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# **Towards integrated pest and pollinator management in tropical crops**

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## **Abstract**

Biotic pollination and pest control are two critical insect-mediated ecosystem services that support crop production. Although management of both services is usually treated separately, the new paradigm of *Integrated Pest and Pollinator Management* (IPPM) suggests synergetic benefits by considering them together. We reviewed the management practices in two major tropical perennial crops: cocoa and coffee, to assess IPPM applications under the tropics. We found potential synergies and antagonisms among crop pest and pollination management, however, very few studies considered these interactions. Interestingly, we also found management practices focusing mainly on a single service mediated by insects although species can show multiple ecological functions as pests, natural enemies, or pollinators. The tropics represent a promising area for the implementation of IPPM and future research should address this concept to move towards a more sustainable agriculture.

**Keywords:** Biodiversity; Pest control; Cocoa; Coffee; Ecosystem services; IPPM; Landscape management; Pollination

## Introduction

Insect-mediated ecosystem services are critical in agriculture [1\*\*]. Beyond interactions between crops and their abiotic environment, crop yield is driven by ecosystem services including pollination and pest control and pollination, which are governed by antagonistic and mutualistic biotic interactions [2]. Animal pollination is critical for yield improvement of three-quarters of the world's major crops [3]. Overall, 5 to 8% of global crop production would be lost without animal pollination [4]. A wide diversity of insects are often assessed as efficient pollinators [5,6\*] but pollination limitation is frequently driven by a lack of insect pollinators [7]. Crop pests herbivory is another well-known driver of important crop yield losses due to a decrease in plant survival, growth, and reproduction [8]. Worldwide yield losses are estimated from 7.9% to 15.1% [8]. Biological pest control is defined as a process by which predators, parasitoids or pathogens reduce pest abundance. Apart from alleviating the negative impact from crop pest, managing the diversity of natural pest enemies to support crop yield could help reduce both the use of synthetic pesticides in agriculture [9\*] and the associated detrimental effects on biodiversity and human well-being [10]. Given the evidence of benefits from pest control and pollination on crop production, management practices should be developed to foster the ecosystem services and mitigate the ecosystem disservices provided by insects [1\*\*,11].

Crop pest control is commonly performed by means of species management approaches such as pesticide use [12–14]. However, many concerns are associated with over-reliance on pesticide applications including not only pest resistance, outbreaks of secondary pests, but also loss of natural enemies [9\*]. Alternatively, there is evidence that landscape management can promote the presence of natural enemies, and thus enhance biological control which could reduce pesticide application [18\*\*–21\*\*]. Pest control practices are distinguished between human input-based practices and biodiversity based, respectively [18\*\*,19\*\*], along with the concept of Integrated Pest Management (IPM). On the other hand, the management of crop pollination was also divided among different strategies from human input-based practices (e.g. the implementation of managed beehives [11]) to habitat and resource promotion to maintain or attract wild pollinators [20,21]. Nevertheless, the management practices of pest control and pollination services are usually treated independently [18\*\*]. IPM has been used as a response to mitigate pollinator decline, yet IPM itself is not necessarily "pollinator friendly" [18\*\*]. The impact on yield is affected by the

success of both pollination and insect pest control services, thus a more holistic approach is essential.

### **New paradigm of *Integrated Pest and Pollinator Management (IPPM)***

The concept of Integrated Pest and Pollinators Management (IPPM) emerged in 2015 with the main goal of considering adverse effects and synergies of pest control management on pollinators and *vice versa* [18\*\*,19\*\*,22,23]. IPPM has been further defined by categorizing and prioritizing co-management practices to limit adverse environmental impacts. A pyramid has thus been proposed as a decision support tool for choosing preventive and biodiversity-based management practices rather than curative and human-based ones [18\*\*,19\*\*] (**Figure 1**). At the top of the pyramid are the human-based practices, such as pesticide application, which are widely used for their effectiveness on target species but are also highly criticized for their effects on beneficial insects [24]. These practices involve a direct management of targeted species (e.g. controlling pests or fostering pollinators) and are differentiated in two management strategies according to the use of biotic or abiotic inputs (**Figure 1**). The biodiversity based-practices stand at the base of the pyramid and are differentiated among field and landscape management strategies [19\*\*] (**Figure 1**). Landscape components, namely habitat quantity and density, have a primary role in maintaining insect communities [25\*\*]. Landscape simplification affects pollination and pest control services through negative effects on the abundance, richness and diversity of pollinators and predators [26\*\*]. Consequently, the objective in such practices is no longer to directly manage the arthropod population but to manage their dynamics through the provision of nesting sites and food resources. However, while recent studies applied the concept of IPPM in field-based trials [25\*\*], IPPM remains essentially conceptual since its establishment in 2015 [23]. Here, we carried out a systematic review of the management practices of pest control and pollination services in two major tropical crops: cocoa and coffee, in order to assess for the first time IPPM applications on those crops.

### **IPPM application in tropical crops**

Coffee (*Coffea canephora* and *Coffea arabica*) and cocoa (*Theobroma cacao*) are two tropical crops with different levels of animal-mediated pollination required for yield improvement. The species *T. cacao* and *C. canephora* have a high dependence

on pollinators for fruit set, *C. arabica* has a moderate dependence [3]. Coffee and cocoa suffer important pressures from crop pests [27,28]. We performed our systematic review on these two crops by selecting the scientific publications published since the emergence of the IPPM concept in 2015 (**Box 1**). Despite the importance of insects to coffee and cocoa –as pollinators, pests and natural enemies– very few studies have applied the IPPM concept. We found no study addressing both pollination and pest control services in cocoa and only three in coffee. Some studies assessed the effects of shade cover in agroforestry systems, ground cover, and distance to forest [29\*,30]–or the use of vector-disseminated biopesticides [31]–on both services (**Table 1**). Otherwise, most studies focused on a single service or a single insect species mediating that service. Nevertheless, some studies considered a more holistic framework by assessing arthropods' community without considering their ecological function [32,33\*]. Other studies focused only on pest and predator communities [17,34–47] or pollinators and predators [48\*–51\*].

Overall, we found fewer experiments conducted on the pollination service compared to the pest control service (**Figure 1**). Moreover, in cocoa and coffee crops, pollination management seems to depend to a greater extent on the concept of IPM. Conversely to pest management, the promotion of pollination relies more on biodiversity-based practices at the landscape scale than on human practices. Considering both crops, the impact of abiotic and biotic inputs is studied on the pollination service in only 10% of cases (6 experiments) compared to 90% on the pest control service (53 experiments). Conversely, 69% of the experimental units (35 experiments) investigated the effect of landscape-level practices on pollination, compared to 31% (16 experiments) on pest control (**Figure 1**). While IPPM encourages the use of landscape-level practices as a priority, plot-level practices are the most common since they represent 57% of the practices studied on cocoa (11 pollination experiments vs. 19 pest control experiments) and 49% on coffee (36 pollination experiments vs. 49 pest control experiments). This particularity could be explained by the fact that coffee and cocoa plantations are complex systems where the implementation of agroecological practices within the plot, such as agroforestry [52], is easier than in annual crop plantations. Importantly, we found that landscape level management strategies are rarely studied in cocoa compared to coffee for the pollination service. It is likely that this difference is explained by the short distance foraging behav-

ior of the main cocoa pollinators (e.g. small flies) [53] compared to those of coffee crop (e.g. bees) [54\*].

### **Synergies and antagonisms among crop pest and pollination managements**

Complementary and synergistic effects can occur in crop management practices with potential positive interactions between pollinators and natural enemies on crop yield [55]. We examined such synergies but also potential antagonisms among the practices performed for crop pest and pollination management in cocoa and coffee. Several practices were studied specifically on one of the two services (i.e. pollination or pest control) in both cocoa and coffee, although there were fewer studies on cocoa (**Table 1**). The large majority of the practices involving abiotic and biotic inputs (i.e. pesticides, traps, biopesticides and biocontrol agents) were evaluated for their effectiveness on pest control but rarely on pollination service (**Table 1**). However, these practices can have antagonistic effects by negatively affecting the pollination service [24] or the community of beneficial arthropods [56]. Surprisingly, we found an experiment showing an increase of pollination service linked with pesticide use. This result can be explained by the family of the pesticide used, a fungicide, and by its effect on the plant physiology by increasing flower retention capability that could attract more insect pollinators [57]. Similarly, several biodiversity-based practices applied at the plot level and landscape level (e.g. mechanical management such as sanitary harvesting, pruning and exclusion netting, and the practices of biodiversity conservation such as bird-mediated predation) were only considered affecting pest control (**Table 1**). Nevertheless, these practices may also lead to antagonistic adverse effects on pollination or pest control services if, for example, birds also predate on pollinators and predators [22].

On the other hand, practices such as promoting floral resources in the plot and enhancing abundance of semi-natural habitats at the landscape scale are almost exclusively studied on the pollination service. However, studies carried out in temperate regions, i.e. where farmers can receive financial incentive to set flower strip, show benefits of such practices on pest control [58], suggesting that floral resources and semi-natural habitats could represent an interesting approach that offers a synergetic practice on both services. For instance, breeding substrates, vegetal ground cover and agroforestry are practices that could validate the IPPM concept through synergetic effects among pest control and pollination. However, the impact of agroforestry

on insect-mediated services is mixed (**Table 1**). This result is likely due to the large diversity of agroforestry systems with variability in tree size and the species of shade trees [59] and the differences in the survey scales chosen by the different studies. Shade tree species may affect their attractiveness and repellency to arthropod species. The size of the trees influences the microclimate, which in turn affects the development cycle of arthropods in various ways, depending on the species considered [52,53]. Surprisingly, most of the practices studied at the landscape scale aim to promote forest areas as arthropod-friendly habitats. Indeed, little attention has been paid to the landscape composition in terms of crops [60]. However, these crops can share the same pest or pollinator species assemblage, or can host arthropods performing multiple functions in the cropping system.

### **Multiple services mediated by insects**

Our systematic review confirms that pest control and pollination management are mainly treated separately in cocoa and coffee (**Figure 1**). Interestingly, we also found that most management practices focus on targeted insect species for a single service (i.e. pollination or pest control) although numerous species have multiple ecological functions as crop pests, natural enemies or pollinators. In other words, very few works consider the multiple ecological functions of insects while the species are usually classified by their major ecological function for example pollinators, pests, or natural enemies. Nevertheless, many insects can provide multiples services improving crop production due to their double ecological functions over their development stages (e.g. larvae as herbivore vs. adult as pollinator) or over different crops. For instance, *Forcipomyia* spp (Diptera) are pollinators in cocoa [53] and also natural enemies of *Dione juno* (Lepidoptera: Nymphalidae) [61] that damages many tropical crops (e.g. passion fruit, tomato, sugarcane, among others) [62,63]. In coffee, *Syrphus* sp. (Diptera: Syrphidae), *Allobaccha brevis* (Diptera: Syrphidae) and *Hemipyrellia* sp. (Diptera: Calliphoridae) are recorded as pollinators but these species are also reported as insect natural enemies in passion fruit and avocado [62,64].

On the other hand, other insects can have adverse effects (e.g. providing a service and a disservice) such as Sciaridae that are pollinators in cocoa [65] but are also considered as pests in watermelon [66]. *Trigona spinipes* Fabr. (Hymenoptera: Apidae) is a pollinator in coffee that can be detrimental to coffee fruit set [67] and is also considered as a pest due to its damages of open galleries on fruits reducing fruit



quality [68]. The *Azteca sericeasur* ant is known to be an effective predator of the coffee berry borer [69], a major coffee pest, but its aggressiveness towards pollinators visiting the coffee flowers has been studied little [56]. Overall, it is accepted that improving insect diversity in croplands benefits crop yield [70]. However, despite diversity being important, studies that evaluate whether an insect is an efficient and or effective pollinator, predator or has multiple ecological functions are valuable [54\*]. For instance, *Trigona jaty* (Hymenoptera: Apidae, meliponinae) is a flower visitor in cocoa but is considered as an inefficient pollinator given its pollen robbing action that weakens flower fitness [71]. Pollination efficiency of many flower visitors in coffee and cocoa crops are not yet tested and although studies suggest their ecological function as pollinators, they can also act as pests or natural enemies in other crops. Neglecting the multiple ecological functions of insects and their efficiency carrying out these ecosystem services and disservices would considerably limit crop yield improvement.

## **Perspectives**

The tropics are home to the highest diversity and abundance of arthropods [72], and as such, represent an excellent area for considering IPPM approaches in agricultural systems. Through the study of two tropical crops, we found that few experiments have investigated the effect of agricultural practices simultaneously on pests, natural enemies and pollinator communities despite IPPM recommendations. Although it is rather recognized that analyzing the influence of a single ecosystem service on crop yield can be complex due to context-dependency, studying combined effects of pollinator and pest managements implies interacting relationships that are current challenges in applied ecology [55]. Integrating pest and pollinator management strategies in agriculture is therefore pioneering and represents future a direction towards sustainable food production. Consideration of the landscape scale also invokes the possibility of multiple ecological functions that insects may have [22] as pests of one crop and pollinators of a neighboring crop. This consideration should be even more important when species richness and abundance are high. In the future, the growing awareness of the landscape scale effect and the multiple ecological functions of arthropods in relation to crops should lead to further consideration of the neighboring agricultural landscape, i.e. the nature of the established crops and their pollinator, pests and predator assemblages.

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**Declarations of interest:** none.

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This review synthesizes the diversity and the importance of non-bee insects as crop pollinators. They recorded the visitors and pollinators of 105 global food crops that are known to benefit from animal pollinators. Non-bee insects are commonly observed visiting crop flowers, including mostly Diptera, Coleoptera, Lepidoptera and Hymenoptera. Interestingly, they also discussed the distinction between flower visitation and pollination efficiency for some species.

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### Box 1. Cocoa and coffee tropical crops

The genus *Coffea* (Rubiaceae) originates from tropical and subtropical Africa. Coffee is a crop of global importance cultivated in approximately 80 tropical countries with Brazil being the greatest producer and exporter [73]. The two main varieties cultivated in the tropics have different pollination requirements since in *Coffea arabica* (self-compatible), animal pollination represents only 10 to 40% of total pollination while animal pollination represents more than 40% in *Coffea canephora* (self-incompatible) (Figure S2 in [3]). Interestingly, the absence of pollinators could decrease coffee yields from 20 to 30% [20] and pest attacks harm up to 26 to 38% of productions [28]. The species *Theobroma cacao* is the main fruit cultivated from the genus *Theobroma* (Malvaceae). Native to the rainforest regions of the northern part of South America, it is currently cultivated mainly in Africa, and the Ivory Coast is the leading producer country providing more than a third of global production [73]. Most of the cocoa cultivated varieties are self-incompatible and the sticky pollen is not dispersed by the wind. Cocoa pollination is therefore highly dependent on animal-mediated pollination [3]. We performed a systematic review on the management practices of pest control and pollination services in cocoa and coffee crops, from 2015 (i.e. the establishment of the IPPM concept, [23]) to May 2021 and based on two search string equations in Web of Science (using the "topics" field search, [74]). Each of the equations identified the scientific articles dealing with one of the two services on both crops: (*Equation 1*) pest\* and (damage\* or control\* or monitor\* or manag\* or suppress\* or regulat\*) and (cocoa or cacao or coffee or coffea); (*Equation 2*) pollin\* and (manag\* or enhance\* or benefi\* or success or increase\* or promot\* or monitor\* or facilita\* or support\* or improv\* or favo\*) and (cocoa or cacao or coffee or coffea). Out of 1224 reviewed studies, only 32 studies on cocoa [14,21\*\*,37,39,48\*,53,65,75–99] and 70 studies on coffee [13,15–17,20,29\*,44,45\*,51\*,56,57,67,69,100–156] were considered by reading the abstracts and full texts and selecting that (i) address coffee and cocoa in field experiments, (ii) include arthropods and (iii) did not consider the effect of a practice on the ecosystem service (e.g. pest or pollinator biology, climate effect, monitoring and detection). The combination of the article, the ecosystem service studied, the management practice and the response metric (ex: the abundance, the diversity, the richness or the infestation) was named an 'experimental unit' and used to perform an analysis of the management strategies conducted on cocoa and coffee crops.

## Figure legends

**Figure 1.** Integrated Pest and Pollinator Management (IPPM) application in coffee and cocoa illustrated with a systematic review of the management strategies for pollination and pest control services from 102 scientific articles. The pyramid and the four categories of management from human input-based strategies (in gray) to biodiversity-based strategies (in dark green) are inspired from Lundin et al. 2021 [19\*\*]. The category "sampling, monitoring and threshold" was not considered in the pyramid because these practices aim to monitor the level of arthropods communities without trying to regulate or promote them. Icons: [www.flaticon.com](http://www.flaticon.com) and [www.vecteezy.com](http://www.vecteezy.com)

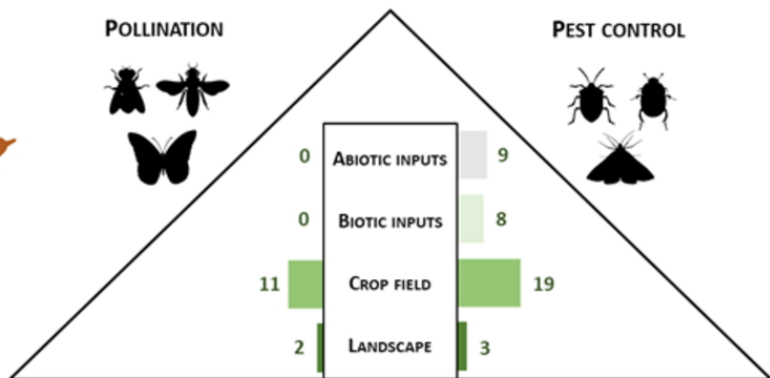
**(A) COCOA**



**POLLINATION**



**PEST CONTROL**



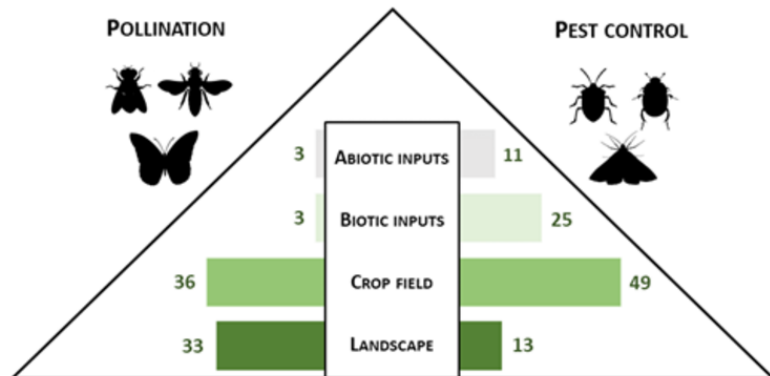
**(B) COFFEE**



**POLLINATION**









**PEST CONTROL**





**Table 1:** Effects of IPPM management strategies and practices on pest control and pollination services in cocoa and coffee. Studies are synthesized from January 2015 to May 2021 through a systematic review, as explained in **Box 1**. The effects presented are the result obtained on the expected ecosystem service, i.e. a practice that increases the abundance, richness and visitation rate of pollinators, or decreases their mortality, is considered to have a positive effect on the pollination service. For the pest control service, a practice that reduces the abundance or diversity of pests, or decreases their observed damage level is assumed to have a positive effect. Among the selected studies, we chose to consider only the ones that provided a conclusion on the overall effect of the practice. So, we did not include studies that aimed to compare the modalities of implementation, such as color traps or biopesticides' date of application on practice effectiveness, and studies that compared agroecosystems with many differences in term of management. N = total number of action effects; n = action effect not considered for the synthesis because they were comparisons of action modalities (ex: trap's color, biopesticide's dose) instead of showing a negative, positive or null effect. Icons: [www.flaticon.com](http://www.flaticon.com) and [www.vecteezy.com](http://www.vecteezy.com)

			<div>Pollination</div> <div></div>				<div>Pest control</div> <div></div>					
Crop	Management strategy	Practice	Negative	Null	Positive	N(n)	Negative	Null	Positive	N(n)	References	
Cocoa	Abiotic inputs	Pesticides	0	0	0	0	0	1	1	2(0)	[75]	
		Traps	0	0	0	0	0	3	2	10(5)	[14,76–81]	
	Biotic inputs	Biocontrol agent	0	0	0	0	3	4	5	12(0)	[37,82–86]	
		Biopesticides	0	0	0	0	0	0	1	2(1)	[75,87]	
	Crop field management	Agroforestry	1	3	1	6(1)	1	4	4	9(0)	[21**,37,39,53,65,88–91]	
		Fertilization	0	0	0	0	0	2	2	4(0)	[89,92,93]	
		Intensification	0	0	0	1(1)	0	0	0	2(2)	[94,95]	
		Mechanical management	0	0	0	0	0	0	2	2(0)	[91,96*]	
		Plot floral abundance	0	1	1	2(0)	0	0	0	0	[21**]	
		Nesting habitat diversity	0	2	2	7(3)	2	1	1	5(1)	[21**,48*,75,83,96*–99]	
	Landscape management	Biodiversity conservation	0	0	0	0	2	2	2	6(0)	[37,88]	
		Semi-natural habitats	0	1	1	2(0)	0	0	0	0	[21**]	
Coffee	Abiotic inputs	Pesticides	0	1	1	2(0)	0	3	3	6(0)	[13,57,100–103]	
		Traps	0	0	0	2(2)	0	1	0	6(5)	[104–110]	
	Biotic inputs	Biocontrol agent	3	0	0	3(0)	3	11	12	26(0)	[15–17,56,69,101,111–117]	
		Biopesticides	0	0	0	0	0	1	7	10(2)	[100,106,118–123]	

Crop field management	Agroforestry	7	8	3	18(0)	6	15	8	30(1)	[16,29*,44,45*,101,124–140]
	Fertilization	2	2	2	6(0)	0	2	1	3(0)	[45*,136,140,141]
	Intensification	3	3	1	7(0)	1	3	2	7(0)	[20,45*,125*,128,142–144]
	Mechanical management	0	0	0	0	2	3	5	10(0)	[13,103,106,145–148]
	Plot floral abundance	2	3	8	13(0)	0	0	0	0	[20,129,130,140]
Landscape management	Nesting habitat diversity	1	3	1	5(0)	2	4	4	10(0)	[29*,101,130,136,137,149,150]
	Biodiversity conservation	0	0	0	0	1	2	3	6(0)	[29*,151,152]
	Semi-natural habitats	4	19	13	38(2)	4	5	7	16(0)	[15,17,20,29*,44,51*,67,125*,130,133,140,152–156]

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Pollination



Pest control



**IPPM**

**Application to tropical crops?**



Cocoa



Coffee