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Role of regulating ecosystem services in reducing the use of chemical pesticides

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Abstract

The widespread use of chemical pesticides in agriculture poses significant threats to the environment, biodiversity, and human health. Regulating ecosystem services, particularly natural pest control by predators and parasitoids, offer sustainable alternatives to reduce dependence on chemical inputs. This study explores the mechanisms and efficacy of these services, emphasizing the benefits of promoting biodiversity, enhancing habitat complexity, and adopting conservation biological control. Findings demonstrate that these practices can effectively reduce pesticide use while maintaining crop productivity. The study advocates for ecosystem-based approaches to foster sustainable agriculture and provides actionable recommendations for policymakers, farmers, and stakeholders.

Keywords: Regulating Ecosystem Services**,** Chemical Pesticide Reduction**,** Natural Pest Control**,** Integrated Pest Management**,** Sustainable Agriculture

INTRODUCTION

In recent years, the demand for pesticide-free, healthy, and high-quality agricultural products has grown among both producers and consumers. Meeting global food demands while conserving the environment poses significant challenges. Moreover, pesticide usage is projected to triple globally by 2050 (Tilman et al., 2001), potentially exacerbating biodiversity loss and environmental degradation. The thesis that, whenever possible, the use of broad-spectrum pesticides should be reduced or completely avoided is gaining increasing popularity.

The European Union (EU) has committed to reducing pesticide use as part of its Biodiversity Strategy and Farm to Fork Strategy, which underpin the Green Deal (European Commission, 2020). This ambitious framework aims to lower greenhouse gas emissions, protect and restore ecosystems, and promote biodiversity conservation. Reducing pesticide reliance necessitates adopting alternative methods in pest management strategies.

Chemical pesticides, while effective, have adverse environmental impacts, including pollution, reduced biodiversity, and development of pest resistance, which often requires higher dosages or new formulations to maintain control (Naylor & Ehrlich, 1997). Adopting regulating ecosystem services and biological method of control is an approach in the sustainable management of pest populations, which is an alternative to the use of synthetic chemicals and safe from an ecological point of view (Karova, 2011). Given the ecological and agronomic risks associated with pesticide overuse, integrating ecosystem services into pest management strategies is increasingly recognized as a crucial step toward sustainable agriculture**.**

The aim of the study is to identify the role of ecosystem services as an environmentally sustainable approach to pest management and their role in modern crop protection strategies.

ECOSYSTEM SERVICES

Ecosystem services encompass the wide array of benefits that humans derive from the natural environment and the optimal functioning of ecosystems. These services indirectly support human existence and directly sustain over a billion people globally (Costanza et al., 1997; Turner et al., 2007), with biodiversity forming their foundation (Heong, 2008). Schowalter et al. (2018) broadly classify ecosystem services into four categories: provisioning, regulating, cultural, and supporting services.

Regulating ecosystem services include the benefits provided by ecosystems through the regulation of ecological processes and functions, often in ways critical for maintaining environmental health and balance. While not directly related to material goods production, these services are essential for human well-being and ecosystem functionality. Agricultural practices and systems impact biodiversity and its associated ecosystem services in two contrasting directions: decreasing biodiversity and thereby reducing benefits, or maintaining and enhancing biodiversity to increase ecosystem services.

A significant regulating ecosystem service provided by biodiversity is natural pest control (Wilby, 2002), which is based on the principles of natural regulation. In pest management, two critical ecological functions—predation and parasitism—play a central role, directly linked to the diversity of predators and parasites (Heong, 2008). However, in modern times, natural pest control is among the ecosystem services threatened by human activities as the anthropogenic impacts have disrupted the self-regulatory capacity of agroecosystems (Popov et al., 2017).

ECO-FUNCTIONAL INTENSIFICATION IN AGRICULTURE

Eco-functional intensification in agriculture aims to preserve and promote biodiversity and the sustainable use of associated ecosystem services to support efficient production (Geertsema et al., 2016). Employing ecologically-based management strategies can enhance the sustainability of agricultural production while mitigating negative environmental impacts (Matson et al., 1997). This approach creates favorable conditions for the proliferation and conservation of beneficial species both above and within the soil, which can keep pest populations below their economic damage thresholds.

Agroecological intensification is grounded in managing ecosystem processes, integrating biological and ecological functions into food production systems, and minimizing reliance on non-renewable inputs. In this context, ecological intensification in agriculture is based on principles of agroecosystem resilience and sustainability, ensuring that outputs are generated within the system's boundaries (Gaba et al., 2014). The primary objective is to establish sustainable agri-food systems by enhancing soil fertility, mitigating the environmental impact of agriculture, and implementing agricultural practices that align with food safety standards. This involves exploring alternatives to costly and hazardous agrochemicals and optimizing energy efficiency in agricultural production**.** The agricultural system should be conceptualized as a living organism**,** where all components—soil, plants, animals, microorganisms, pests, and beneficial organisms—are interconnected through dynamic ecological relationships. Biodiversity plays a crucial role in enhancing system productivity and fostering beneficial interactions among its components, thereby contributing to greater ecosystem resilience and sustainability.

The management of organisms that provide regulating services, such as pest control, is a tool to optimize production through ecological intensification. Biological control agents, derived from natural ecosystems, have been successfully utilized for plant protection against insect pests (Kevan et al., 2020).

Ecological intensification aims to foster beneficial biological interactions to limit the extensive use of pesticides and fertilizers and reduce environmental impacts. Reducing pesticide usage is a vital component of integrated pest management. Beneficial insects contribute to pollination and biological control in both natural and human-altered systems. The use of pesticides directly disrupts functioning of the ecosystems and biodiversity, because when carrying out chemical control, not only pests are affected, but also beneficial species in crops. The use of synthetic pesticides has detrimental effects on both natural enemies and pollinators. Pesticides can impact multiple life cycle stages, leading to reduced reproductive capacity, impaired predation or parasitism efficiency, and increased mortality rates (Ndakidemi et al., 2016). The decline of natural enemies can disrupt pest population dynamics, potentially leading to pest resurgence or the emergence of secondary pests, ultimately exacerbating the need for chemical interventions. Predators and parasitoids are generally more sensitive to pesticides than herbivorous insects, as the latter possess plant-derived detoxification mechanisms that enhance their resistance (Gill & Garg, 2014).

Use of regulating ecosystem services are critical for fruit and vegetable crops grown in fields and greenhouses. For instance, hoverflies (Diptera: Syrphidae) support ecosystem services in agroecosystems through their dual role: adults as pollinators and larvae as predators of pests (Dunn et al., 2020). Their larvae feed on pests, while adults provide crop pollination (Li et al., 2023).

MECHANISMS OF REGULATING ECOSYSTEM SERVICES IN PEST CONTROL

Modern trends in plant protection emphasize the need for ecological foundations, aligning with fundamental ecological principles and the approaches of sustainable agriculture.

In natural ecosystems, biotic and abiotic factors regulate population densities, preventing certain species from reaching pest status. This process, known as natural control, consists of two main components: abiotic factors (e.g., climate, soil conditions, and environmental variability) and biotic factors (e.g., natural enemies such as predators, parasitoids, and pathogens). When natural enemies are disrupted – whether through human activities or the introduction of species into new environments without their natural regulators—natural control mechanisms often fail, leading to uncontrolled pest population growth. This population increase results from both natural drivers (e.g., migration and environmental changes) and anthropogenic influences**,** such as: the introduction of invasive species into novel ecosystems; changes in agricultural technologies and land-use practices**;** habitat modifications that disrupt predator-prey dynamics; unintended side effects of pesticide use, which can reduce natural enemy populations; monoculture cultivation, which provides stable food resources for pest species, enabling their proliferation.

The use of pesticides directly disrupts ecosystem balance and biodiversity, as chemical pest control measures affect not only target pest species but also beneficial organisms within agroecosystems. Synthetic pesticides negatively impact natural enemies and pollinators, affecting multiple stages of their life cycle by reducing reproductive capacity, impairing parasitism or predation efficiency, and causing direct mortality (Ndakidemi et al., 2016).

The decline of natural enemies can have cascading ecological consequences, including pest population outbreaks and the emergence of secondary pests**,** which further destabilize the system. Predators and parasitoids are generally more vulnerable to pesticide exposure than herbivorous insects, as many plant-feeding species possess plant-derived detoxification mechanisms, enhancing their resistance (Gill, 2014).

These disruptions highlight the need for sustainable pest management strategies that minimize non-target effects and support natural pest regulation within agricultural landscapes.

Biological control has existed for millions of years, alongside the emergence of the first insects. However, humans began to recognize its importance only around 10,000 BCE, with the advent of agriculture (DeBach, 1964). Nearly a century ago, in 1927, prior to World War II, Speyer began exploring biological control in greenhouses at the Cheshunt Experimental Station, and documented successful control of the greenhouse whitefly, *Trialeurodes vaporariorum*, using the specialized parasitoid *Encarsia formosa* (Speyer, 1927). After World War II, plant protection shifted towards developing new, highly effective synthetic insecticides, which reduced the prevalence of biological control. Nevertheless, the need for alternative pest control methods soon became evident due to resistance development from frequent and improper pesticide use. Additionally, awareness of environmental conservation, including water and soil protection, and the risks of chemical residue contamination in produce have stimulated the development of biological control. In 1949, resistance to organic acaricides was observed in the pest *Tetranychus urticae Koch* (Acari: Tetranychidae). This spurred research into alternative methods, such as biological control using the predatory mite *Phytoseiulus persimilis Athias-Henriot* (Acari: Phytoseiidae), effective against *T. urticae*. This predator helps maintain pest populations without the need for insecticides (Perdikis et al., 2008). Such examples demonstrate how biological control has evolved over recent decades, proving successful pest management strategies through natural enemies without relying on plant protection products (Pijnacker et al., 2020). Since the 1970s, the availability of natural enemies for biocontrol in greenhouses has grown rapidly, alongside the industry producing these control agents (van Lenteren, 2012). Greenhouses are particularly suitable for biological control due to their unique characteristics. These enclosed systems provide barriers that prevent natural enemies from dispersing, allowing them to concentrate within the environment. Greenhouses also facilitate close monitoring and management of the entire system. Pest and natural enemy populations can be closely tracked, and environmental conditions can be adjusted to favor natural enemies over pests. Greenhouses also enable timely sanitary measures for crops when needed and are less prone to mass pest invasions compared to open-field crops (Perdikis et al., 2008).

A primary reason for employing biological control in greenhouses is that pests in these environments are more likely to develop resistance to frequent and improper pesticide use due to their faster reproduction in controlled conditions. Pest resistance to pesticides increases with each generation, and species with rapid reproduction cycles develop resistance faster. Scientific evidence shows that signs of pesticide resistance in insects can appear after six successive generations (Andreev, 2021). In recent decades, biological control has increasingly replaced chemical control in greenhouse pest management worldwide (Pilkington et al., 2010), aiming for ecological, economic, and social sustainability. Introducing natural enemies has become a key practice, particularly when chemical pest control is ineffective, infeasible, or undesirable. This approach has proven effective and has taught growers and plant protection experts that biological control is an essential tool for pest management (Elliott, 1995; Albajes et al., 1999).

The use of biological control agents for weed management has been also practiced for over a century (Gassmann, 1996). Biological weed control programs have been implemented in more than 50 countries, successfully managing over 41 invasive weed species (DeLoach, 1991).

In classical biological control, natural enemies of weeds are transferred from their native ecosystems to newly established agroecosystems with the aim of reducing weed density and spread to levels that minimize economic and ecological damage (Goeden & Louda, 1976). This approach is based on the ecological principle that interactions between plants and their specialized herbivores and pathogens regulate weed populations in their natural environments. The practice of biological control relies on the assumption that natural enemies can serve as limiting factors for weed populations and that certain species exhibit high host specificity, reducing risks to non-target plants (Harley & Forno, 1992).

Biological control seeks to restore ecological balance between weeds and their natural antagonists, rather than completely eradicating invasive plant species. Classical biological control functions as a self-sustaining regulating mechanism, where introduced biological agents establish permanent populations within the ecosystem. Most successful biological control programs utilize a complex of interacting biological agents to enhance effectiveness. However, long-term success requires rigorous evaluation, careful management, and ongoing monitoring to ensure sustainable weed suppression and minimize unintended ecological consequences.

Bioagents can be applied through three primary methods: introduction, seasonal colonization, and conservation (De Bach, 1964). Most biological control strategies rely on saturation methods, where natural enemies are periodically introduced in large quantities to address pest issues (Stinner, 1977; Collier and Van Steenwyk, 2004). This method, also known as "classical" biological control, is commonly used against invasive pests that appear in new regions without their natural enemies. However, this approach can sometimes overshadow more cost-effective but equally efficient natural enemies (Pijnakker et al., 2020). Huffaker & Kennet (1969) outlined five principles that contribute to the success of biological agents - adaptation to environmental and host conditions, significant ability to search for the food plant, multiplication and increase in population size in accordance with the food plant, mobility and ability to spread, minimal lag in development when the number of the host decreases.

In recent years, there has been growing interest in strategies that enable pre-regulation of pest populations through settlement methods (Messelink et al., 2014). In some cases, additional resources are necessary for successfully establishing natural enemies. These resources may include food resources from plants, suitable egg-laying sites, shelters, and prey availability. Biological control in such systems can be improved by supplementing missing resources to encourage predator or parasitoid integration and prevent potential issues (Messelink et al., 2014).

Biological control, however, does not rely solely on bioagents. For effective pest management, predators can be combined with other biological plant protection methods. Habitat management is a powerful tool that focuses on modifying agricultural landscapes to enhance the activity and effectiveness of natural enemies. By creating favorable conditions for predators, parasitoids, and other beneficial organisms, habitat management reduces pest populations naturally and minimizes the reliance on chemical pesticides. Introducing inter-row cover crops is a successful measure in control strategies. Cover crops act as attractants for beneficial species and contribute to soil structure by improving aeration, water retention, and reducing erosion and nutrient loss. Using buffer zones around or within crops, as part of integrated pest management or organic farming, can enhance product quality and profitability while reducing pesticide use and secondary pest attacks (Boucher et al., 2003). Such zones preserve and increase biodiversity, including natural enemies, which help lower harmful pest populations.

CONCLUSIONS

The integration of regulating ecosystem services, such as biological control, into pest management strategies provides a sustainable and effective alternative to chemical pesticides. This approach aligns with global and European Union policies aimed at reducing pesticide dependency**,** preserving biodiversity, and maintaining high-quality agricultural production. In greenhouse systems, the combination of natural enemies with complementary methods—such as cover crops and buffer zones – demonstrates significant potential for keeping pest populations below economic thresholds.

Unlike chemical pesticides, biological control does not aim for the complete eradication of a species but rather regulates populations, enhancing the efficacy of integrated pest management (IPM) strategies**.** However, this method presents certain challenges. The impact of biological control agents is often seasonal and may not result in the complete suppression of the target weed or pest species. Additionally, bioagents exhibit varying adaptability to different climatic conditions and plant biotypes, influencing their effectiveness.

Implementing biological control programs requires significant financial, human, and technical resources**,** particularly due to the stringent testing protocols needed to ensure host specificity and prevent unintended effects on non-target species. Long-term success depends on careful planning, ecological assessments, and continuous monitoring**.**

Despite these challenges, biological control remains widely utilized worldwide and is recognized as a cost-effective, efficient, and environmentally safe pest management strategy. By fostering beneficial ecological interactions and reducing environmental impact, biological control contributes to eco-functional intensification in agroecosystems, promoting both environmental sustainability and agricultural productivity**.** Expanding its adoption can enhance resilience in food production systems, supporting the transition toward more sustainable and regenerative agricultural practices**.**

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