

Effects of Fruit-Crop Agroforestry Systems on Pest and Natural Enemy Diversity

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Abstract: Agricultural intensification has led to an increase in monoculture and the use of chemical pesticides, resulting in a decline in biodiversity and a reduction in ecosystem services, particularly biological pest management. However, studies have shown that agroforestry can not only improve land productivity and biodiversity but also regulate some ecosystem services. This study reviews the impacts of physical and biological factors on herbivorous pests, parasites, and predatory natural enemies in fruit-crop agroforestry systems. Fruit-crop agroforestry systems provide high spatial heterogeneity by altering crop layouts, regulating the microclimate and soil quality, and offering food resources and shelter for natural enemies, thus promoting biological pest control. This enhances biological control and makes the agrocomplex system an effective tool for sustainable agriculture. Our research shows that volatile plant substances attract or repel pests and natural enemies based on the characteristics of the insects themselves. When scientifically designed, fruit-crop agroforestry systems provide high spatial heterogeneity and favorable microclimatic conditions, which enhance biological pest control and make the agroforestry system an effective tool for sustainable agriculture. Our research shows that fruit-crop agroforestry systems can provide richer food resources and habitat, enhancing biological pest control and improving pest management.

Keywords: agroforestry, pest, natural enemy, biodiversity, effect factors

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果农复合系统对害虫和天敌多样性的影响

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摘要: 农业集约化导致单一作物种植和化学农药使用的增加, 从而导致生物多样性的下降和生态系统服务的减少, 尤其是生物害虫管理。然而, 研究表明, 农林复合系统不仅可以提高土地生产力和生物多样性, 还可以调节一些生态系统服务。本文综述了物理因素和生物因素对果农复合系统中食草害虫、寄生虫和捕食性天敌的影响。果农复合系统可以通过改变作物布局、调节农田微气候和土壤质量, 为天敌提供食物资源和栖息地, 提供了高度的空间异质性。这增强了生物害虫防治, 使农林复合系统成为可持续农业的有效工具。研究发现挥发性植物物质根据昆虫自身的特征吸引或驱赶害虫和天敌。由此表明, 科学设计的果农复合系统提供了高度的空间异质性和有利的微气候条件, 还可以为天敌提供更丰富的食物资源和栖息地, 以增强生物害虫控制并改善害虫管理。

关键词: 农林复合系统; 害虫; 天敌; 生物多样性; 影响因素

To address future challenges in climate, economics, and society, agriculture must enhance productivity, stability, and resilience while minimizing environmental impacts^[1]. While

agricultural productivity has historically been boosted by the heavy use of chemical fertilizers and pesticides, these practices have led to negative environmental consequences, including

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biodiversity loss and soil degradation. Agricultural intensification, through increased monoculture and chemical pesticide use, reduces biodiversity and negatively impacts ecosystem services, including pest management^[2-3]. These services include decomposition and nutrient cycles, pollination, and biological control^[4]. For instance, while chemical fertilizers and pesticides can increase crop yields, they also impact species richness, community composition, and the abundance of individual species, thereby altering species interactions, the food web structure, and ecosystem function^[5]. Biological pest control is an ecosystem service of great economic value provided by predators, parasitoids, and pathogens^[6]. The suppression of crop pest populations by natural enemies provides environmental and economic benefits as it reduces yield loss without the negative environmental consequences due to chemical pesticide use^[7]. Conservative biological control aims to improve and maintain alternative food resources and habitat quality for naturally occurring pests and natural enemies in agricultural ecosystems, especially by increasing the diversity of plants or habitats in or around the field^[8]. The primary factors influencing natural enemy population dynamics in agricultural environments are food supplies, such as alternative arthropods or prey, hosts, and resources for pollen and nectar, shelter, or nesting locations^[9-10]. In the context of agroecological intensification, diverse farming systems such as agroforestry have received renewed attention^[11]. Agroforestry systems, which incorporate trees into agricultural land, not only promote sustainable intensification by increasing land productivity and biodiversity but also help regulate ecosystem services, including pest control^[12]. Through enhanced biodiversity and spatial complexity, agroforestry systems, through enhanced biodiversity and spatial complexity, create environments that support natural enemies of pests, thus enhancing their potential for biological control^[13-14]. Notably, spatial heterogeneity caused by alternation between tree rows and crops may

facilitate differential habitat use by predators, as in the use of strips as refuge and breeding habitat and crops as foraging habitat^[15]. The main potential of agroforestry systems to resist pests and diseases in general lies in the ability to create environmental conditions that are favorable to crops and unfavorable to pests. A well-designed agroforestry system can increase plant resistance to pests and diseases by providing ample shade, reducing temperature extremes, avoiding high winds, and improving soil fertility. This also affects the conditions under which pests and their predators thrive. However, poorly designed agroforestry systems can increase crop susceptibility to pests and diseases due to excessive competition for light, water, and soil nutrients, which may undermine their potential for pest control^[16].

Many studies^[6] have demonstrated the benefits of agroforestry systems, including improved soil quality, microclimate regulation, and better weed control. Agroforestry also enhances crop productivity and stability while optimizing the use of environmental resources such as water, light, and nutrients. Despite these well-documented benefits, few studies have specifically explored the impact of agroforestry on herbivorous and predatory arthropods, particularly in terms of abundance and diversity^[17]. This review aims to explore factors influencing biological pest control in agroforestry systems. This could assist future agricultural workers to be more thoughtful when using fruit-crop agroforestry systems for biological control to design fruit-crop agroforestry systems that can effectively produce biological control. Future research should focus on experimental studies that quantify the impact of various agroforestry designs on pest and natural enemy dynamics to optimize agroforestry for pest management.

This article provides a comprehensive study of how agroforestry affects arthropod communities in agroecosystems and assesses the biological control potential of agroforestry. Therefore, the primary objective of this review is to answer the following questions: (1) What key factors in fruit-crop

Tab.1 A partial list of the complete literature used

Number	Crop pattern	Factors	Pests and enemies	Region	Influence (+/-)
1	Apple/Alfalfa	Soil organic ↑	<i>Aphos citricolavander Goot</i> ↓ / <i>Chrysoperla sinica Tjeder</i> , <i>Coccinellidae</i> , <i>Parasitoid</i> ↑	Shandong, China	+
2	Apricot/Cotton	Microclimate ↑	<i>Miridae</i> , <i>Tetranychus cinnabarinus</i> ↓	Xinjiang, China	+
3	Apple/Pea	Soil organic ↑	<i>Coccinellidae</i> , <i>Chrysoperla sinica Tjeder</i> , <i>Orius similis Zheng</i> ↑	Hebei, China	+
4	Apple/Various grassses	Vegetation, food, shelter ↑	<i>Stability of arthropod community structure</i> ↑	Hebei, China	+
5	Peach/Various grassses	Vegetation, food, shelter ↑	Predator of predatory insects ↑	Guizhou, China	+
6	Persimmon/Various grassses	Soil temperature ↓ quality ↑	<i>Aphidoidea</i> , <i>Frankliniella intonsa</i> , <i>Tetranychus cinnabarinus</i> ↑	Hebei, China	+
7	Apple/Various grassses	Habitat ↑	<i>Orius similis Zheng</i> ↑	Shandong, China	+
8	Pear/Aromatic plants	Volatile substance	<i>Homoptera</i> , <i>Holotrichia oblita</i> ↓ / <i>Coccinellidae</i> , <i>Hyme-noptera</i> , Pollinator ↑	Beijing, China	+
9	Apple/Mint	Volatile substance (hide)	Pest subcommunity abundance ↓	Beijing, China	+
10	Apple, jujube/Cotton	Crop pattern, Microclimate	<i>Miridae</i> , <i>Tetranychus cinnabarinus</i> ↓ / Spider natural enemy ↑	Xinjiang, China	+
11	Walnut, jujube/Wheat	Wind Speed, temperature, photosynthesis ↓	<i>Macrosiphum avenae</i> ↑	Xinjiang, China	-
12	Peach/Cotton	Crop pattern, habitat	<i>Macrosiphum avenae</i> ↓ / <i>Tjeder</i> , <i>Coccinellidae</i> ↑	Xinjiang, China	-
13	Walnut/Wheat	Microclimate, sanctuary	<i>Coleoptera</i> ↑	France	+
14	Apple/Pea	Trap crop	<i>Aphidoidea</i> ↓	Sweden	+
15	Walnut/Vegetables	Microclimate ↑	<i>Sider natural enemy</i> ↑	France	+
16	Jujube/Cotton	Vegetation, food, shelter ↑	<i>Tetranychus cinnabarinus</i> ↑	Xinjiang, China	-
17	Apple/Grains	Soil organic ↑	<i>Enemy</i> ↑	England	+
18	Aspen/Winter wheat	Microclimate	<i>Aphidoidea</i> ↓	France	-

Tab.2 Frequency of physical and biotic factors present in fruit-crop agroforestry systems with increased '+' and reduced '-' activity of natural enemies and pest pressure (m; microclimate, p; pattern, h; habitat condition, v; volatile substances, d; population dynamics)

	Effect	Physical factors			Biotic factors	
		m	p	h	v	d
Natural enemies	+	42%	8%	67%	8%	0%
	-	0%	0%	0%	0%	0%
Pest pressure	-	18%	9%	9%	27%	0%
	+	9%	9%	18%	0%	0%

agroforestry systems influence biological pest control?

(2) How do these factors impact pest and natural enemy dynamics? (3) How can agroforestry systems be designed for optimal pest control?

1 Materials and methods

To find the articles likely to be most useful for research, we conducted a literature search using the Web of Science that focused on literature published prior to 2021. In an initial screening, we excluded some studies because they were not sufficiently

relevant to our topic of interest or did not provide up-to-date information due to their age. For example, some studies may have focused on other types of agroforestry systems rather than fruit tree agroforestry systems and were therefore excluded. In addition, some studies may not have provided sufficient data or methods and were excluded. After screening, we identified a number of studies reporting on the effects of fruit-crop agroforestry systems on herbivorous pests, predators and natural enemy parasites. The literature we reviewed mainly includes three

types: intercropping of fruit trees with cereals, legumes and grasses. After further in-depth reading and analysis of the literature, we finally adopted those studies that explored the effects of biological factors (volatile matter and habitat improvement) and physical factors (arable land microclimate and planting conditions) on pests, predators, and predators in fruit agroforestry systems. and the study of the effects of natural enemy parasites. These studies provide important insights into the role of physical and biological factors in fruit agroforestry systems and have high reference value for our research questions. Approximately 35% of the literature described physical factors, such as the arable land microclimate and planting, and 65% described biological factors, such as volatile substances and habitat improvement. Regions included Asia, Europe, and North America. However, we found a lack of data on the impact of agroforestry on plant diseases, and the impact on a large number of invertebrate pests and natural enemies was unclear.

The literature selection was based on the following criteria: (1) studies conducted at a plot, field, or farm scale; (2) studies explicitly addressing factors influencing the regulation of plant pests and diseases in fruit-crop agroforestry systems; and (3) experimental settings allowing for adequate research. The same staple crops were used in both the treatment and control.

2 Results and Discussion

2.1 Physical factors

The following conclusions were obtained. First, both physical and biological factors were beneficial for an increase in natural enemies, and when expressed as percentages, natural activity was most often associated with habitat (67%), followed by farmland microclimate (42%), and less with planting patterns (8%) and volatile substances (8%). The reduction in pest stress was typically associated with volatile substances (27%), followed by farmland microclimate (18%), and

finally planting patterns (9%) and habitat (9%). A total of 18% of the literature reported that an increase in pest stress was also associated with habitat, followed by microclimate (9%) and planting patterns (9%). However, incompleteness of the data prevented general conclusions regarding changes in the population dynamics of natural enemies and pests.

2.2 Regional and climate

The impact of climate change on pest and natural enemy populations is significant. Rising temperatures and changing precipitation patterns directly affect the growth and reproduction of pests^[18]. For instance, the outbreak of brown planthoppers is closely related to their adaptability to environmental factors; climate change has made their living conditions more favorable, leading to an increase in their population numbers^[19]. Additionally, global warming alters the structure of plant communities, which in turn affects the habitats of pests and the predation efficiency of natural enemies. Research indicates that climate change not only influences the physiological characteristics of pests but may also indirectly affect pest population dynamics by altering the living conditions of their natural enemies. Secondly, the ecological environment and land use patterns of a region significantly influence the population structure of pests and natural enemies. Changes in agricultural landscapes, such as the expansion of arable land and the disappearance of non-crop habitats, lead to the simplification of farmland ecosystems, which affects the occurrence of pests and the biological control functions of natural enemies^[20]. For example, the expansion of farmland may lead to an increase in pest populations, while the number of natural enemies may decline due to habitat loss; this imbalance exacerbates pest damage^[21]. Moreover, the impact of land use transformation on the ecological environment is increasingly being recognized, especially in the context of climate change, where changes in land use may lead to alterations in regional climates, further influencing the interactions between pests and natural enemies^[22]. Finally, the regional climate

characteristics, such as precipitation patterns and temperature changes, also play a crucial role in the population dynamics of pests and natural enemies. Studies have shown that variations in precipitation affect soil moisture and plant growth, which in turn influence the habitats of pests and the living conditions of natural enemies^[23]. For instance, pest populations in arid regions may decrease due to insufficient moisture, while in humid regions, favorable growth conditions may lead to an increase in pest populations. Simultaneously, climate change may also cause some pests to migrate and spread, affecting their distribution and population dynamics across different regions^[24].

In summary, different regions and climatic conditions influence pest and natural enemy populations in agroforestry systems through multiple mechanisms. Climate change, land use patterns, and changes in the regional ecological environment collectively alter the dynamic balance between pests and natural enemies, thereby impacting agricultural production and the health of ecosystems.

2.3 Agricultural microclimate

The existence of trees in an agroforestry intercropping system changes the crop growth environment with regard to such factors as light, temperature, water, and wind speed^[25]. Chao et al^[26] showed that the intercropping of apricot and cotton significantly changed the microclimate of the farmland. Compared with a monocrop field, the air temperature, surface temperature, and wind speed of an intercrop farmland were significantly reduced, and the air humidity was relatively increased. This indirectly affects the community structure of arthropods and the natural enemies in the community^[27]. Because insects are ectothermic, their metabolism, activity, and feeding rates are particularly susceptible to small changes in ambient temperature. Tree rows alter the microclimate of the crop, and this altered temperature may alter the developmental rate of insects, including aphids and their natural enemies^[28]. In the range of 10 ~ 20 °C, the developmental rate and reproductive rate of aphids

increased with increasing temperature, and the lower abundance of aphids in arable interrow rows may have been due to relatively lower temperatures^[29].

Since most of the movement of these small insects is passive and aerial, windbreaks in rows of trees can also affect aphid colonization in crops^[30]. The dispersal of flying insects is affected by air movement around obstacles and at the edges of crops, and the presence of trees not only slows down the wind speed but also acts as a physical barrier to facilitate the landing of pineapple aphids between rows of intercropped crops^[31]. The dispersal patterns of insects in shady crops and in the air are primarily determined by the height and permeability of windbreaks and the direction of prevailing winds^[32].

Fruit-crop agroforestry systems have a certain shading effect compared to monocropping fields due to their high spatial heterogeneity, and the shading and accompanying humidity increase and temperature decrease affect both pests and their predators. Many Hymenoptera parasitoids exhibit greater host-seeking capabilities in unshaded conditions, so the efficiency of Hymenoptera parasitoids as natural biocontrol agents should be higher^[33]. It should be noted that this also depends on the characteristics of the pest. For example, most aphids prefer shaded conditions in warm climates, while the density of herbivorous beetles on bean monocultures is higher than that on maize under shade^[34]. A study by Martin-Chavel et al.^[35] found that in a 20-year-old organic vegetable crop and hybrid walnut tree agroforestry system, different levels of shading treatments had different effects on the species distribution, such as two species of spiders appearing in a tomato crop field. The shaded treatments had significantly higher activity densities than the controls, while the lowest number of drought-loving species (*Pseudoophonus rufipes* (Coleoptera, Carabidae)) was observed in the two most shaded treatment plots. The management of a crop (such as fertilization), regional environmental factors (such as temperature and rainfall), and the prevalent pests and pathogens at the location in

question all play a role in determining which level of shading is best for a particular crop.

2.4 Crop type and layout

When new species are added to an agroforestry system, the impact on pests and diseases often depends on the identity of the species rather than its diversity. If the wrong species are selected, agroforestry systems may experience the same or even higher rates of pest infestation than simple agricultural systems. As such, the key to using plant diversity to reduce pests is that related species are neither hosts to pests nor share the same pests and diseases^[16]. Li et al.^[36] found that under the two modes of a cotton-jujube intercrop and a jujube monoculture, the overall abundance of spider mites (*T. troncatus* and *T. dunhuangensis*) under the intercrop mode was generally higher than that under the monoculture mode. This is because spider mite phytophagous pests—which can feed on a variety of host plants—feed on both jujube and cotton, resulting in cross-spreading of the pest between the two. Zhang et al.^[37] observed that different planting layouts had different effects on pests and natural enemies in apple orchards, and the results showed that the number of natural enemies in alfalfa apple trees planted in alternate rows was the highest. In other instances, greater pest diversity may result in lower predator foraging rates due to higher vegetation complexity or the presence of alternative prey species that divert predators' attention away from the target pests. This is because the response of pests to intercropping may be species-specific and also influenced by the pest diet and the range of host plants^[38]. The spatial arrangement of plants is crucial in preventing the spread of pest and disease organisms throughout the system, in addition to choosing species that are compatible with one another. For example, almond-cotton intercropping (north and south directions) is beneficial to the occurrence of cotton field aphids and predatory natural enemies, while almond-cotton intercropping (east and west directions) is not conducive to their occurrence^[39].

2.5 Benefits of grass in orchards

The use of chemical pesticides and clear tillage management have seriously damaged the ecological environment of orchards, making natural enemies lose the basis for survival and reproduction^[40]. The increase of vegetation between orchard rows can not only improve the basic quality of the soil, increase soil fertility, thereby improving the resistance of fruit trees and fruit quality, but also provide sufficient nectar source plants and alternative prey for natural enemy insects, and at the same time become a seasonal harvest and orchard use Pesticides are good niches and shelters for natural enemies. Grass in orchards has obvious proliferation and protection effects on natural enemies. Plants can attract natural enemies and other herbivorous pests on plants, which strengthens the control of herbivorous pest populations. The above is also the main reason for the relatively low number of herbivorous pests^[41]. Long et al.^[42] found that by artificially planting *Phoenix glabra* in rows of persimmon trees, the heat preservation and moisture retention capacity of the soil in the orchard was strengthened, and the soil fertility and air permeability were significantly improved, especially the organic matter content of the persimmon orchard soil. The artificial planting of *Vitex glabra* significantly increased the types and numbers of natural enemies of orchard aphids, thrips, red spiders, and other pests and played a role in biological control. Furthermore, Zhao et al.^[43] found that compared with clear plowing orchards, the number of species of natural enemy insects in an orchard planted with ryegrass + white clover + alfalfa increased by eleven species, the occurrence period of the primary natural enemies was advanced and prolonged, the control effect on important orchard pests reached 90%, and there was no obvious peak period for the occurrence of pests. Therefore, the rational layout of ground vegetation not only contains huge natural enemy resources but can also adjust the community structure of arthropods in the canopy, which is conducive to the establishment and reproduction of enemy populations

in early spring and reduces the population density of the pest balance point.

In an orchard ecosystem, predatory and parasitic natural enemies have a strong control effect on herbivorous insects, thus becoming important factors that affect the stability of the arthropod community structure. The diversity of orchard ground cover plants is closely related to the diversity of arthropod communities. Grass growth in orchards can increase the types and quantities of ground vegetation in orchards, improve their habitats, create favorable conditions for the protection and proliferation of natural enemies, and help natural enemy populations overcome food shortages. The interference of an adverse environment can enhance the dynamic complementarity of natural enemy populations at multiple temporal and spatial scales^[44].

2.6 Plant volatile substances

Plant volatile substances are a type of small molecule compound produced during plant secondary metabolism, which play a vital role in phytochemical defense and are also the medium of communication between plants and plants and plants and insects. Plant volatile substances participate in host selection and status processes in herbivorous insects^[45]. In addition, plant volatile substances have a direct or indirect impact on the process of insect oviposition and reproduction, pest trapping, and natural enemy insect predation and positioning^[46]. Volatile organic chemicals (VOCs) are abundant (primarily terpenes, alcohols, aldehydes, esters, and aromatic compounds) and non-herbivorous insects (pollinators, predators, and parasitoids) are susceptible to these chemical signals when hunting their prey^[47]. Research performed by Lenardis et al.^[48] found that *Artemisia annua* produces and releases secondary metabolites (primarily terpenes) that can have positive interactions with soybean crops that are beneficial to the richness of insect communities without reducing crop yields. This is due to the production of secondary metabolites that may be an alternative food for herbivorous insects. It is known

that the effect of *Artemisia annua* on attracting or repelling insects depends on the proportion of plant species and the biomass of each species. Huang et al.^[49] found that intercropping mint in apple orchards can adjust the growth relationship between natural enemies and pests, making the control effect of natural enemies on pests better, thereby reducing the abundance of pest subcommunities and affecting the apple orchard arthropod communities, as well as the structure of pest and natural enemy subcommunities. This may be because the volatile organic compounds of aromatic plants have repellent properties that reduce the feeding frequency of dominant pests, interfering with the habitat selection behavior of pests and reducing the egg-laying rate and larval survival rate of pests, thus reducing the overall occurrence of pests^[50]. Intercropping aromatic plants in pear orchards can significantly reduce the occurrence of Homoptera (primarily psyllids) and scarab pests and significantly increase the number of natural enemies of ladybugs, parasitoids of Hymenoptera, and neutral pollinators, optimizing the composition structure of various groups of arthropod communities in pear orchards. This is also of great significance for the continuous regulation of harmful insects in pear orchards, pollination, and pollination during flowering. This is because lush aromatic plants can provide natural enemies with habitat, shelter, intermediate hosts, food, and attractants, increasing the abundance of natural enemies and thereby inhibiting the occurrence of a large number of pests in pear orchards. In orchard intercropping, the selection of aromatic plant species, intercropping methods, intercropping times, and other orchard intercropping modes and the biodiversity regulation mechanisms of different modes also need to be considered in actual production and application^[51].

2.7 Population dynamics of pests and natural enemies

With an increase in the predator population, the prey population gradually declines. When the prey population drops to a certain value, the number

of the predator population declines due to hunger. Hence, the prey population can recover until the prey population reaches a certain value. When the population density rises to a higher density, the number of predator populations increases again, and the cycle continues^[52]. A variety of natural enemies have obvious hysteresis effects on pests, indicating that predatory natural enemies have a following effect on herbivorous pests. Zhang et al.^[53] observed in northern mountainous peach orchards that were compared with a clear tillage treatment, the rise in herbivorous insects on the ground in the grassland was likely connected to a rise in predatory natural enemies under the trees.

The hosts of the leafhopper are primarily gramineous weeds that are harmless to fruit trees and are one of the prey of predatory natural enemies in peach orchards. Therefore, the number of leafhoppers in grasslands is relatively large. Regardless of a clear tillage or grass treatment, when the number of leafhoppers is low, the number of natural enemies gradually decreases, and when the number of leafhoppers begins to increase, the number of predatory natural enemies follows closely, and the number also gradually increases. This is a relatively obvious dynamic relationship of mutual growth and decline. Of course, this dynamic relationship is restricted by the quality and quantity of prey resources of ground vegetation and fruit tree crowns as well as the biological and ecological characteristics of different types of natural enemies^[54]. Ladybugs, lacewings, and small flower bugs are the primary predatory natural enemies in Taoyuan. These natural enemy insects have strong dispersal abilities and easily migrate between the crown and the underside of the tree. Therefore, when the number of natural predators under the tree increases, they can migrate to the tree, thereby increasing the number of natural enemies in the canopy and strengthening biological control^[55].

Pests cannot be typically controlled below a certain economic threshold level in this case because the predator population response is insufficient

to overcome the growth of the pest population. Therefore, the early seasonal arrival of predators is an important prerequisite for pest control. In an orchard ecosystem, planting insectary plants (insect plants) can provide natural enemies with pollen, nectar, and alternative plants as food resources, which is beneficial for predators to lay eggs and reproduce on plants in advance, thereby increasing the population and population of predatory natural enemies. Diversity and predatory natural enemies from insectary plants can be transferred to fruit trees for the biological control of pests^[56]. This control measure is common in many fruit-crop agroforestry systems.

We have discussed which factors in fruit-crop agroforestry systems affect the population dynamics of pests and natural enemies above, and the results include both biological and physical factors. Compared to monoculture systems, the results are generally positive, although they are always mixed. This occurs because the combination of trees and crops provides greater niche diversity and complexity both in time and space than the mixed cultivation of annual crops^[57]. There are also interactions between various factors. For example, the shading of trees affects factors such as temperature, humidity, and wind speed in an agricultural and forestry system. These factors do not affect the occurrence of pests in isolation, but it is often not easy to decipher which one is most causal in a specific situation. This article lists several types of influencing factors just to make readers more thoroughly understand the topic. The complexity of the interactions between agroforestry systems and pests and diseases further increases with an increase in system diversity, which is also difficult to decipher.

2.8 Some recommendations for management practices and research methods.

Firstly, ecological monitoring and sample collection are fundamental to understanding the population dynamics of arthropods. Utilizing various insect traps (such as sticky traps, sweep nets, and pitfall traps) can effectively capture different types of arthropods. For instance, sticky traps are suitable for

capturing flying insects, while sweep nets are effective for catching insects in vegetation^[58]. Additionally, stable isotope analysis (SIA) can assist researchers in tracking the food sources and ecological niches of arthropods, thereby providing deeper insights into their population dynamics^[59]. Combining traditional sampling methods with modern molecular techniques (such as DNA barcoding) can enhance the accuracy of identifying and classifying arthropod diversity. Secondly, experimental designs should consider the impact of climate change on arthropod populations. Future studies could simulate the effects of climate change on the physiology and behavior of arthropods by setting different temperature and humidity conditions. For example, research has shown that temperature fluctuations can affect the activity rates and predation efficiency of predators^[60]. By adopting this approach, it is possible to assess the adaptability and population dynamics of arthropods under varying climatic conditions, thus providing scientific evidence for pest management^[61]. Moreover, evaluating ecosystem functions is also an important research direction. By analyzing the relationship between predator diversity and pest suppression, researchers can reveal the interactions among different species within ecosystems. For instance, studies have found that the diversity of predators has a highly context-dependent effect on pest population suppression, indicating that different ecological environments and management practices may yield varying results^[62-63]. Therefore, conducting comparative studies across regions to analyze the impacts of different agricultural management practices (such as monoculture versus diversified planting) on arthropod populations and pest management will help formulate more effective agricultural management strategies^[64].

3 Conclusion

This paper focused on the impact of physical and biological factors on population changes of herbivorous pests and predatory natural enemies in fruit-crop agroforestry systems. We concluded that

fruit-crop agroforestry systems provided increased arthropod diversity compared with monoculture planting systems. An agroforestry system not only improved the microclimate of farmland but also provided food resources, overwintering habitats, and shelters for natural enemy insects, thereby helping the biological control of the agroecosystem. Furthermore, we addressed the effects of agroforestry measures on the structure of arthropod communities, plant diseases, and the extent of plant damage by insect herbivores. Most of the selected articles had a certain similarity and lacked a summary of the impacts of regional and climate differences on pests and natural enemies in fruit-crop agroforestry systems. Therefore, agroforestry workers, when promoting the use of fruit-crop agroforestry systems in agricultural planting systems, should consider biological control by increasing diversity as well as the interaction between plant species, planting design and management practices, pests and diseases and their natural enemies, and knowledge and technology when making decisions. In addition, areas of future research should encourage farmers to adopt diversified cropping systems can enhance crop richness, thereby increasing the stability and resilience of ecosystems. Additionally, implementing integrated pest management strategies can reduce reliance on chemical pesticides. Finally, the government should formulate policies to protect and restore ecological habitats, such as hedgerows and wetlands, which can provide living environments for natural enemies.

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