Topics in Agricultural Entomology XIII

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Daniel Dalvan do Nascimento | Edimar Peterlini
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(organizadores)

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PREFACE

The Graduate Program in Agronomy (Agricultural Entomology) at the UNESP Faculty of Agricultural and Veterinary Sciences in Jaboticabal has always been characterized by its focus on Integrated Pest Management (IPM). Since its foundation, the program has graduated 287 students with a master's degree and 148 Ph.D. students. They are now active in various areas of the public or private sector and contribute to agriculture's economic and environmental sustainability.

This e-book entitled "Topics in Agricultural Entomology - XIII" was made possible through the immense effort of the Organizing Committee, formed by MSc and Ph.D. students from all research areas of our Graduate Program. In its 14 chapters, readers will find information on the most diverse areas of IPM, with a richness of information on both the fundamental and applied aspects of IPM.

As coordinator of the 2022 edition of the Winter Workshop on Agricultural Entomology, it is my pleasure to provide event attendees with an e-book of excellent content, demonstrating the importance of our research to society.

Prof. Ricardo Antônio Polanczyk

FCAV/UNESP

PPG Entomologia Agrícola Coordinator

SUMÁRIO

CAPÍTULO 2

CONSERVATION PRACTICES FOR MAINTENANCE OF NATURAL ENEMIES IN AGROECOSYSTEMS

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1 I INTRODUCTION

Conventional agriculture has greatly impacted several agroecosystems due to improper management and constant, often indiscriminate, agrochemical applications. These products usually drastically reduce not only populations of insect pests but also their natural enemies, often causing imbalances and selective pressure for resistance in pest populations, also contributing to significant yield losses and negative impacts on the environment.

According to Michereff & Barros (2001), several environmental problems have occurred in conventional agriculture, including contamination of food, soil, water, and animals; intoxication of farmers; resistance of pathogens, insects, and invasive plants; biological imbalance, altering the cycling of nutrients and organic matter; elimination of beneficial organisms; and reduction of biodiversity.

Monocultures drastically interfere with the natural diversity of the environment, replacing a complex vegetative system with a few cultivated species. The use of agrochemicals from planting to harvest contribute to biological imbalances, where population outbreaks of insect pests compete with cultivated species, causing economic damage to the agricultural exploitation, environmental problems resulting from native vegetation destruction, biodiversity reduction, soil erosion, and contamination of natural resources and food.

According to Edwards (1989), agricultural systems must be redesigned and practices and conventional system inputs replaced, aiming at self-sustainability of agricultural production. Based on this premise, these methods should be used more often, which is not due to many institutional, economic, social, legal, and educational barriers (Zalom, 1993).

Thus, and according to Diniz et al. (2006), implementing alternative systems significantly reduces the risks of pollution and intoxication of operators and consumers. Notably, an integrated management involves conservationist practices, which are extremely important in agroecosystems, as integration between different management types has led to a reduction in agrochemical applications and environmental impacts, thus contributing to agriculture sustainability.

2 I SUSTAINABLE AGRICULTURE AS AN ALTERNATIVE TO THE TRADITIONAL MODEL

Agriculture became a practice more than 12 thousand years ago from means of subsistence and by advances such as adoption of chemical fertilization, crop rotation, mechanization, plant breeding, and transgenics. This agricultural practice intensified and modernized, starting to be referred to as “conventional agriculture” (Veiga, 1991; Costa Neto, 1999).

Although these advances have been revolutionary for the sector, as they have increased food supply to the population, they have had negative impacts on the environment, causing soil imbalance and narrowing down genetic biodiversity. Moreover, they increased susceptibility of cultivated varieties to attack by pests and diseases, leading to a dependence on agrochemicals, mainly insecticides and fungicides. The use of these products has promoted the emergence of chemical residues, contaminating the environment and human beings (Ehlers, 1994; Azevedo, 2018).

When conventional agriculture began to present problems due to the use of agrochemicals, biologist Raquel Carson played a very important role in raising awareness and changing behavior in relation to agricultural methods used, through the publication of her book “Primavera Silenciosa,” “Silent Spring” in English (Carson, 1962).

In the 1970s, many alternative systems emerged due to concerns about the negative impacts of conventional agriculture, including Organic Agriculture, Agroecology, Alternative Agriculture, Biodynamic Agriculture, Regenerative Agriculture, Natural Agriculture, Organic Agriculture, and Permaculture (Aubert, 1985; Carmo; Comitre & Dulley, 1988; Jesus, 1996; Zamberlam & Froncheti, 2007). However, these practices still had little adherence and financial support for adoption (Blobaum, 1984; Kramer, 1984; Hill, 1992).

After international meetings on environmental issues, the practice of more sustainable agriculture increased, which was positive for its political and economic reach (Ribeiro, 2001; De Passos, 2009). According to FAO (2001), sustainable agriculture acted efficiently in promoting crop production with available resources, offering food in quantity and quality to the population and preserving the environment.

According to Ehlers (1994):

> ...the notion of sustainable agriculture is still inaccurate and contradictory, ranging from the establishment of simple adjustments in the current production pattern to long-term goals that enable structural changes, not only in agricultural production but in society as a whole.

As Erhlers (1994), Weid (1994) compared conventional and sustainable systems, both authors observed imperfections in their literal states with a gradient between them, when combined, these practices result in a better production system that maintains productivity and preserves the environment.

Undoubtedly, the biggest challenge for agriculture is to combat food shortages. However, this problem cannot be solved without considering a sustainable management of natural resources and innovations in the sector, especially regarding pollution prevention (Da Veiga, 1994; Matten & Moon, 2020). In this sense, food production success becomes dependent on "sustainable innovations." Consumers want to purchase products of superior quality to those of conventional agriculture; therefore, a greater number of companies must adhere to this sustainable system (Hart, 1997; Hafezi & Zolfagharinia, 2018).

The search for sustainability in agriculture comes from the demand for production systems to adapt to processes that are less aggressive to the environment, farmers, and other human beings (Silva et al., 2013). Moreover, such an adhesion will result in healthier products in terms of toxic substances, and may even achieve lower production costs, as the use of external inputs is reduced (Canuto, 2021).

Recently, the Brazilian government (Ministry of Agriculture, Livestock and Supply - MAPA) has launched a sectoral plan for Adaptation to Climate Change and Low Carbon Emissions in Agriculture, aiming at a Sustainable Development (2020-2030), it is known as the ABC + Plan. This strategic view aims at productivity and sustainability of the domestic rural sector (agriculture and livestock), based on sustainable production technologies (MAPA, 2021).

In the Brazilian scenario, conventional agriculture is still predominant but has increasingly been adapted to a mix between conventional and sustainable practices, given technological advances in many social contexts of national agricultural production. In world agriculture, sustainability is inevitable, although it is an arduous task and requires medium and long-term structural changes, especially in the current agricultural context. Thus, work must be done to make the current scenario increasingly sustainable.

3 I CONSERVATIVE BIOLOGICAL CONTROL

Biological control is a major tool in Integrated Pest Management (IPM) programs. This tool can be applied either by maintaining existing natural enemies using selective products or releasing reared ones (Fernandes et al., 1999). In general, this method isefficient and compatible to be used in conjunction with other strategies, acting in harmony with the environment (Oliveira et al., 2004).

The arthropod complex in natural plant systems (herbivores [pests] and carnivores [natural enemies]) normally tend towards biological equilibrium. Such a situation can be obviously achieved without anthropic interference. Notably, biological control can and should be one of the alternatives to reduce impacts from pesticides applied in conventional farming system.

Based on agricultural aspects, biological control can be generically classified into three types: classic, augmentative, and conservative. The first refers to importation of exotic natural enemies to act on exotic or native pests; the second consists of inundative releases of parasitoids and predators, produced in biofactories; finally, the third is based on conservation and increase of natural enemies already present in the area (Ehler, 1998; Parra, 2000; EMBRAPA, 2006a; Abreu; Rovida & Conte, 2015).

Conservative biological control, then, refers to the population of naturally occurring enemies. In this model, one of the basic precepts of biological control must always be met, namely conservation. In this sense, populations of parasitoids and/or predators must be preserved through environmental manipulation, aiming at favorable conditions for survival, development, and behavioral and physiological performance of these organisms, since they are important/ essential for pest management programs (Barbosa, 1998).

A conservative biological control practice is one of the main tools of ecological management of insect pests. However, given the existing difficulty for interactions among plant populations, insect-pests, and natural enemies, this practice still has many challenges in terms of field applicability. Thus, it is essential to build conservative biological control strategies that are integrated with other practices carried out in a production system (Tylianakis & Binzer, 2014). This strategy requires more knowledge about the ecology of natural enemies present in agroecosystems. In addition, this method has numerous advantages such as ease of use, as well as being an alternative in pest management for sustainable crops, such as organic systems for example (Jonsson et al., 2008).

Natural biological control is based on taking care of natural enemies already present in farming areas, adopting practices to diversify agroecosystems (Landis et al., 2000). The agricultural practices, therefore, must influence populations of natural enemies within each agricultural system. In this sense, intercropping with companion plants can serve as a strategy, as it improves harmony and resistance to disturbances, in addition to enhancing environmental recovery (EMBRAPA, 2006b).

One way to increase the diversity of natural enemies in agroecosystems is adopting polyculture (plant diversity). This method consists of cultivation of a few plant species together, in intercropped or not (Altieri & Nicholls, 1999). According to Root (1973), abundance of natural enemies tends to be higher in diversified systems, since these increase the availability of foraging, refuge, and hibernation habitats (microhabitats). Such resources directly influence stability in phytophage population dynamics, favoring biology and dynamics of beneficial arthropods. Unlike monocrops, diversifying plant species in agroecosystems can directly influence the establishment of natural enemies of insect pests (Tschumi et al., 2015).

In diversified systems, biodiversity provides "ecological services" that go beyond production of food, fiber, energy, and income. This environmental characteristic promotes nutrient recycling, microclimate control, and regulation of water processes and abundance of undesirable organisms by predators, parasitoids, or pathogens (Aguiar-Menezes, 2004).

4 I PLANTS ATTRACTIVE TO NATURAL ENEMIES: BENEFITS AND STRATEGIES FOR MAINTENANCE AND INCREMENT

The success in introducing insect-attracting plants, also called "insectary plants," relies in the vital resources they provide such as shelter, mating, oviposition or hibernation sites, and food alternatives. These resources maintain the desirable insects in agrosystems, preventing their migration outside (Aguiar-Menezes & Silva, 2011; Naranjo et al., 2015; Wang et al., 2020).

Nectar and/or pollen, sometimes extrafloral nectar, represent alternative food resources for non-carnivorous life stages of parasitoids and certain predatory insects. These dietary items can also be a food supplement if prey is of inferior quality, or nutritional supplement when of superior quality (Portillo et al., 2012; He et al., 2021).

Floral resources act as vital sources for some beneficial insects, acting directly on their survival, fecundity, longevity, retention time, and immigration, positively influencing biological control (Aguiar-Menezes & Silva, 2011). They may also harbor non-pest phytophagous insects, which serve as alternative hosts or prey for entomophages, particularly when pests are at low population levels or absent (Souza et al., 2021).

Hinds & Barbercheckb (2020) demonstrated the importance of insectary plants for natural enemies, noting that buckwheat and cowpea increase longevity and fecundity of *Orius insidiosus* (Hemiptera: Anthocoridae). Irvin, Pierce & Hoddle (2021) proved the efficacy of buckwheat in increasing longevity of *Tamarixia radiata* (Hymenoptera: Eulophidae), as well as the number of mature eggs in ovaries. Another example of successful introduction of insectary plants was *Cnidium monnieri* (Apiaceae) in apple orchards, attracting natural enemies and providing efficient control of aphids (Cai et al., 2020).

Introducing or adding strips of insectary plants for beneficial insects between or around crop rows is one of the most feasible alternatives for farmers to increase population and diversity of biological control agents (Aguiar-Menezes & Silva, 2011). For instance, flies of the Syrphidae family benefit from attractive plant strips introduced in simple landscapes, with little plant complexity, since these predators can easily identify floral resources where there are not so many odors being emitted (Haenke et al., 2009).

Preliminary studies are crucial to identify the effect of attractive plants on natural enemies and protected crops (Winkler et al., 2010). One aspect to be considered is the distance between plant strips that benefit natural enemies in the field. Chaney (1998) mentioned that growing one row of alyssum [*Lobularia maritima* (Brassicaceae)] every twelve rows of lettuce [*Lactuca sativa* (Asteraceae)] benefits the parasitoid *Diaretiella rapae* (Hymenoptera: Braconidae).

Despite the increase in biodiversity and sheltering, the introduction of insectary plants into an agricultural environment can also interact negatively with beneficial insects (Gontijo, 2019). Not every plant or floral resource will attract natural enemies or ensure an effective biological control (Moore et al., 2019). Some plants and their floral resources can interact benefiting pests and reducing the effectiveness of their natural enemies (Moore et al., 2019) due to interactions among themselves (Lavandero et al., 2006; Jonsson et al., 2009).

Unsuitable shelters in crops can hamper biological control by undermining natural enemy movements, harboring pests, diverting predator attacks, mediating antagonistic interactions among insects (pests or not), and providing poor vital resources to support natural enemy populations. Such interactions depend on several factors, particularly plant traits, in addition to the physiology and behavior of arthropods involved. Understanding how these interactions occur is essential to plan and apply the most suitable shelters for natural enemies (Gontijo, 2019).

5 I CROP PRACTICES AND AGRICULTURAL LANDSCAPE MANAGEMENT: FEASIBLE AND LOW-COST STRATEGIES

One of the main current challenges for Brazilian and global agriculture is to ensure food security, combined with biological diversity conservation (Sunderland, 2011; Abranches, 2020). Over the last 50 years, the world population has grown unprecedentedly, and advanced techniques of food production have been developed, reducing the world's hunger. However, 30% of the world's population is still under-nourished (Uzêda et al., 2017; SOFI, 2021), demanding an increase in agricultural production by 60% to secure world's food supply until 2050 (SOFI, 2021).

However, increases in agricultural production have come at the expense of natural resources. The main tangible aspect has been significant changes in landscapes, converting natural areas into land used for production. This process makes the areas less complex and more homogeneous (Butcart et al., 2010), with 80% of the terrestrial surface being under anthropic alterations (Ellis & Ramankutty, 2008).

In this way, landscape can be broadly understood as a hybrid entity, building specific and interspecific natural, social, and cultural relationships (Uzêda et al., 2017). Agricultural landscape is highlighted for having numerous characteristics of its own, such as: intensity of crop management, extensive and routine soil management practices, in addition to wide and diversified use of inputs (Chabrerie et al., 2013), generally shaping local and regional landscapes.

Furthermore, the mosaic formed by current agricultural systems allows the formation of large and continuous homogeneous sites of land use system. These spaces are not very different from each other and are defined as monocultures. The dynamics of these places with their surroundings must be widely understood, defining appropriate management for agricultural production and conservation of diversity at the landscape level.

Despite being homogeneous, agricultural landscapes can favor the natural occurrence of organisms of interest, especially pollinators and natural predators (Landis et al., 2000; Langelloto & Denno, 2004). However, they must be properly managed to promote biodiversity corridors, reducing the effects of isolated fragments, depending on cultivation system, management, and land-use intensity (Gabriel et al., 2010).

Responses of organisms of agricultural interest, as well as others, occur on wide space-time scales (Benton et al., 2002). Therefore, biotic interactions, and mainly observed diversity patterns, are often conducted to multiple habitats and at different times (Tscharntke et al., 2005).

In this sense, extensive multiple-scale studies are needed (Gabriel et al., 2010), always considering agricultural landscapes of interest and local and regional mosaic. With this, potentialities of these areas can be identified, since food demand will continue to increase, and environmental issues will continue to be a trend.

In natural ecosystems, abundance of herbivores rarely increases to the point of causing noticeable damages such as massive loss of biomass and deleterious effects on plant reproduction (Sujii et al., 2010). This is largely due to the natural fluctuation of their populations and dynamism of naturally occurring ecological interactions (Townsend et al., 2006; Ricklefs & Relyea, 2016). These interferences result in beneficial or deleterious interactions at a specific (same species) or interspecific (different species) level (Ricklefs & Relyea, 2016).

In this sense, different forms of specific competition can be observed in production fields. Therein, plants of interest are specifically and minimally spaced, interfering little with each other during their growth and development. The current agroecosystem approach enables certain inferences consistent with well-established ecological theories, in which the more complex a habitat (landscape), the more resilient and productive it will be (Gliessman, 2005; Ricklefs & Relyea, 2016).

5.1 Crop intercropping and rotation

Intercropping and rotation systems are based on associations of two or more crop species, which have different life cycles and vegetative architectures. Examples of that can be corn and beans, corn and brachiaria, and soybeans and brachiaria, among others. Living mulch or cover crops can also be considered intercropping with species planted intentionally or grown spontaneously. These plants have special functions to the soil, such as reducing raindrop impacts; increasing soil water retention, porosity, and aeration; and decreasing temperature and humidity oscillations. Moreover, these roles of cover plants help to increase edaphic fauna and soil microbiological activity (Hartwig & Ammon, 2002).

Polycropping allows the maintenance of different plant groups simultaneously, making habitats more complex and heterogeneous. Such systems are often composed of vegetation mosaics that make it difficult for pests to locate resources. They also hinder weed establishment, which can negatively interfere with crop production (Root, 1973).

5.2 Agroecology or Agroforestry

Agroecology has gained a lot of prominence nowadays. This approach involves a way of producing food using few external inputs. In this system, human life and human and environmental health are valued in a broad perspective. Its differential is to include local and/or popular knowledge, which was historically built by the population (Gliessman, 2001;

Caporal, 2016; Reiniger et al., 2017). In turn, agroforests are adaptations of these concepts to forest environments, where there is a predominance of tree species, with concomitant exploitation of resources in natural environments.

6 I CHEMICAL PEST CONTROL: SEARCH FOR SELECTIVE PRODUCTS/ BOTANICAL ORIGIN INSECTICIDES

Food production has always been a great challenge for humanity. One of the main hurdles is the attack of insect pests, which have destroyed about a fifth of the world's total agricultural production annually (Hikal et al., 2017). In this scenario, insecticides have been the main strategy used for control, due to the ease of acquisition, high biological efficiency, low cost, and already established management and application programs.

A large part of the world market for insecticides is still dominated by synthetic products (organophosphates, carbamates, sulfonamides, pyrethroids, among other classes). However, these agrochemicals are widely reported as responsible for damages to both non-target organisms and the environment. Parallel to this, another important factor regarding synthetic insecticides is their persistence in the environment, which allows their accumulation at different food-chain trophic levels (Devine et al., 2008; Chowańsk et al., 2014). In recent decades, for example, many studies have shown the presence of agrochemical residues in food, soil, and water.

Much is discussed about economically viable and at the same time sustainable alternatives to synthetic insecticides. Some of these alternatives for controlling insect pests were presented throughout the chapter; yet insecticides of botanical origin are yet to be discussed. Looking back, botanical insecticides were once the main form of pest control in crops around the world and are still widely used nowadays. The number of studies on the use of substances of botanical origin to control pest arthropods has increased considerably in recent years, mainly due to the number of plant species that can be exploited and the ease of obtaining plant material.

Plants are rich sources of bioactive chemical compounds, which can be found in several species (Table 1). These compounds normally play a defense role in plants against pathogens and herbivores, in addition to modulating the relationship with pollinators, natural enemies, and seed spreaders. The compounds accumulate in small proportions in plant tissues and, from them are obtained powders, botanical extracts, and essential oils that can often be used as insecticides, repellents, and attractants in agriculture.

Extraction of essential oils requires elaborate equipment and techniques. Their applicability to agriculture depends almost entirely on the acquisition of those available in the market. At the same time, extracts and botanical powders can be produced by farmers themselves ("on farm"), using plants grown on their properties. Powders are obtained from dried and ground plant tissues, while extracts by contact of plant parts previously ground or not with solvents (water, ethanol, among others) (Santos et al., 2013). Compared to essential oils, extracts are less stable in the environment (mainly aqueous) and less concentrated in active ingredients. However, extracts need less sophisticated equipment to be prepared, in addition to less plant material for processing, thus reducing cost compared to essential oils.

When compared to synthetics, botanical insecticides (powders, extracts, and oils) are usually less toxic to non-target organisms, mammals, and plants; biodegradable; fast-degrading; and highly selective. Despite these advantages, plant origin insecticides cannot be considered harmless, as the toxic potential of a molecule varies with their chemical structure and not origin (Coats, 1994). Thus, all insecticides, whether synthetic or biological, must undergo tests for persistence in the environment and toxicity to non-target organisms.

After analyzing the advantages and risks of botanical insecticides, why are there still few products available on the market? In fact, many of the tested botanical insecticides have higher production costs than do the synthetic ones. This high cost comes from a lack of raw materials for production on a commercial scale. Moreover, the complex chemical characteristics of oils and extracts make it difficult to standardize formulations in terms of amounts of active ingredient with insecticidal properties. Thus, they cannot be launched on the market as regulatory bodies require proof of the concentrations of active ingredients (Shivkumara et al., 2019).

Botanical species	Main insecticidal compounds	References
Allium sativum	Methyl Allyl Disulfide, Diallyl Trisulfide	Ahmad et al. (2018)
Azadirachta indica	Azadirachtin	Tulashie et al. (2021)
Cinnamomum verum	Cinnamaldehyde, Eugenol	Marčić (2021)
Lonchocarpus negrensis	Rotenone	Doracenzi et al. (2021)
Melia azedarach	Isoxazole, Benzothiazoles	Khoshraftar et al. (2020)
Mentha piperita	Menthol, Menthone	Marčić (2021)
Nicotiana tabacum	Nicotine	Sarker and Lim (2018)
Piper nigrum	Piperamides	Scott et al. (2008)
Sophora flavescens	Oxymatrine, Matrine	Kim et al. (2009)
Syzygium aromaticum	Eugenol	Marčić (2021)
Tagetes erecta	α-terthienyl	Supriani and Wardini (2018)
Tanacetum cinerariifolium	Pyrethrum	Marčić (2021)
Thymus vulgaris	Thymol	Vite-Vallejo et al. (2018)

Table 1 - Some botanical species with insecticidal activity described in the literature

Botanical insecticides have a promising future in an increasingly demanding market for healthy food and sustainable production. Nevertheless, the focus of research has to be changed so that these insecticides could reach the consumer market, seeking technologies that allow the standardization and use of already known botanical insecticides, favoring their commercial production.

7 I FINAL CONSIDERATIONS

Conservation agronomic practices should be adopted to improve natural enemy richness and diversity in agroecosystems. The combined use of these strategies can increase resilience in these environments and decrease disturbances due to intense human interventions.

As discussed in this chapter, several methods can be used to maintain and attract natural enemies in agroecosystems. The techniques range from adoption of more sustainable production systems, against the so-called conventional agriculture, until pest control strategies deemed environmentally and socially safer.

With increasingly advanced studies and new research results published daily, besides an increasingly demanding consumer market for healthy and contaminant-free foods, conservation practices have become a cornerstone for current and future agricultural systems. The recognition of the importance of natural enemies and their contribution to insect pest population maintenance, as well as cost reductions agrochemical sprays, has led more farmers to use conservationist agronomic practices on their properties, highlighting the strong growth of the market of bioproducts acting against agricultural pests.

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