Impact of Neonicotinoid-Based Insecticide Treatments on Non-Target Arthropods in Cotton Cultivation

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ABSTRACT

The use of neonicotinoids in cotton cultivation contributes to the control of pest organisms but may also affect beneficial arthropods involved in the natural regulation of pests. This study evaluated, under experimental station conditions (CNRA, Bouaké, 2024-2025 growing season), the impact of foliar treatments based on acetamiprid (three application rates), thiamethoxam, and a combination of emamectin-acetamiprid on non-target arthropods. The experiment was conducted using a randomized complete block design (six treatments) with five applications. Beneficial arthropods were sampled at 3, 7, and 13 days after application using the diagonal sampling method. A total of 202 individuals were recorded, dominated by black ants (*Camponotus* sp.) (60.4%) and lady beetles (*Micraspis lineola* and *Exochomus nigromaculatus*) (33.2%), along with red ants (*Oecophylla* sp.) and lynx spiders (*Oxyopes* spp.). Insecticide treatments generally reduced the abundance of beneficial arthropods, with reduction rates ranging from 27.8% to 61.1% for *M. lineola* and *E. nigromaculatus*, from 34.1% to 95% for *Camponotus* sp., and up to 100% for *Oecophylla* sp. These results highlight the importance of rational cotton protection strategies incorporating integrated pest management principles (intervention thresholds, selection of the least harmful treatments, and rotation of modes of action) in order to preserve biological control services. Within the conditions of this study, they indicate a potential risk of non-target impacts that should be validated across broader cotton-growing contexts.

1. INTRODUCTION

Cotton cultivation occupies a strategic position in agricultural systems in West Africa, both because of its socio-economic importance and its role in export value chains. However, this crop is subject to high phytosanitary pressure due to the diversity of arthropod pest complexes that attack it at all phenological stages. These pests notably include Hemiptera (true bugs), sap-sucking insects such as aphids, jassids, and whiteflies, Lepidoptera (defoliating and boll-feeding caterpillars), as well as mites, whose outbreaks can result in yield losses exceeding 50% in the absence of effective control measures [1].

Over recent decades, the management of these pests has relied heavily on the use of synthetic insecticides, particularly neonicotinoids, due to their broad spectrum of activity, systemic properties, and effectiveness against piercing-sucking insects [2]. Among these active substances, acetamiprid and thiamethoxam are commonly used in cotton protection programs in Africa, especially for the control of jassids and whiteflies.

However, numerous studies have shown that neonicotinoids, while targeting pest species, also affect non-target arthropods that play a key role in the natural regulation of pest populations [3]. As systemic neurotoxic insecticides, these compounds interfere with nicotinic acetylcholine receptors in insects, causing lethal or sublethal effects that may impair the survival, behavior, and reproduction of exposed organisms [4].

Non-target arthropods, such as lady beetles, hoverflies, lacewings, lynx spiders, and certain ant species, constitute a cornerstone of ecosystem services in cotton systems. They contribute to the biological control of aphids and other pests through predation [5]. A reduction in their populations due to insecticide treatments may lead to biological imbalances, promoting pest resurgence or the emergence of secondary pests. This situation may further increase reliance on chemical inputs [6].

Several studies have implicated neonicotinoids as having detrimental effects on non-target arthropods. The magnitude of this impact varies depending on the active substance, application rate, and frequency of treatments. Acetamiprid is generally considered less toxic than other neonicotinoids; however, under repeated applications or high exposure conditions, significant negative effects may occur on various non-target arthropods [7, 8]. Thiamethoxam, on the other hand, has been reported by some authors to exhibit high toxicity toward many non-target invertebrates, with both acute and persistent effects on arthropod communities [9].

Therefore, from an integrated pest management and sustainability perspective, a differentiated assessment of insecticide impacts on beneficial arthropods is essential. In this study, we evaluated the effects of foliar neonicotinoid-based treatments in cotton (acetamiprid applied along a dose gradient; thiamethoxam; and an emamectin–acetamiprid combination) on a set of non-target arthropod groups monitored in the crop canopy (lady beetles, ants, and lynx spiders). Specifically, we aimed to: (i) quantify treatment-related changes in the abundance of these beneficial groups relative to an untreated control; (ii) test whether acetamiprid shows a dose-dependent effect on the most frequent groups; and (iii) assess whether treatments are associated with shifts in community composition and diversity metrics computed on the monitored groups. We hypothesized that (H1) insecticide treatments reduce the abundance of beneficial arthropods compared with the control, (H2) reductions increase with acetamiprid application rate, and (H3) treated plots show lower group richness and higher dominance (*i.e.*, community simplification) than the control. The results are intended to inform rational cotton protection strategies in Côte d'Ivoire that better reconcile pest control with the conservation of biological control services.

2. MATERIALS AND METHODS

2.1. Study Site and Experimental Design

The experiment was conducted at the cotton research station of the Centre National de Recherche Agronomique (CNRA) in Bouaké, Côte d'Ivoire, during the 2024-2025 cropping season. The experimental design was a randomized complete block (RCBD) comprising six treatments with four replicates. Within each block, the six treatments were randomly assigned to plots (one plot per treatment per block). Each elementary plot measured 10 m × 10 cotton rows, corresponding to an area of 80 m^2, of which the eight central rows were used for observations. The two outer rows served as border rows to minimize contamination effects between plots.

2.2. Description of Treatments

The treatments consisted of different application rates of neonicotinoid-based insecticides, applied alone or in combination, as follows:

- A: untreated control;
- B: acetamiprid at 37.5 g active ingredient (a.i.) per hectare;
- C: acetamiprid at 50 g a.i./ha;
- D: acetamiprid at 75 g a.i./ha;
- E: thiamethoxam at 30 g a.i./ha;
- F: combination of emamectin (12 g a.i./ha) + acetamiprid (16 g a.i./ha).

These treatments were selected to assess the dose-dependent effect of acetamiprid and to compare its impact with that of thiamethoxam, as well as with a commonly used insecticide combination in cotton protection programs in Côte d'Ivoire.

2.3. Insecticide Application

Insecticides were applied by foliar spraying using a calibrated knapsack sprayer delivering a spray volume of 60 L/ha. Five applications were performed at 14-day intervals, starting 30 days after cotton emergence.

2.4. Observations of Non-Target Arthropods

Observations were conducted at 3 days (T + 3), 7 days (T + 7), and 13 days (T + 13) after each application. Counts were performed on 30 plants per plot, selected using the diagonal sampling method. This approach consisted of selecting six groups of five consecutive plants while moving along the diagonal of the plot. The observed arthropod groups included lady beetles (*Micraspis lineola* and *Exochomus nigromaculatus*), ants (*Camponotus* sp. and *Oecophylla* sp.), and lynx spiders (*Oxyopes* spp.). For lady beetles, larvae and adults were counted during field observations; for the descriptive abundance results, counts can therefore reflect both stages. For diversity calculations, lady beetles were treated as a single functional group by aggregating larvae + adults.

2.5. Statistical Analysis

Arthropod abundance data were subjected to statistical analyses to evaluate the effects of insecticide treatments on the structure and diversity of the studied communities. First, descriptive statistics were computed to characterize the mean abundance of different non-target arthropod groups per treatment. Relative proportions of functional groups were calculated to analyze community structure across treatments. The percentage reduction in populations compared with the untreated control was also determined.

A one-way analysis of variance (ANOVA) was performed to assess the effect of treatments on beneficial arthropods associated with cotton, after verifying normality and homogeneity of variance assumptions. For each plot and sampling date, counts corresponded to the total number of individuals recorded on the 30 sampled plants. To estimate a global (season-integrated) effect of each treatment, plot-level totals were averaged across T + 3, T + 7 and T + 13 and across the five applications to obtain a single value per plot prior to one-way ANOVA. This aggregation focuses on overall treatment effects rather than date-specific dynamics. Then, to assess the persistence of the treatments' effects, comparisons were made at T + 3, T + 7, and T + 13, respectively. When the ANOVA indicated significant differences among treatments ($\alpha = 0.05$), means were separated using Tukey's Honest Significant Difference (HSD) post hoc test to identify homogeneous groups.

The structure and diversity of non-target arthropod communities were assessed using ecological indices computed with the *vegan* package [10], including group richness (S), Shannon-Weaver diversity index (H), maximum diversity (H max), Pielou's evenness (J), Simpson's dominance index (D), and Simpson's diversity index (1 − D).

The relationship between acetamiprid dose (0, 37.5, 50, and 75 g a.i./ha) and beneficial arthropod abundance was assessed using simple linear regression, with model fit evaluated by the coefficient of determination (R^2) and Pearson's correlation coefficient (r). To confirm a monotonic dose-response relationship, Spearman's rank correlation (r_s) was calculated, with values interpreted as weak (|r_s| < 0.3), moderate (0.3 ≤ |r_s| < 0.7), or strong (|r_s| ≥ 0.7); a value of r_s = -1.0 indicates a perfect decreasing monotonic trend. Percent reduction relative to untreated control was calculated for each dose level. Analyses were performed separately for lady beetles, black ants, and total beneficial arthropods to assess differential sensitivity to acetamiprid.

All statistical analyses were performed using the R software [11], a reference environment for ecological and agronomic data analysis.

3. RESULTS

3.1. Overall Abundance of Non-Target Arthropods

A total of 202 individuals belonging to four monitored beneficial arthropod groups were recorded across the entire experimental setup (Table 1). Black ants (*Camponotus* sp.) were the dominant group (122 individuals; 60.4%), followed by lady beetles (*Micraspis lineola* and *Exochomus nigromaculatus*) (67; 33.2%). Red ants (*Oecophylla* sp.) represented 12 individuals (5.9%), whereas lynx spiders (*Oxyopes* spp.) were rare (1; 0.5%). Given the extremely low number of lynx spiders recorded, results for this group are presented descriptively only.

Table 1. Frequencies and proportions of the different recorded arthropod groups.

Predatory arthropod group	Total count	Proportion (%)
Lady beetles (*M. lineola* and *E. nigromaculatus*)	67	33.2
Black ants (*Camponotus* sp.)	122	60.4
Red ants (*Oecophylla* sp.)	12	5.9
Lynx spiders (*Oxyopes* spp.)	1	0.5
Total	**202**	**100**

3.2. Effect of Insecticide Treatments on the Diversity of Non-Target Arthropods

Diversity patterns were evaluated using complementary ecological indices computed from the monitored arthropod groups (group richness, Shannon diversity, Pielou's evenness, and Simpson dominance; Table 2). Here, these indices provide a synthetic description of how treatments may simplify the assemblage (fewer monitored groups and/or stronger dominance by one group) rather than a full assessment of species-level biodiversity.

Group richness (S) ranged from 2 to 4 monitored arthropod groups depending on the insecticide treatment. The untreated control and the low-dose acetamiprid treatment (37.5 g a.i./ha) showed the highest richness (S = 4). In contrast, the intermediate dose acetamiprid treatment (50 g a.i./ha) retained only two groups (S = 2), suggesting a marked simplification of the monitored assemblage under this treatment.

The Shannon index, which integrates both richness and the relative abundance of the monitored groups, differed among treatments. The untreated control showed the highest value (H = 1.049), consistent with a more balanced distribution among groups. In contrast, the lowest values were observed for thiamethoxam at 30 g a.i./ha (H = 0.602) and acetamiprid at 50 g a.i./ha (H = 0.598), reflecting a less diverse and/or more uneven assemblage under these treatments.

Table 2. Group richness and diversity indices (Shannon, Pielou's evenness, and Simpson) of beneficial arthropods according to insecticide treatments.

Treatment	Richness (S)	Shannon (H)	H max	Evenness (J)	Simpson (D)	1 − D
Untreated control	**4**	**1.0**	**1.4**	0.8	0.4	0.6
Acetamiprid (37.5 g/ha)	4	0.9	1.4	0.7	0.5	0.5
Acetamiprid (50 g/ha)	2	0.6	0.7	0.9	0.6	0.4
Acetamiprid (75 g/ha)	3	0.8	1.1	0.8	0.5	0.5
Thiamethoxam (30 g/ha)	3	0.6	1.1	0.5	0.7	0.3
Emamectin + Acetamiprid (12 + 16 g/ha)	3	0.7	1.1	0.6	0.6	0.4

Based on the Shannon index, treatments ranked as follows: control > acetamiprid 37.5 g/ha > acetamiprid 75 g/ha > emamectin + acetamiprid > thiamethoxam 30 g/ha > acetamiprid 50 g/ha, indicating comparatively higher diversity in the control and under the lowest acetamiprid dose.

Pielou's evenness index, reflecting the distribution of individuals among the monitored groups, showed contrasting trends. The acetamiprid treatment at 50 g a.i./ha exhibited the highest evenness value (J = 0.863), which corresponds to a simplified community composed of two groups with relatively similar abundances. Conversely, thiamethoxam at 30 g a.i./ha showed the lowest evenness (J = 0.548), indicating strong dominance by a single group. In this treatment, black ants were strongly reduced, so adult lady beetles represented a larger share of the remaining observations (more than 80% of recorded individuals), leading to an uneven assemblage.

Simpson's index confirmed the patterns observed with the other metrics. Thiamethoxam (30 g a.i./ha) exhibited the highest dominance (D = 0.680), corresponding to the lowest diversity (1 − D = 0.320). In contrast, the untreated control displayed the highest diversity (1 − D = 0.558), consistent with a more even distribution among the monitored groups.

3.3. Reduction Rates of Non-Target Arthropod Abundance according to Treatments

Figure 1 illustrates the reduction rates (%) of the main arthropod groups (lady beetles, black ants, and red ants) observed in treated plots compared with the untreated control (A). The results highlight a differential response of arthropod groups depending on the type and dose of insecticides applied.

Overall, all insecticide treatments led to a decrease in the abundance of beneficial arthropods, although the magnitude varied among functional groups. Lady beetles showed reduction rates ranging from 27.8% to 61.1%, indicating moderate to high sensitivity to treatments. The lowest reduction was observed with thiamethoxam (E), whereas the highest reductions were recorded with the emamectin + acetamiprid combination (F) and acetamiprid at the intermediate dose (50 g a.i./ha), suggesting a significant impact on this key biological control group.

Black ants (generalist predators) appeared markedly more sensitive than lady beetles, with reduction rates ranging from 34.1% to over 95%. Thiamethoxam (E) induced reductions of up to 95%.

Red ants, which had very low initial populations, were almost eliminated by most treatments, with reduction rates reaching 100% in four out of five treatments.

Table 3 and Table 4 provide a formal support for the acetamiprid dose-related pattern. In the monotonic trend analysis (Table 3), the total number of beneficial arthropods (lady beetles + ants) decreased as the acetamiprid rate increased from 37.5 to 75 g a.i./ha (33, 28 and 23 individuals, respectively), corresponding to increasing reductions relative to the control (50.0%, 57.6% and 65.2%). The fitted regression indicates a strong negative monotonic relationship ($R^2 = 0.964$; $r = -0.982$; $p < 0.001$). Pearson correlations (**Table 4**) are consistent with this result: the dose-response association is very strong for black ants ($r = -0.945$; $R^2 = 0.89$) and for total beneficial arthropods ($r = -0.982$; $R^2 = 0.96$), whereas it is weak for lady beetles ($r = -0.143$; $R^2 = 0.02$), suggesting that the overall trend is driven mainly by ant declines. Because these dose-response statistics are based on only three dose levels, they should be interpreted as supportive evidence rather than as a full characterization of the functional form of the dose-response relationship.

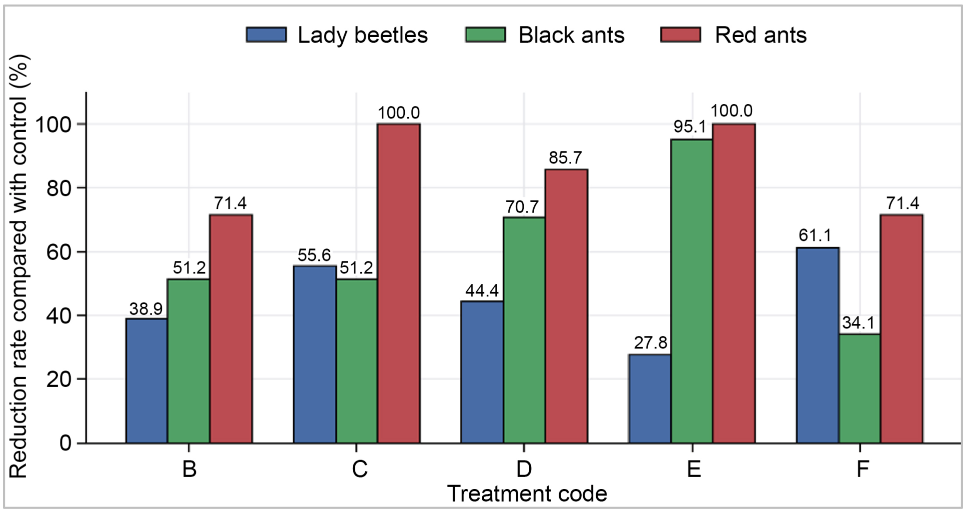

Figure 1. Percentage reduction (%) in the abundance of lady beetles and black ants under different insecticide treatments, relative to untreated control. (A): untreated control; (B): acetamiprid at 37.5 g a.i./ha; (C): acetamiprid at 50 g a.i./ha; (D): acetamiprid at 75 g a.i./ha; (E): thiamethoxam at 30 g a.i./ha; (F): combination of emamectin (12 g a.i./ha) + acetamiprid (16 g a.i./ha).

Table 3. Monotonic trend test (acetamiprid dose-response).

Rate (g a.i./ha)	Lady beetles	Ants	Total	% Reduction
0 (Control)	18	48	66	-
37.5	11	22	33	50.00%
50	8	20	28	57.60%
75	10	13	23	65.20%

Table 4. Pearson correlations for dose-response.

Variable	Pearson r	R^2
Lady beetles	−0.143	0.02
Black ants	−0.945	0.89
Total beneficial arthropods	−0.982	0.96

3.4. Variation in Mean Densities of Non-Target Arthropods according to Treatments

Analysis of variance (ANOVA), followed by Tukey's post hoc test, revealed significant differences among insecticide treatments (Table 5). For lady beetles, the untreated control plot (0.28 ± 0.10) exhibited a significantly higher abundance than those observed under acetamiprid at 50 g a.i./ha and under the emamectin + acetamiprid combination ($p < 0.05$), highlighting the negative effect of these treatments on this group of beneficial arthropods. The most pronounced impact was observed on black ants: treatment with thiamethoxam at 30 g a.i./ha resulted in a drastic 95% reduction in abundance (0.03 ± 0.03) compared to the untreated control (0.64 ± 0.21; $p < 0.05$), indicating high toxicity of this compound toward this functional group.

Table 5. Mean abundance (± standard deviation) of lady beetles, black ants, and total beneficial arthropods according to insecticide treatments.

Treatment	Lady beetles (*M. lineola* and *E. nigromaculatus*)	Black ants (*Camponotus* sp.)	Total beneficial arthropods
Untreated control	**0.28 ± 0.10 a**	**0.64 ± 0.21 a**	**1.03 ± 0.27 a**
Acetamiprid (37.5 g/ha)	0.17 ± 0.07 ab	0.31 ± 0.12 ab	0.52 ± 0.16 b
Acetamiprid (50 g/ha)	0.13 ± 0.05 b	0.31 ± 0.12 ab	0.44 ± 0.15 bc
Acetamiprid (75 g/ha)	0.16 ± 0.06 ab	0.19 ± 0.08 bc	0.36 ± 0.11 bc
Thiamethoxam (30 g/ha)	0.21 ± 0.1 ab	0.03 ± 0.03 c	0.25 ± 0.09 c
Emamectin + Acetamiprid (12 + 16 g/ha)	0.11 ± 0.05 b	0.42 ± 0.14 ab	0.56 ± 0.17 b
F	1.89	2.87	2.52
p	0.0347	0.0146	0.0291

Values followed by the same letter are not significantly different (Tukey HSD test).

4. DISCUSSION

This study was designed to test whether foliar neonicotinoid-based treatments used in cotton protection can reduce the abundance of beneficial arthropods and simplify the monitored assemblage (H1 and H3), and whether acetamiprid shows a dose-dependent impact (H2). Overall, the results support these expectations: compared with the untreated control, treated plots showed lower abundances of key beneficial groups and, in several cases, lower group richness and higher dominance. The strongest effects were observed for black ants (*Camponotus* sp.), for which reductions ranged from ~34% to ~95%, with a clear increase in reduction as acetamiprid dose increased. Lady beetles were also affected (reductions ~28% - 61%), although responses were less pronounced and varied among treatments. These patterns are consistent with the neurotoxic mode of action of neonicotinoids and with field exposure pathways combining direct contact during foliar sprays and exposure to systemic residues [2-4].

A functional interpretation helps explain the contrast between groups. Ants are highly active canopy foragers and are likely to experience intense contact exposure during foliar applications, which may account for their strong declines—especially under thiamethoxam and at higher acetamiprid doses. In turn, these ant reductions contributed to the dominance patterns reported in Table 2 (lower evenness and higher Simpson dominance in some treatments), because other groups represented a larger share of the remaining observations. Lady beetles, although susceptible, may partially buffer exposure through mobility (flight) and recolonization from surrounding habitats, and their observed densities can also be influenced indirectly by prey availability and disruption of trophic interactions [5, 6]. More generally, neonicotinoids may affect natural enemies not only through mortality but also through sublethal effects (orientation, feeding, reproduction) that can reduce biological control efficiency [3, 9-14]. In addition, documented trends in neonicotinoid uses and modes of action highlight the importance of considering metabolites and exposure pathways when interpreting non-target effects [15]. In addition to these between-group differences, our dose-gradient design provides insight into how impact magnitude may change with application rate.

Acetamiprid was tested along a dose gradient to examine the hypothesis of a dose-dependent effect. The observed trends suggest that increasing doses may intensify pressure on certain beneficial groups. However, community responses are not necessarily linear, as they are also influenced by ecological factors (e.g., dispersal, recolonization, predator-prey dynamics) and agronomic practices (e.g., frequency of applications, crop canopy heterogeneity). This is consistent with previous syntheses indicating that the magnitude of neonicotinoid effects varies depending on the compound, dose, application frequency, and cropping context, and that sublethal effects may play a substantial role in field-level impacts [3, 6-9]. In this context, approaches focusing on demographic and behavioral parameters are valuable for linking individual-level responses to population-level consequences [16]. Beyond rate effects, the timing of responses after spraying is critical for distinguishing acute impacts from recovery processes, and for translating short-term effects into IPM-relevant guidance.

Post-treatment dynamics represent a key component of interpretation. Under field conditions, declines observed shortly after application may reflect acute effects (mortality, disorientation, reduced activity), whereas subsequent trends depend on residue persistence, repeated exposure, and the ability of beneficial arthropods to recolonize treated plots from untreated areas. Given that neonicotinoids are systemic and potentially persistent compounds, their effects may extend beyond the immediate exposure window, thereby slowing the recovery of certain taxa [4-13]. These findings are consistent with reviews emphasizing the importance of considering chronic exposure and sublethal effects when evaluating impacts on non-target invertebrates [3, 9-12].

Beyond variations in abundance, changes in diversity and dominance patterns suggest a potential simplification of beneficial arthropod communities under certain treatment regimes. Less diverse and more dominance-structured communities may be more vulnerable to disturbances and exhibit reduced resilience, potentially decreasing the stability of natural pest regulation. This interpretation aligns with agroecological frameworks linking biodiversity, trophic network functioning, and ecosystem services in agricultural systems [5, 6]. At a broader scale, several reviews highlight that widespread exposure to systemic insecticides may contribute to declines in invertebrate biodiversity and, indirectly, to alterations in ecosystem functioning [3-13].

From an operational perspective, these findings reinforce the importance of implementing rational crop protection strategies aimed at preserving beneficial arthropods and the ecosystem services they provide. Within an integrated pest management (IPM) framework, this includes restricting applications to justified situations (economic thresholds), prioritizing options that are less harmful to natural enemies, and integrating complementary practices such as monitoring, rotation of modes of action, and agronomic practices favorable to beneficial arthropods [5].

Several limitations should be considered when interpreting these results: the assessment targeted a limited set of monitored groups (and some taxa had low counts), the experiment was conducted at a single site/season, and pest pressure and yield were not monitored in parallel. Accordingly, further multi-site and multi-season studies integrating pests, natural enemies, yield outcomes, and mechanistic indicators (e.g., residue dynamics and sublethal endpoints) would strengthen the agronomic relevance of the patterns observed and support locally adapted IPM recommendations.

The study provides evidence, under experimental station conditions in Bouaké (2024-2025 season), that foliar neonicotinoid-based treatments can reduce the abundance of key beneficial arthropod groups in cotton and shift the structure of the monitored assemblage toward lower group richness and higher dominance. Black ants (*Camponotus* sp.) were the most strongly affected group and showed a clear dose-related response to acetamiprid, whereas lady beetles exhibited moderate to high reductions depending on treatment.

For red ants (*Oecophylla* sp.) and lynx spiders (*Oxyopes* spp.), very low overall counts limit statistical inference; treatment-level patterns for these taxa should therefore be considered descriptive. These conclusions should be interpreted in light of the study scope, which focused on a limited set of monitored groups and was conducted at a single site and season.

From an integrated pest management perspective, the findings support strengthening rational crop protection strategies that reduce unnecessary sprays and limit non-target impacts (monitoring and economic thresholds, selection of less harmful options when available, and rotation of modes of action). However, because beneficial arthropod responses can vary with landscape context, agronomic practices, and exposure conditions, the present results should be viewed as an indication of risk rather than a full prediction of impacts across cotton-growing areas in Côte d'Ivoire.

Future work should extend this assessment across multiple sites and seasons, broaden the taxonomic and functional coverage of beneficial arthropods, and jointly monitor pests, natural enemies, and yield outcomes. Complementary measurements of residue dynamics and sublethal effects would help clarify mechanisms and recovery processes, thereby supporting more robust, locally adapted recommendations for sustainable cotton pest management in Côte d'Ivoire.

CONFLICTS OF INTEREST

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

REFERENCES

1. Cauquil, J. and Vaissayre, M. (2004) Principaux ravageurs et maladies du cotonnier en Afrique au sud du Sahara. CIRAD, 1-68.
2. Elbert, A., Haas, M., Springer, B., Thielert, W. and Nauen, R. (2008) Applied Aspects of Neonicotinoid Uses in Crop Protection. *Pest Management Science*, **64**, 1099-1105. https://doi.org/10.1002/ps.1616
3. Pisa, L.W., Amaral-Rogers, V., Belzunces, L.P., Bonmatin, J.M., Downs, C.A., Goulson, D., *et al*. (2015) Effects of Neonicotinoids and Fipronil on Non-Target Invertebrates. *Environmental Science and Pollution Research*, **22**, 68-102. https://doi.org/10.1007/s11356-014-3471-x
4. Bonmatin, J.-M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D.P., Krupke, C., *et al*. (2014) Environmental Fate and Exposure; Neonicotinoids and Fipronil. *Environmental Science and Pollution Research*, **22**, 35-67. https://doi.org/10.1007/s11356-014-3332-7
5. Landis, D.A., Wratten, S.D. and Gurr, G.M. (2000) Habitat Management to Conserve Natural Enemies of Arthropod Pests in Agriculture. *Annual Review of Entomology*, **45**, 175-201. https://doi.org/10.1146/annurev.ento.45.1.175
6. Desneux, N., Decourtye, A. and Delpuech, J.-M. (2007) The Sublethal Effects of Pesticides on Beneficial Arthropods. *Annual Review of Entomology*, **52**, 81-106. https://doi.org/10.1146/annurev.ento.52.110405.091440
7. INRAE (2019) Des solutions alternatives aux néonicotinoïdes. https://www.inrae.fr/actualites/solutions-alternatives-aux-neonicotinoides
8. ANSES (2025) Les néonicotinoïdes. https://www.anses.fr/fr/content/les-neonicotinoides
9. Pisa, L., Goulson, D., Yang, E., Gibbons, D., Sánchez-Bayo, F., Mitchell, E., *et al*. (2017) An Update of the Worldwide Integrated Assessment (WIA) on Systemic Insecticides. Part 2: Impacts on Organisms and Ecosystems. *Environmental Science and Pollution Research*, **28**, 11749-11797. https://doi.org/10.1007/s11356-017-0341-3
10. Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin, P., O'Hara, R., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., *et al*. (2026) Vegan: Community Ecology Package. R Package Version 2.7-3. https://CRAN.R-project.org/package=vegan
11. R Core Team (2021) R: A Language and Environment for Statistical Computing. R Foundation for Statistical

Computing. https://www.R-project.org/

12. Goulson, D. (2013) Review: An Overview of the Environmental Risks Posed by Neonicotinoid Insecticides. *Journal of Applied Ecology*, **50**, 977-987. https://doi.org/10.1111/1365-2664.12111
13. van der Sluijs, J.P., Amaral-Rogers, V., Belzunces, L.P., Bijleveld van Lexmond, M.F.I.J., Bonmatin, J., Chagnon, M., *et al*. (2014) Conclusions of the Worldwide Integrated Assessment on the Risks of Neonicotinoids and Fipronil to Biodiversity and Ecosystem Functioning. *Environmental Science and Pollution Research*, **22**, 148-154. https://doi.org/10.1007/s11356-014-3229-5
14. Douglas, M.R. and Tooker, J.F. (2016) Meta-Analysis Reveals That Seed-Applied Neonicotinoids and Pyrethroids Have Similar Negative Effects on Abundance of Arthropod Natural Enemies. *PeerJ*, **4**, e2776. https://doi.org/10.7717/peerj.2776
15. Simon-Delso, N., Amaral-Rogers, V., Belzunces, L.P., Bonmatin, J.-M., Chagnon, M., Downs, C., Furlan, L., Gibbons, D.W., Giorio, C. and Girolami, V. (2014) Pesticides néonicotinoïdes. Tendances, usages et modes d'action des métabolites. https://hal.science/hal-01171969/
16. Stark, J.D. and Banks, J.E. (2003) Population-Level Effects of Pesticides and Other Toxicants on Arthropods. *Annual Review of Entomology*, **48**, 505-519. https://doi.org/10.1146/annurev.ento.48.091801.112621