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Effects of Insecticides on Soil Arthropods in the Rice Crop Ecosystem

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

It is known that soil fauna performs a critical role in the biological turnover and nutrient release from plant residue. The presence of pollutants in the soil leads to disruptions that cause both qualitative and quantitative changes in the fauna, ultimately impacting soil functioning. The present study was undertaken to evaluate the impact of different insecticides on non-target soil arthropods, with a focus on collembolan populations, which made up 42.57% of the total recorded soil arthropods in the rice cropping ecosystem. All insecticide treatments led to significant reductions in collembolan numbers, with the combinations of Fipronil 15% + Imidacloprid 5% SC and Fipronil 15% + Indoxacarb 5 % SC causing the most substantial decreases in the total population mean of 2.71 and 2.75, respectively. In contrast, Chlorantraniliprole 20% SC had the least effect in the total population mean 4.06, indicating a potentially lower risk to non-target species. According to these results the potential adverse impacts of insecticides on soil health, emphasizing the need of careful selection of pest management strategies to preserve soil biodiversity and maintain ecological balance.

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Keywords: Rice crop; insecticides; fipronil; imidacloprid; arthropod; chlorantraniliprole.

1. INTRODUCTION

Rice (*Oryza sativa* L.) stands as the world's most important crop cultivated across 117 countries and serving as the staple food source for more than 3.5 billion people worldwide, which is nearly half of the global population. It is especially important in Asia, where it serves as the primary source of calories and nutrition for the majority of the population (Food and Agriculture Organization of the United Nations, 2004). Globally, India ranks first in rice cultivation area with covering an area of 44.6 million hectares, with production of 137 million metric tons in year 2023-24 thereby accounting for 26% of the world's rice production (United States Department of Agriculture Foreign Agricultural Service, 2024).

Many species of arthropods inhabit rice fields, although most of them are not truly noxious to the crops. For instance, some 500 species of insects and spiders may appear in a rice field in a particular season, only few of them are potential threat to the crop. In addition to the terrestrial arthropods, various other arthropods are also found in soil that significantly contributes to the soil fauna. Soil fauna is typically categorized based on their size into microfauna (e.g., protozoa, nematodes), mesofauna (e.g., mites, springtails), and macrofauna (e.g., earthworms, beetles). Each group contributes to the overall functioning and biodiversity of the soil ecosystem.

In terms of species richness, arthropods account for up to 20% of the soil fauna and constitute a significant portion of the meso and macro fauna populations within the soil environment. Soil-dwelling arthropods carry out several important functions within the soil and serve as bioindicators of soil quality (Cortet et al., 2002). Nutrients in the soil are mineralized by arthropods through microbial consumption, thereby completing the process of nutrient recycling and the composition of soil mainly consists of arthropod’s excreta (Sagi, Nevo, & Hawlena, 2021). Collembola are the most abundant arthropods in soil, which have an extremely high density of almost 20,000 collembolan per square meter of soil (Paul et al., 2011) and play a significant role as decomposer in food webs (Petersen, 2002).

The introduction of high-yielding varieties led to a substantial increase in the use of commercial inputs and agrochemicals. While these inputs have contributed to higher crop yields and protection against pests, but their indiscriminate use has reduced soil fertility. Soils have become repositories for various chemical inputs, including insecticides (Bhuyan et al., 1993), which are beneficial for crop production but have negative impacts on non-target organisms (Adamski et al., 2007; Charmillot et al., 2001). in addition to deposition of toxic residues in food, water, air, and soil, pest resurgence, resistance etc. The extent of these hazards is directly co-related with the persistence of the insecticides. The longer they remain in the soil, the higher the risk of affecting soil fauna and contaminating the environment, ultimately leading to disruptions in soil health.

These repeated pesticide applications are harmful to soil -dwelling arthropods (Vig, Singh, & Sharma, 2006). Akoijam & Bhattacharyya, (2012) reported that four insecticides *i.e.,* carbosulfan, isofenphos and phorate had negeative effect on non -target soil arthropods especially collembolns and soil mit. Therefore, the present study was conducted to check the effect of various insecticides on the abundance of collembolan population in rice crop ecosystem, which could be used for better decision on choosing an insecticide for insect pest management in rice.

2. MATERIALS AND METHODS

The field experiment was conducted during the Kharif season of 2021-22 at the A2/3 block of the Crop Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar, located in the Tarai belt of the Himalayan foothills (latitude 29°N, longitude 79.5°E, altitude 243.83 m above sea level). During this period, the mean maximum temperatures ranged from 29.7°C to 39°C, and mean minimum temperatures ranged from 24.1°C to 26.9°C. Total rainfall was 1378.5 mm, with August receiving the highest amount at 665.5 mm, accounting for 48.3% of the total rainfall over 35 rainy days. Total pan evaporation was 380.1 mm, with weekly averages fluctuating from 7.3 mm in June to 2.7 mm in August. Relative humidity ranged from a maximum of 80.1% to 95.1% and a minimum of 67.7% to 84.0%. Average weekly sunshine hours were lowest (1.0 hour) in the first week of August and highest (6.4 hours) in

June. Wind velocity ranged from a minimum of 1.1 km/hr in August to a maximum of 7.5 km/hr in late June. The soil in the experimental plot was silty clay loam with a neutral pH of 7.2, medium organic carbon (0.69%), and medium levels of phosphorus (21.5 kg/ha) and potassium (222.3 kg/ha), but low in available nitrogen (216.3 kg/ha).

The experiment included seven insecticidal treatments, viz. chlorantraniliprole 20% SC at 150 ml/ha, fipronil 5 % SC at 1000 ml/ha, cartap hydrochloride 50 % SP at 1000g/ha, flubendamide 480 % SC at 50 ml/ha, indoxacarb 14.5 % SC at 500 ml/ha, fipronil 15 % SC + imidacloprid 5 % SC at 500 ml/ha, and fipronil 15 % SC + indoxcarb 5%SC at 1000 ml/ha. A control plot was also maintained for comparative analysis.

Rice (variety HKR-47) nursery was sowed in the month of June and the transplanting of seedling in the experimental field was done in the 1st week of July. Experimental plots were laid out in Randomize block design with three replications. The experimental plots size was 5m × 5m at a spacing of 20×10cm between rows and 20 cm between plant to plant. The total no. of row/plot was 24. Visual observations were recorded randomly so that when the insect pest complex of rice reaches to the threshold level control measure should be applied. The insecticides were applied after 30-35 days after transplanting.

To study the arthropod abundance in the experimental site, soil samples were collected at pretreatment and at 15, 30, and 75 days after spraying (DAS) from three random locations within each rice plot using a Trowel (soil sampler) in a "V" shape manner. The sampling depth was consistently maintained at 15 cm from the soil surface. Following extraction, the soil samples (500g) were carefully removed from the sampler to avoid disturbing the soil profile. Each sample was placed into polythene bags and sealed to prevent moisture loss, with all relevant information recorded. The samples were then transported to the laboratory for the extraction of soil arthropods.

Soil arthropods were extracted using a Tullgren funnel equipped with a 100-watt electric bulb, which provided high light intensity for a continuous exposure period of 48 hours (Alves et al., 2014). The extraction method relied on the principle that soil arthropods are photophobic and is repelled by light; additionally, the temperature gradient created by the bulb forced the arthropods downwards. The extracted arthropods were collected in 40 ml tubes containing 70 percent ethyl alcohol. The collected micro arthropods were then transferred into clean Petri dishes (15 cm diameter) for group-wise sorting. Morphological identification of the soil arthropods was conducted using a stereo microscope for proper identification.

To study the diversity of soil arthropods two diversity indexes i.e., Shannon (H) and Simpson diversity index (1-D), as well as the evenness index of Pielou (J), were used to assess insect diversity within. In accordance with (Magurran, 2004), the unequal distribution of abundance between species allowed the use of the dominance index of Berger–Parker (1/d) to express the proportion of individuals accounted for by the most abundant species in each site. The species richness index of was used to highlight the most species-rich site.

1. Shannon Diversity Index (H)

The Shannon diversity index measures the entropy (uncertainty or diversity) within a dataset. It is calculated as:

$$\mathbf{H} = -\sum(\boldsymbol{pi}.\,\mathbf{In}\,\boldsymbol{pi})$$

Where, *pi* is the proportion of the i^{th} species. Higher values indicate greater diversity.

2. Simpson Diversity Index (1-D)

Simpson's index measures the probability whether the randomly selected from a sample would belong to the same species. It is calculated by using the following formula:

$$\boldsymbol{D} = \sum \boldsymbol{p}_{\boldsymbol{i}}^{\mathbf{2}}$$

Where, pi is the proportion of the i^{th} species. However, 1−D (Simpson's Index of Diversity) is often used, where higher values indicate greater diversity.

3. Pielou's Evenness Index (J)

Pielou's evenness index measures how evenly individuals are distributed across the species in a community. It is calculated by using the following formula:

$$J = \frac{H}{In\,S}$$

Where, H is the Shannon's diversity index and S is the total number of species. Values range from 0 to 1, with 1 indicating perfect evenness.

4. Berger–Parker Index (1/d)

The Berger–Parker index gives the proportional dominance of the most abundant species. It is calculated by using the following formula:

$$d = \frac{Nmax}{N}$$

N_{max} is the number of individuals of the most abundant species, and N is the total number of individuals. The inverse, 1/d, is used to express diversity, where higher values indicate greater diversity. All these indices are commonly used in ecological community studies (Magurran, 2004).

Statistical Analysis:

The collected data was subjected to statistical analysis using Duncan's multiple range test (DMRT) to compare the specific difference of mean with the help of SPSS (26) software.

3. RESULTS AND DISCUSSION

The present study revealed that non target soil arthropods were negatively affected by all the different insecticides. Firstly, the pretreatment population of non-target soil arthropods was recorded from the extracted soil arthropods. Then four group of soil non target arthropods were selected based on pretreatment data collection (Table 3).

The soil collected from the experimental fields has a diverse assemblage of soil arthropods, predominantly from the class Insecta, which represents 83.54% of the total population. Within this collection, Collembola (Isotomidae, Hypogastruridae) are the most abundant, comprising 42.57% of the total soil arthropod collected from experimental field. Following Collembola, Isoptera (Termitidae) constitute 29.32%, and Hymenoptera (Formicidae) make up 7.23%. Other insect orders include Coleoptera (Staphylinidae, Scarabaeidae, Carabidae) at 3.21% and Dermaptera (Forficulidae) at 1.21%. The class Arachnida, accounting for 7.23% of the total, is predominantly represented by Oribatida (Phthiracaridae) at 5.62%, with Araneae (spiders) contributing 1.61%. Diplopoda (millipedes) represent 4.83%, Chilopoda (centipedes) 2.01%, and Annelida (Lumbricidae) 2.41%. This distribution highlights a rich and varied soil ecosystem, with a clear dominance of insect species, particularly springtails, which play a crucial role in the maintaining soil health and environment (Table 1, Fig. 1).

Results indicate significant reductions in collembolan populations across all treated groups compared to the control (Table 3). The pre-treatment population varied slightly across treatments but remained within a comparable range, with the control group (T8) having an initial population of 5.55 individuals.

The combination treatments of Fipronil 15% + Imidacloprid 5% SC (T6) and Fipronil 15% + Indoxacarb 5 SC (T7) resulted in the most significant reductions in collembolan populations, with mean populations of 2.71 and 2.75 individuals per 500g of soil, and percentage reductions of 51.74% and 50.98% over the control, respectively. Conversely, Chlorantraniliprole 20 SC (T1) and Flubendamide 480 SC (T4) showed comparatively lower reductions, with mean populations of 4.06 and 3.95 individuals and percentage reductions of 27.56% and 29.62%, respectively.

Fifteen days post-treatment, T6 and T7 exhibited the most pronounced immediate impact, with the lowest recorded populations of 1.38 and 1.53 individuals, respectively. These treatments continued to demonstrate the highest levels of population suppression 30 days post-application, while T1 and T4 exhibited higher populations, indicating either lesser impact or quicker recovery. By 75 days, some recovery in collembolan populations was observed across most treatments, although T6 and T7 still maintained the lowest populations, underscoring their prolonged efficacy. The control group maintained a stable population of 5.61 individuals per 500g of soil throughout the study, highlighting the natural resilience of the collembolan population in untreated soil (Table 3, Fig. 2).

Overall, results suggest that the combination insecticides, Fipronil 15% + Imidacloprid 5% SC and Fipronil 15% + Indoxacarb 5 SC as the most negatively impacted treatments in reducing collembolan populations whereas Chlorantraniliprole 20 SC exhibited the least impact, suggesting a potentially lower risk to non-target organisms.

This could be attributed to the synergistic effects of the combined active ingredients, leading to higher contribution in reducing soil-dwelling arthropods. These findings align with previous studies that have highlighted the broad-spectrum activity of fipronil-based insecticides and their impact on non-target soil organisms (Rajagopal et al., 1990). The substantial reduction in collembolan populations raises concerns about the potential long-term ecological consequences, given the crucial role of collembolans in soil health and nutrient cycling (Hopkin, 1997). The differential impact observed across the various insecticides underscores the need for careful consideration when selecting pest control strategies in agricultural ecosystems.

Although, the effective pest management is essential, the potential adverse effects on beneficial soil organisms must be weighed to maintain ecological balance. Further research is warranted to explore the recovery dynamics of collembolan populations post-insecticide application and to investigate alternative pest management practices that mitigate harm to soil biodiversity (Pisa et al., 2015).

Table 1. Abundance of soil arthropods found in the experimental location

Class	Order	Family	Individuals	% of Total Count
Insecta	Coleoptera	Staphylinidae, Scarabaeidae, Carabidae	8	3.21
	Collembola	Isotomidae, Hypogastruridae	106	42.57
	Hymenoptera	Formicidae	18	7.23
	Isoptera	Termitidae	73	29.32
	Dermaptera	Forficulidae	3	1.21
Total Insecta			**208**	**83.54**
Arachnida	Oribatida	Phthiracaridae	14	5.62
	Araneae		4	1.61
Diplopoda	Millipedes		12	4.83
Chilopoda	Centipedes		5	2.01
Annelida	Earthworms	Lumbricidae	6	2.41
Grand Total			**249**	**100**

Table 2. Species diversity and species richness indices calculated for insects associated

Diversity Index	Value
Shannon Diversity Index (H)	1.50
Simpson Diversity Index (1-D)	0.72
Pielou's Evenness Index (J)	0.65
Berger–Parker Index (1/d)	2.35

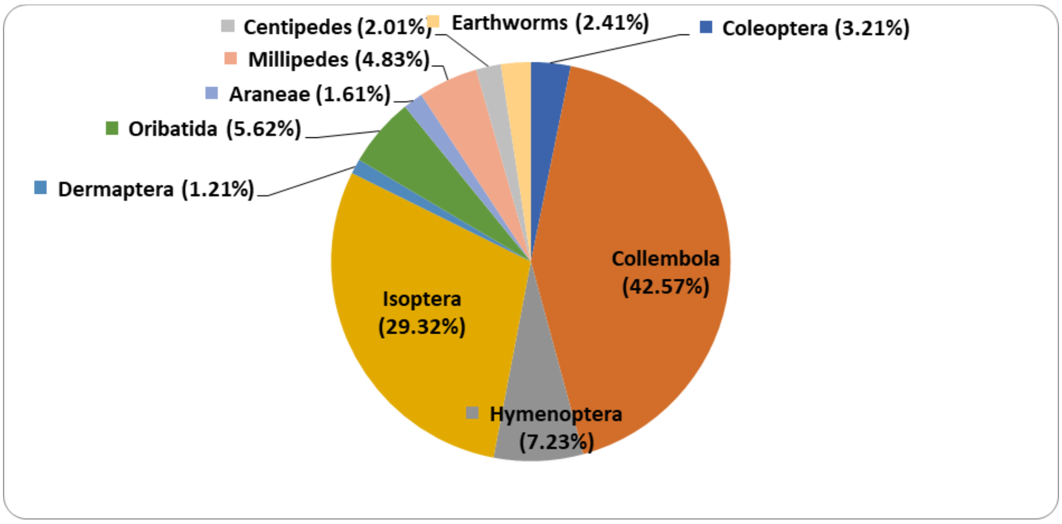

Fig. 1. Abundance of soil arthropods found in the experimental location

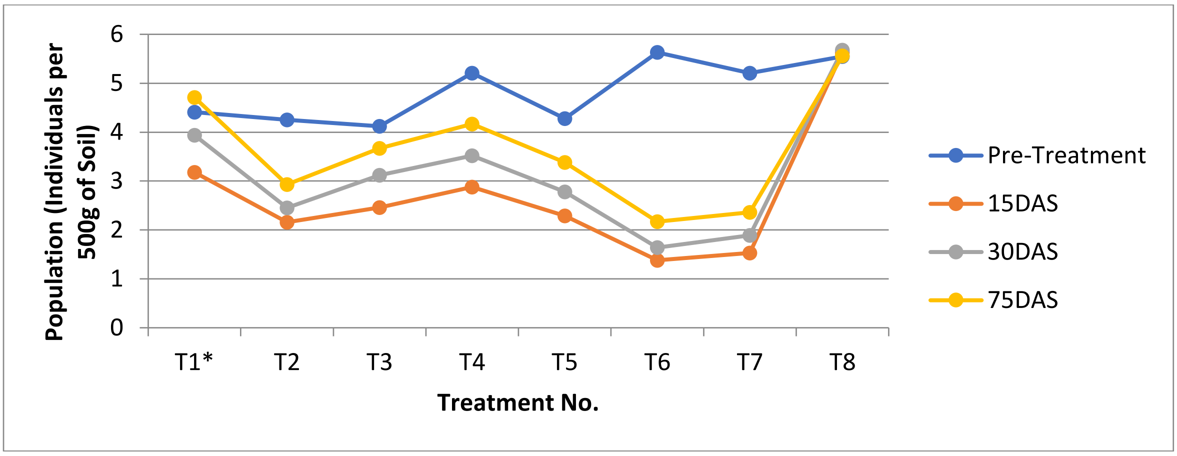

Fig 2. Effect of insecticides on collembolan population at different intervals

Table 3. Effect of insecticides on collembolan population at different interval

Treatment	Pre-Treatment	15 DAS	30 DAS	75 DAS	Mean	% ROC
T1*	4.41±0.03^{b}	3.18±0.03^{f}	3.94±0.08^{g}	4.71±0.03^{g}	4.06	27.56
T2	4.25±0.10^{ab}	2.16±0.04^{c}	2.45±0.06^{c}	2.93±0.07^{c}	2.92	47.90
T3	4.12±0.07^{a}	2.46±0.06^{d}	3.12±0.05^{e}	3.67±0.09^{e}	3.34	40.37
T4	5.21±0.110^{c}	2.88±0.07^{e}	3.52±0.06^{f}	4.17±0.10^{f}	3.95	29.62
T5	4.28±0.06^{ab}	2.29±0.05^{c}	2.78±0.04^{d}	3.38±0.07^{d}	3.18	43.22
T6	5.63±0.06^{d}	1.38±0.01^{a}	1.64±0.02^{a}	2.17±0.03^{a}	2.71	51.74
T7	5.21±0.09^{c}	1.53±0.06^{b}	1.89±0.02^{e}	2.36±0.02^{b}	2.75	50.98
T8	5.55±0.01^{d}	5.63±0.06^{g}	5.68±0.13^{h}	5.56±0.01^{h}	5.61	27.56

**T1= Chlorantraniliprole 20 % SC, T2= Fipronil 5 % SC, T3= Cartap Hydrochloride 50 % SP, T4= Flubendamide 480 % SC, T5= Indoxacarb 14.5% SC, T6= Fipronil 15%+ Imidacloprid 5% SC, T7= Fipronil 15%+Indoxcarb 5 % SC, T8= Control*

DAS= Days after spray, ROC = Reduction over control

***Numbers followed by same letters are statistically at par (otherwise significantly different at $p < 0.05$)*

4. CONCLUSION

This study demonstrates that the application of various insecticides, particularly those containing fipronil in combination with Imidacloprid or Indoxacarb, significantly reduced the collembolan population in rice cropping systems. The reduction in collembolan numbers, which play a vital role in soil health and nutrient cycling, raises concerns about the long-term ecological consequences of these insecticides. The results underscore the importance of considering the broader ecological impacts when selecting insect pest control strategies. Further research is necessary to investigate the recovery of collembolan populations post-insecticide application and to explore alternative pest management practices that minimize harm to beneficial soil organisms. These findings contribute to the understanding of how agrochemicals affect soil biodiversity and highlight the need for sustainable agricultural practices.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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