, 2005; Kleiman et al., 2021). Some weed species growing in cover crops during fallow periods may benefit plant communities by retaining nitrogen and reducing soil erosion (Baraibar et al., 2021), conserving water and organic material (Ditsch & Alley, 1991; Wardle, 1995).

Weed species present in agroecosystems foster biodiversity in general (Marshall et al., 2003); this applies both to wild species associated with the agroecosystem, insects and birds (Albrecht, 2003; Marshall et al., 2003; Storkey, 2006; Makowski et al., 2007) and to helpful species whose life cycles are tied to organisms that act against pests (Lenné & Wood, 1999; Norris & Kogan, 2000; Marshall et al., 2003; Makowski et al., 2007). This makes it possible to identify the weed species that are most significant for biodiversity (Marshall et al., 2003). Furthermore, it is worth noting that organic farming is likely associated with greater weed species diversity in landscapes with simple structures (Roschewitz et al., 2005), providing a compelling reason to promote the transition from conventional to organic agriculture. Cultivation practices determine weed diversity through the selective pressures they exert (Dekker, 2011). Understanding this diversity is fundamental to weed management. Thus, related studies can contribute to the development of sustainable management systems and practices (Marshall et al., 2003; Paleologos et al., 2017; Neve et al., 2018; Avilés-Baeza et al., 2025).

Whether retaining weeds helps or harms depends on several criteria that should be assessed together. Based on the principles of habitat management and agroecological weed management, the following criteria are presented for the retention or removal of weeds (Altieri & Letourneau, 1982; Landis et al., 2000; Marshall et al., 2003; Nicholls et al., 2015):

Crop stage: Weeds may be tolerated during early crop growth or fallow periods but should be removed during the critical period of crop-weed competition, when their presence is most likely to cause unacceptable yield losses (Swanton & Weise, 1991; Zimdahl, 2004).

Weed abundance: At low densities, many weed species supply resources to natural enemies and help protect the soil, but beyond a certain threshold, competitive effects on the crop outweigh these benefits (Marshall et al., 2003; Navas, 2012).

Species identity: Weed species that offer nectar, pollen, or alternative prey to beneficial arthropods are candidates for retention, whereas highly competitive, allelopathic, or aggressive species are more likely to be removed (Landis et al., 2000; Marshall et al., 2003; Navas, 2012).

Spatial location: Weeds located at field margins, in strips, or between crop rows can support natural enemies without directly competing with the crop, whereas

weeds within the crop row compete more intensely for resources (Landis et al., 2000; Marshall et al., 2003).

Pest-host potential: Weeds that serve as hosts for the crop's pests, nematodes, or pathogens should generally be removed, even if they also provide shelter for natural enemies (Altieri & Letourneau, 1982; Norris & Kogan, 2000).

Taken together, these criteria suggest that weed retention is most justified when a species is scarce, occurs outside the critical period of competition, is located away from the crop row, supply resources to natural enemies, and does not act as a host for the crop's pests. This approach aligns with the agroecological principle of Holistic Pest Management (HPM), which emphasizes the efficient use of internal resources, the reduction of external inputs, and the design of diverse agroecosystems that are more resilient to disturbance (Barrera, 2006, 2020; Altieri et al., 2007).

6. Examples of Weed Management

Cover crops are used to manage several kinds of weeds. In coffee and banana, for instance, living ground covers include weeds and some leguminous crops. In Colombia, coffee growers practice selective weed control, leaving beneficial ("noble") covers and removing weeds under the coffee plants, which achieved 95% efficiency in soil conservation without adverse effects on production (Gómez, 1987). In some banana farms in northern Panama, *Geophila repens* (redondilla; Rubiaceae) is increasingly used as a living ground cover against weeds (Herrera, 1997). In Costa Rica, selective weed control and hoeing were used to manage weeds (Herrera, 1997). Field observations showed that weed cover in banana cultivation reduces erosion (Agüero-Alvarado et al., 2018). Rye, bur clover, wheat, buckwheat, black mustard, Sudan sorghum, oats, alfalfa, and rice control weeds effectively when used as dead cover on the soil (Mangan et al., 1995; Masiunas et al., 1995; Medrano et al., 1996; Weston, 1996).

In Mexico, fallows improved with the legumes *Mucuna deeringianum* (vitabosa), *Canavalia ensiformis* (giant stock bean), *Leucaena leucocephala* (white leadtree), and *Lysiloma latisiliquum* (Caribbean walnut) reduced weed growth and improved corn yield (Caamal-Maldonado et al., 2001). Small farmers in Central America use traditional practices based on legumes (*M. deeringianum* and *Canavalia* spp.) as cover crops. With these practices, they have managed to bring degraded land back into use, cut down on chemical fertilizer, and triple corn yield, all at a lower cost than farmers who depend on chemical fertilizers and monocultures (Caamal-Maldonado et al., 2001; Altieri & Nicholls, 2002). *M. deeringianum* was also used successfully in Urabá, Colombia, where it controlled *Imperata cylindrica* (cogon grass, locally guayacana) and doubled the yield of the following maize crop (Van Eijk-Bos et al., 1987). In Brazil, *Mucuna aterrima* (velvet bean) is recommended as a cover crop in direct-seeding systems because of its allelopathic effect on *Cyperus rotundus* (purple nutsedge) and many other weed species (Lorenzi, 1984). *Mucuna pruriens* exerts strong shading, which gives it greater

potential for weed suppression (Favero et al., 2001; Petter et al., 2015).

In central coastal California, winegrowers turned to weed control practices aimed at protecting biodiversity in their vineyards while still holding yields steady (Sanguankeo & León, 2011). Weed management using cover crops promoted greater plant density and diversity, which can generate ecological benefits in vineyards by enhancing the activity of beneficial organisms. The carabid beetles *Calathus ruficollis* (red-collared harp ground beetle) and *Tanystoma maculicolle* (tule beetle) preyed more heavily on the seeds of the common weeds *Brassica nigra* (black mustard) and *Capsella bursa-pastoris* (shepherd's purse). Not every case favors selective approaches, however. In Hungarian rice crops, filamentous algae, the most abundant weeds, were positively associated with deep tillage, deep-water planting, and surface planting. This example shows that weed management is complex and that, in some systems, herbicides remain the most effective option; weather also matters, because generally heavy rain eliminates these algae (Pinke et al., 2014).

In Tepeyahualco de Cuauhtémoc, in the Mixteca region of Puebla (Second Section), the traditional agroecological system known as tecorral is managed (Rojas-Serrano, 2021). Weed management practices in this system include crop association, intensive management, avoiding burning, mulches and plant cover, integration of animals for weed control, brush cutting and weeding, and crop rotation. Good management also makes it possible to select plants used as food or fodder (quelites and amaranths). The system additionally yields protein from edible insects (maguey larvae and mesquite bugs, or cocopaches), which helps recover the traditional diet and culture (Rojas-Serrano, 2021). This kind of system shows how weed management can support resilience at the household level as well as in the field.

7. Conclusion

Weeds cause substantial losses, but they also feed natural enemies, protect the soil, and add plant diversity. Managing them well therefore means considering their abundance, diversity, phenology, and relationship with the rest of the agroecosystem before deciding what to remove and what to leave. In some systems, such as the Hungarian rice fields described above, herbicides may still be the most effective option, so selective management is not a universal rule. Within HPM, this approach supports the agroecological principle of reducing external inputs and gives producers and farmers a way to obtain sustainable products, build resilience to risk, and manage socio-environmental systems in line with their quality of life.

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Author Contributions

Mayumi Vega-Polanco contributed to the conception and design of the study, as well as to the drafting and revision of the manuscript. Raisa Yarina Escalona-Domenech contributed to the revision and editing of the manuscript. Both authors reviewed and drafted corrections to earlier versions of the manuscript. Both authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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