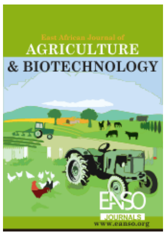

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Original Article

Banana Xanthomonas Wilt Disease Management through Roguing Affects Ground-Dwelling Arthropods Composition, Abundance and Diversity

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ABSTRACT

The role of ground-dwelling arthropods in sustaining cropping systems by providing ecosystem services is well appreciated. This study was conducted to determine the effects of roguing of diseased banana plants as a banana Xanthomonas wilt (BXW) management practice on ground-dwelling arthropod composition, abundance and diversity in a banana cropping system. The study determined the composition, abundance and diversity of ground-dwelling arthropods in banana plots of different roguing levels during two seasons, and evaluated the seasonal effects on the diversity of species in the different plots of different roguing levels. Arthropods captured from plots of different roguing levels were assessed for richness, evenness and diversity index. The total number of arthropod families captured from different plots was generally similar. A total of 62, 64, 65 and 72 families were captured from plots of 0, 25, 50, and 100% roguing levels, respectively. The number of species captured in the four treatments was statistically similar, although they increased with the level of roguing. The Shannon diversity index was lowest for catches in 25% (0.029) and highest in 100% (1.28) rogued plots. The Shannon diversity index values were generally low, suggesting that few species were more abundant than others and that the different plots had low arthropod diversity. The arthropod diversity was generally similar to samples taken during the wet and dry seasons. This study provides evidence that the BXW disease control practices did not negatively impact the ground-dwelling arthropods' composition, abundance and diversity.

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INTRODUCTION

Bananas and plantains play a major role in food security in the region of Eastern and Central Africa (ECA). Most of the bananas are consumed in the region, and in many parts of Uganda and Rwanda, a meal is incomplete without bananas. The ECA region has an estimated per capita consumption of over 200 kg, which ranks highest globally (Kalyebara et al., 2006; Karamura, 1993). The crop has roots and leaves, which help in maintaining soil fertility through providing soil cover. Banana plants are also used for animal fodder, mulching and some cultivars are known to be of medicinal value (Kilwinger et al., 2019).

Banana Xanthomonas wilt (BXW) disease has severely affected banana production in the ECA region over the last two decades. The disease has been reported to cause yield loss of up to 100% (Kubiriba et al., 2023; Ndungo et al., 2006; Tushemereirwe et al., 2008), with infected plants often dying within a month of showing symptoms. The disease outbreaks significantly impact food availability and household incomes for banana-dependent communities in ECA (Geberewold, 2019; Kubiriba et al., 2023). The disease spreads very quickly through contaminated tools, infected planting material, and insect vectors, leading to rapid epidemics (Kubiriba et al., 2023; Petsakos et al., 2023). There are currently no commercially available banana varieties that are resistant to the disease, making its management challenging (Tripathi et al., 2008).

Mass uprooting of entire mats with diseased plants (roguing) and burying the refuse was originally recommended as a practice for the management of the disease. Completely uprooting infected mats from a field with an 80% incidence required waiting six months before replanting, incurring costs of replanting and the inevitable biological fact that new banana fields take at least one year to produce the first bunch. The cultural practices are also labour-intensive, time-consuming and costly. This, in addition, promotes banana and plantain genetic erosion and environmental degradation, including potentially affecting soil macrofauna composition, abundance and diversity. On the other hand, different cultural practices in a banana cropping system are known to improve the overall farm health and crop tolerance to biotic/abiotic factors (Sivirihauma et al., 2017). Cultural practices are crucial agro-ecological intensification practices for enhancing food productivity and soil health.

Several studies have observed that ground-dwelling arthropods, especially termites and earthworms, play a major role in sustaining agricultural productivity through their impact on soil ecosystem services (Brown et al., 2004; Kanwal et al., 2023; Santos et al., 2018; Siqueira et al., 2016). The combination of the various management practices that are used by farmers in different cropping systems is important in influencing the soil macrofauna community. The practices play an important role in influencing soil macro-fauna numbers, limiting their negative effects and promoting their beneficial activities on soil fertility and crop production (Coulis, 2021; Davidson et al., 2024). The negative effects of farm management practices may result in reduced abundance and diversity of soil macrofauna populations or may result in the elimination of key species that are important in ecosystem processes

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(Ayuke et al., 2015; Azembouh et al., 2021; Davidson et al., 2024). Previous studies have reported that macrofauna species richness and abundance are negatively impacted by increased intensity of agriculture management practices (Eggleton et al., 2005; Kooyman & Onck, 1987; Okwakol, 2000). There are reports that indicate that some agronomic practices result in the destruction of nests and nesting sites, thus exposing soil macrofauna to unfavourable environmental conditions and predators (House & Parmelee, 1985; Kelly et al., 2021).

Studies on the diversity of edaphic soil invertebrate macrofauna in *Musa acuminata* agroecosystems have been reported (Zuniga-Gonzalez & Caballero-Hernández, 2024). Their results revealed a relationship between the banana production system and the abundance of soil macrofauna, especially the Hymenopterans and earthworms. The dynamics of ground-dwelling arthropods' abundance and diversity across farms and landscapes due to the management of BXW by roguing banana diseased plants have received no research attention. This study determined: a) the composition, abundance and diversity of ground-dwelling arthropods in banana fields that received different roguing levels; b) the seasonal effects on the distribution of ground-dwelling arthropods in the banana fields at different roguing levels. It was hypothesised that the ground-dwelling arthropods would (a) decrease with increasing levels of roguing, and (b) be lower during the dry season compared to the wet season.

MATERIALS AND METHODS

Ground-dwelling Arthropods Collection and Identification

This experiment was conducted at Kifu in Mukono district through a farmer field simulation trial using fields planted with 'Pisang awak'. Plots measuring 10m x 10m and containing 100 plants were randomly subjected to four levels of roguing, i.e. 0 (control), 25, 50 and 100%. No plants were cut at the 0% rouging level, while 25, 50 and 100% of mats were respectively uprooted for the other treatment levels. Each level of roguing was replicated four times. Crop residues in the rogued plots were retained within the plots.

Ground-dwelling arthropods were collected using 500 ml plastic pitfall traps half-filled with 5% formalin as a trapping agent. One pitfall trap was placed at the centre of each plot. The traps were checked every three days, and the arthropods captured were stored in vials containing a solution of 75% alcohol in water for later sorting, counting, recording and identification. The trial was conducted over two dry and two rainy seasons.

All collected ground-dwelling arthropod samples were taken to the Entomological Department at the National Museums of Kenya, Nairobi, for taxonomic identification. The identification was done to the species and family level. Only the chilopods were identified to the order level.

Determination of Ground-dwelling Arthropod Composition, Abundance and Diversity

The number of ground-dwelling arthropods captured from the different treatments was recorded. The species richness (S), evenness (E) and the Shannon diversity index (H′) were calculated for the different roguing levels. The evenness and the Shannon diversity index were calculated according to (Magurran, 1988), which method has also been used by several authors (Sisay & Ketema, 2015; Zuniga-Gonzalez & Caballero-Hernández, 2024). The number of families sampled from each experimental plot was used to calculate the species richness (S). The measure of species evenness (E) was calculated using $E = -\sum (P_i \ln P_i)/\ln S$; where S is the number of families/species richness, and ln is log base$_n$. The values of E range from 0 to 1, where 1 shows a situation in which all families are equally abundant.

The Shannon diversity index (H′) was calculated as $H' = -\sum (P_i \ln P_i)$, where P_i is the proportion of the ith taxonomic group, estimated as n_i/N; where n_i is the number of individuals of the ith families and N is the total number of individuals sampled from within each plot (Magurran, 1988; Sisay & Ketema, 2015; Zuniga-Gonzalez & Caballero-

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Hernández, 2024). Shannon's diversity index is expressed as a positive number that varies between 0.5 and 5. The low values show a situation with low diversity, while higher values suggest a situation of high diversity (Zuniga-Gonzalez & Caballero-Hernández, 2024).

Seasonal Dynamics of Invertebrate Macrofauna

The numbers of ground-dwelling arthropods were recorded during wet and dry conditions from all rouging levels combined. The percentage of individual arthropods recorded during the wet and dry conditions was calculated. Seasonal arthropod diversity was calculated using the Shannon diversity index.

Statistical Data Analysis

Descriptive and inferential statistics were computed using SAS version 9.4. The chi-squared test for goodness of fit on the total numbers of arthropods sampled per plot was used to analyse the distribution of ground-dwelling arthropods in plots rogued at different levels.

RESULTS

Ground-dwelling Arthropods Composition and Abundance

The composition of ground-dwelling arthropods captured in banana plots of different roguing levels is presented in Table 1. A total of 62, 64, 65 and 72 families were captured from plots of 0, 25, 50, and 100% rouging levels, respectively. Family Formicidae (ants) were the most abundant across all the treatments, followed by family Lycosidae (spiders), although the catches from different treatment levels were not significantly different (Table 2). Family Blattidae was significantly ($P<0.0.5$, d.f= 3, $\chi^2 = 8.238$) captured from 100% roguing compared to other levels. Families of Termitidae, Noctuidae and Carabidae were captured most in plots of 100% roguing, although not significant.

Table 1: Composition of Ground-dwelling Arthropods Sampled across Banana Plots of Different Roguing Levels.

Order	Family	Scientific name	Roguing level (%)			
			0	25	50	100
Araneae	Lycosidae	Unknown	+	+	+	+
Chilopoda	Unknown	Unknown	+	+	+	+
Coleoptera	Cantharidae	*Xylobanus*	-	+	-	+
	Carabidae	*Chlaenius sp*	+	+	+	+
		Craspedophorus	+	-	-	+
		Hyparpalus escheri	+	+	+	+
		Procletus singularis	+	+	+	+
		Styphromerus sp	+	+	+	+
	Cerambycidae	*Pseudhammus mymidonum*	+	+	+	+
	Chrysomelidae	*Aspidomorpha confinis*	+	+	+	+
		Aspidomorpha tecta	+	+	+	+
		Aspidomorpha isparetta	+	+	+	+
		Corynodes compressicornis	+	+	+	+
		Laccoptera cicatricosa	+	+	+	+
		Lema austalis	+	+	+	+
		Oides typographica	-	-	-	+
		Lema macrodera	+	+	+	+
	Cicindelidae	*Ropaloteres cinctus*	+	-	-	-
	Coccinelidae	*Cheilomenes sulpurea*	-	+	+	+
		Epilachna sahlbergi	-	+	+	+
		Ortalia sp	+	+	+	+
	Coreidae	*Acanthocoris fasciculatus*	+	-	-	+
		Homoeocerus prismatocerus	+	+	+	+
	Curculionidae	*Cosmopolites sordidus*	+	+	+	+
		Nematocerus sp	+	+	+	+

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Order	Family	Scientific name	Roguing level (%)			
			0	25	50	100
		Alcidodes dentipes	+	+	+	+
	Dytiscidae	*Hydaticus matruelis*	-	-	-	+
	Elateridae	*Prosephus semicastaneus*	+	+	+	+
	Erotylidae	*Megalodacne sp*	-	+	-	-
	Histeridae	*Hister latipes*	+	+	+	+
	Hydrophilidae	*Sphaeridium pictum*	+	-	+	+
	Lagriidae	*Lagria villosa*	+	+	+	+
	Nitidulidae	*Lasiodactylus maculatus*	-	+	+	+
	Rhynchophoridae	*Sitophilus zeamais*	-	-	+	+
	Scarabaeidae	*Adoretus sp*	-	-	-	+
		Isocamenta sp	+	+	+	+
		Onthophagus rufobasalis	+	+	+	+
		Trochalus sp	-	-	-	+
	Staphylinidae	*Philonthus sp*	+	+	+	+
		Platyprosopus beduinus	+	-	-	+
		Staphylinus fortepunctus	+	+	+	+
	Tenebrionidae	*Gonocephalum constractum*	+	+	+	+
		Praeguna splendens	+	+	+	+
Dermaptera	Forficulidae	*Diaperasticus erythrocephala*	-	+	+	+
Dictyoptera	Blattidae	unknown	+	+	+	+
	Dictyopharidae	*Dictyophara serena*	+	+	+	+
Diptera	Sarcophagidae	Sarcophaga sp	+	+	+	+
	Muscidae	Unknown	+	+	+	+
Hemiptera	Cercopidae	*Triephora sp.*	+	+	+	+
	Lygaeidae	*Lygaeus bettoni*	-	+	-	-
	Mononychidae	*Mononyx grandicolis*	+	+	+	+
	Pentatomidae	Unknown	+	+	+	+
	Pyrrhocoridae	*Dysdercus sp*	-	-	+	-
		Odontopus confuses	+	+	+	+
	Scutelliaridae	*Sphaerocoris testudogrisea*	-	-	+	-
	Cydnidae	*Macrscytus brunneus*	+	+	+	+
Heteroptera	Reduviidae	*Maraenaspis sp.*	+	+	+	+
Hymenoptera	Apidae	*Apis mellifera*	+	+	+	+
	Eumenidae	*Eumenes sp.*	+	+	+	+
	Formicidae	*Camponotus maculatus*	+	+	+	+
		Odontomachus sp.	+	+	+	+
		Pachycondylla tarsata	+	+	+	+
		Polyrhachis sp.	+	+	+	+
		Tetramorium sp.	+	+	+	+
	Sphecidae	*Belonogaster sp.*	+	+	+	+
		Liris diabolica	+	+	+	+
		Prionyx kirbyi	+	+	-	+
Isoptera	Termitidae	*Odontotermes Sp.*	+	+	+	+
		Unknown	+	+	+	+
Ixodida	Ixodidae	Unknown	-	+	+	+
Lepidoptera	Noctuidae	Unknown	+	+	+	+
	Pyralidae	Unknown	+	-	+	-
	Saturniidae	Unknown	+	+	+	+
Mantodea	Mantidae	Unknown	+	-	+	+
Neuroptera	Myrmeleontidae	*Palpares sp.*	-	+	-	+
Oligochaeta	Lumbricidae	Unknown	+	+	+	-
Orthoptera	Acrididae	unknown	+	+	+	+
	Gryllidae	*Gryllus sp.*	+	+	+	+
		N=78	62	64	65	72

Signs +or- indicate presence or absence of genera/species.

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Table 2: Abundance of Selected Ground-dwelling Invertebrates Sampled from Plots of Different Roguing Levels

Invertebrate family	Mean number of arthropods captured per plot				χ^2 tests	Significance level
	0	25	50	100		
Formicidae	600.7±57.9	614.6±43.4	615.9±39.9	626.0±40.9	1.723	NS
Lycosidae	46.1±4.2	64.1±6.0	53.4±4.1	72.3±5.2	0.227	NS
Gryllidae	34.9±3.9	38.5±4.9	26.5±3.3	47.3±6.0	0.368	NS
Blattidae	25.3±3.2	35.9±5.6	29.1±3.8	91.2±14.1	8.238	*
Acrididae	10.6±2.9	9.4±1.5	6.4±1.1	14.8±1.5	0.288	NS
Elateridae	10.0±1.7	7.5±1.5	7.6±1.2	9.4±2.2	0.097	NS
Noctuidae	7.6±2.1	7.4±2.3	5.7±0.8	14.8±6.7	0.387	NS
Carabidae	6.0±1.5	3.7±0.5	3.2±0.6	6.7±0.9	0.255	NS
Termitidae	10.2±2.8	4.5±0.8	5.6±0.8	11.0±4.7	0.555	NS

Df=3, tabulated α=7.815; NS= not significant, * significant at $P<0.05$

Among the functional groups of ground-dwelling arthropods (Table 3), the termites (family Termitidae) were significantly higher in the plots of 100% rouging level, while the flies were significantly higher in the 50% and 100 % rogued plots. The percentage abundance of ants and beetles recorded from different treatments was not significantly different.

Table 3: Percentage Abundance of Different Ground-dwelling Arthropods Functional Groups Captured from Plots of Different Roguing Levels

Macrofauna functional group	Roguing levels (%)				χ^2 test	Significance level
	0	25	50	100		
Ants	23.9	25.5	25.6	25.0	0.069	NS
Beetles	24.7	20.9	24.4	30.0	1.689	NS
Flies	14.9	16.1	35.6	33.3	14.520	*
Termites	28.3	11.3	15.4	45.0	27.661	*
Others	18.2	24.4	21.5	35.9	7.131	NS

Df=3, tabulated α=7.815; NS= not significant, * significant at $P<0.05$

Ground-dwelling Arthropods' Diversity, Species Richness and Evenness

The total number of species (species richness) captured during the study was 78. Some of the arthropods were, however, not identified to species level (Table 3). A total of 62, 64, 65 and 72 species were captured from plots of 0, 25, 50, and 100% roguing levels, respectively. The evenness index showed that the arthropods were unevenly abundant or distributed in the banana plots of different roguing levels (Table 4). The evenness score was relatively higher in the 100% (E=0.339) rogued plots, indicating a more uniform distribution of the different macrofauna species. The number of species captured in the four treatments was similar, although there were more species captured in plots which were 100% rogued (Table 4). The Shannon diversity index was lowest for catches in 25% (0.903) and highest in 0% (1.177) rogued plots. The Shannon diversity index values were low, suggesting that few species were more abundant than others and that the different plots had low diversity of arthropods.

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Table 4: Shannon Diversity Index, Evenness and Richness of Ground-dwelling Arthropods Captured from Plots of Different Roguing Levels

Indices	Roguing level (%)			
	0	25	50	100
Diversity	1.177	0.903	0.996	1.162
Evenness	0.278	0.008	0.264	0.339
Species Richness	62	64	65	72

Seasonal Ground-dwelling Arthropods Abundance and Diversity

The total number and abundance (%) of ground-dwelling arthropods captured during the wet season compared to those taken during the dry season were similar for all the plots of different roguing levels (Table 5). The arthropod families of Formicidae (ants), Blattidae, Gryllidae, and Termitidae were equally abundant in both dry and wet seasons. The family Curculionidae (that includes the banana weevils, *Cosmopolites sordidus*) and Family Cynidae were more abundant in the dry season than in the wet season. On the other hand, members of the family Coccinellidae and Scarabaeidae were more abundant during the wet season.

Table 5: Percentage Abundance of Ground-dwelling Arthropods Sampled During Wet and Dry Seasons from Banana Plots

	Dry season		Wet season		χ^2 tests	Significance level
Macrofauna family	Abundance	% Total	Abundance	% Total		
Formicidae	31083	77.06	29119	73.89	64.072	*
Lycosidae	2903	7.20	2876	7.30	0.126	NS
Blattidae	1793	4.45	2629	6.67	158.049	*
Gryllidae	1776	4.40	1820	4.62	0.538	NS
Acrididae	483	1.20	504	1.28	0.447	NS
Noctuidae	493	1.22	265	0.67	68.581	*
Elateridae	182	0.45	498	1.26	146.847	*
Termitidae	247	0.61	266	0.67	0.704	NS
Carabidae	168	0.42	232	0.59	10.24	*
Curculionidae	138	0.34	97	0.25	7.153	*
Cydnidae	128	0.32	71	0.18	16.32	*
Lumbricidae	103	0.26	84	0.21	1.931	NS
Scarabaeidae	59	0.15	124	0.31	22.967	*
Coccinellidae	44	0.11	184	0.47	85.965	*

df=1, α =3.841; NS= Not significant, *=significant < 0.05

Seasonal ground-dwelling arthropod diversity in the banana plots with different roguing levels is shown in Table 6. Total arthropod diversity was generally similar for arthropods captured during the wet and dry seasons. The Shannon diversity index was higher in plots of 100% roguing compared to other roguing levels in both the wet and dry seasons.

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Table 6: Diversity of Ground-dwelling Arthropods Sampled in Wet and Dry Seasons from Plots of Different Roguing Levels

Rouging level (%)	Shannon diversity index (H')	
	Wet Season	Dry Season
0	0.285	0.271
25	0.290	0.276
50	0.276	0.249
100	0.368	0.333
Total	0.298	0.285

DISCUSSIONS

The ground-dwelling arthropod species composition, abundance and diversity under different land use systems are majorly influenced by microclimate, habitat structure and food resources (Karanja et al., 2009; Masebo et al., 2024; Rajwar et al., 2021; Uhía & Briones, 2002). Changes in ecosystems undoubtedly affect faunal composition and their activities (Anas et al., 2011; Zulu et al., 2022). In this study, a total of 78 species of ground-dwelling arthropods were captured from all banana plots of all roguing levels combined. The results did not show differences in individual numbers of arthropods captured from banana plots of different roguing levels, clearly indicating that roguing bananas had limited influence on abundance, composition and diversity. This could have possibly been influenced by the retention of the uprooted crop residues. The termites as a functional group were significantly captured in 100% rouged plots as compared to other roguing levels. This high termite population could have been driven by the abundance of crop litter on the soil surface. It's also reported that termites are among the soil macrofauna that are safeguarded from climatic extremes that come about by building nests and are not affected by disturbed situations (Ayuke et al., 2015). Family Formicidae (ants) were the most dominant group of invertebrate macrofauna captured from all roguing levels. Similar observations were made in a *Musa acuminata* cropping system (Santos et al., 2018; Zuniga-Gonzalez & Caballero-Hernández, 2024). Members of the Formicidae family are reported to be predators of *Cosmopolites sordidus* within the banana cropping system (Gold et al., 2001). They also play important functions in maintaining soil health in different cropping systems (Del Toro et al., 2012; Ribeiro et al., 2024).

The diversity of soil macrofauna depends on land use type. In our study, roguing levels of banana plots did not cause an observable influence on macrofauna species diversity. The Shannon diversity index values in our study were low, suggesting that few species are more abundant than others and that the different plots had low diversity of macrofauna. The results agree with the low Shannon diversity index that was observed in the *Musa acuminata* cropping system (Zuniga-Gonzalez & Caballero-Hernández, 2024). The evenness index showed that macrofauna were unevenly abundant or distributed in the banana plots of different roguing levels. The evenness was relatively higher in the 100% rogued plots, indicating a higher number of macrofauna and better relative distribution. The Shannon index of diversity index was relatively high in plots rogued 100%; contrary to other reports where higher diversity indexes were reported where vegetation is more diverse (Sisay & Ketema, 2015). Species evenness was relatively higher in the 100% rogued plots, indicating a higher number of soil invertebrate macrofauna and better relative distribution.

There are reports of higher catches of macrofauna during the wet months of the year in different agro-ecosystems, including the banana, as compared to the dry months (Owa et al., 2000). It's suggested that better ecological stability during the wet months is the possible reason for higher catches (Siqueira et al., 2016). In our study, members of the family Coccinellidae and

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Scarabaeidae were captured more in the wet season than in the dry season. This can be attributed to their preference for more humid conditions. On the other hand, the banana weevil (Family Curculionidae) was captured more in the dry than the wet months. This can be attributed to an increased activity in search of food and cooler conditions, enhancing the probability of being captured in traps. For our case, we expected permanent feeding conditions in the 0% rogued and in a wet season. The Shannon diversity index for all roguing levels was similar in the wet and dry seasons. These results do not corroborate those reported elsewhere (Asfaw & Zewudie, 2021; Pauli et al., 2011), which observed more macrofauna catches in the wet months than in the dry months in coffee-based agroforestry systems.

Generally, the rogued fields performed better in terms of the composition, diversity and evenness of the ground-dwelling arthropods. This suggests that the disease management practices possibly had no effect on macrofauna populations. However, it should be noted that the application of the practice by farms tends to vary depending on the farmers' resource base. For example, some farmer totally removes all crop residue from the surface of the fields, others introduce other crops, while others leave the plots to fallow (as was the case in this trial). All these differences could differently affect the ground-dwelling arthropods' composition, abundance and diversity.

CONCLUSION

This study demonstrates that mass uprooting (roguing) is an effective strategy for controlling BXW without significantly disrupting ground-dwelling arthropods' composition, abundance, or diversity, particularly when crop residues are retained. These findings highlight the potential for integrating disease management with ecological sustainability, supporting soil health and long-term agricultural productivity. In a broader context, this suggests that BXW control can align with agroecological principles if policies promote residue retention, seasonal adaptation, and equitable access to biodiversity-friendly practices. Practical applications include training extension services to tailor BXW management to local ecological conditions and supporting farmers through incentives and resources. Future research should explore the long-term effects of repeated roguing on soil health, the functional roles of key macrofauna groups, and comparative studies across cropping systems to refine sustainable disease control strategies.

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Data Availability Statement:

Access to the data from this study is available upon request via email.

Conflict of Interest:

The authors declare no conflict of interest.

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