Assessing toxicity of insecticides on soil arthropods in rice ecosystem

Abstract

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.Globally, rice (*Oryza sativa* L.) is one of the most important food cropandacrops, particularly in Asia, where it serves staple food crop for billions of people. The present study was undertakento evaluate the impact of sevendifferent insecticides *viz.*,chlorantraniliprole, fipronil, cartaphydrochloride, flubendamide, indoxacarb, fipronil+imidacloprid and fipronil+indoxacarbon the collembolan population, a key member of soil arthropodcommunity,arthropods, specifically in rice ecosystem. The experiment was carried out at Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, during the *kharif*, 2022. The study revealed significant reductions in collembolan populations across all treatments, with the most substantial effects observed in fipronil+imidacloprid and fipronil+indoxacarb combination treatments. The current findings highlight the potential adverse impacts of insecticides on soil health, emphasizing the need of careful selection of pest management strategies to preserve biodiversityof soil arthropods and maintain ecological balance.

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Introduction

Rice (*Oryza sativa*L.) stands as the world's most important crop cultivated across 117 countries and is astaple food for more than 3.5 billion people worldwide, which is nearly half of the global population. It is especially important in Asia, where it is considered asas the primary source of calories and nutrition for the majority of the population **(FAO, 2004).**Globally, India stands first in terms of area of rice cultivation, covering 44.6 million hectares, and is the second-largest producer, with 137 million metric tons produced in 2023-24, accounting for 26% of the world's total rice production **(USDA, 2023-24).**

Many species of arthropods inhabit rice fields, and only a few are truly noxious to the crop. For instance, about 500 species of insects and spiders may appear in a rice field in a particular season,withof whichonly a few causing potential threat to the crop. In addition to the terrestrial arthropods, various arthropods are also found in the soil that significantly contribute to the soil fauna diversity. The 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 *viz.*, mineralization of soil nutrientsthrough microbial consumption, thereby completing the process of nutrient recycling andthe soil is enriched with the excretaand the dead remains of the soil dwelling arthropods (**Sagi and Hawlena, 2021**). Collembola are the most abundant arthropods in soil 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, their indiscriminate use has indirectly contributed to reduction in soil fertility. Soil have become repositories for various chemical inputs, especially insecticides **(Bhuyan*et al.*, 1993),** that are considered beneficial for enhanced yields and better crop protection but pose negative consequesnces including toxic residues in food, water, air and soil, pest resurgence, resistance and adverse effects on non-target organisms.

The extent of these hazards is directly correlated with the persistenceas well as the relative toxicityof 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. When insecticides are applied, they often accumulate in the top layers at around a depth of 10–15 cm layer of soil having the highest microbial and faunal activity **(Blasco and Pico, 2009).** This enhances theinteractions between insecticide residues and soil fauna, impacting soilhealth andfunctions **(Cortet*et al.*, 1999).**

Soil micro arthropods are frequently used as bio-indicators of soil quality **(Cortet*et al.*, 2002.** Since pesticides are not entirely species-specific, they can cause both lethal and sublethal effects on non-target species, which may vary depending on developmental stages **(Adamski *et al.*, 2007; Charmillot*et al.*, 2001).**There are onevery few collembolans known to damage crop plants hence, most of thethem are considered beneficial in terms of improving soil structure and

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other properties. These non-target organisms that getscollembolansare often exposed to lethal effects of pesticides that are applied for crop protection (**De Santo *et al.*, 2018)**. Biodiversity studies are needed for effective sampling, particularly for highly diverse terrestrial groups like arthropods **(Colwell and Coddington, 1994).**Therefore the, present study was conducted to understandhow agrochemicals, particularly insecticides, impact soil arthropods in rice crop ecosystem.

Materials and methods

The experiment was conducted atCrop Research Centre,Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand, located at 29°01'33.60"N latitude and 79°28'16.19"E longitude during *kharif*, 2022 in rice croppingsystem.Rice (cv.HKR-47) was sownin plots measuring 5m × 5m, at a spacing of 20×10cm between rows and leaving 20 cm between plants.All the experiments were replicated thrice.

Seven insecticides *viz.*,chlorantraniliprole 20 SC @150ml/ha, fipronil 5 SC @1000ml/ha, cartap hydrochloride 50 SP @1000g/ha, flubendamide 480 SC @50ml/ha, indoxacarb 14.5 SC @500ml/ha, fipronil 15SC+imidacloprid 5 SC @500ml/ha, and fipronil 15SC+indoxcarb 5 SC @1000ml/hawere applied atrecommended dose by foliar application at 25-30 days after transplanting.Besides the above insecticides an untreated control was maintained.Three replications were maintained.

The diversity indices of Shannon (H) and Simpson diversity index (1-D), as well as the evenness index of Pielou (J), were used to assess thediversity within the ecosystem?.In accordance with **Magurran (2004)**,of soil arthropods.Further, the unequal distributionof individuals of differentspecies was computed usingthe dominance index of Berger–Parker (1/d) to expressthe proportion of individuals accounted for,byof themost abundant species in eachsamplingsite **(Magurran, 2004)**. The species richnessindex was used to highlight the mostspecies-rich site.

1.Shannon Diversity Index (H):

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

$$H = -\sum (pi. \ln pi)$$

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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 wouldbelong to the same species. It iscalculated by using the following formula (reference):

$$D = \sum p_i^2$$

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 iscalculated by using the following formula (reference):

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

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 iscalculated by using the following formula (reference):

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

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).**

To study the arthropod abundance in the experimental site, observations were taken prior to applying insecticides (pre-treatment) and at 15, 30, and 75 days after insecticide application **(Rajagopal, Kumar, & Gowda, 1990).** The samples were then moved to the laboratory where the Tullgren Funnel was installed. Extraction methods were designed to suit behavior and body structures of the organisms **(Hopkin, 1997; Wallwork, 1970).** The soil micro arthropods were collected and put into containers with 70% alcohol within 48h of extraction and examined under stereo microscope for proper identification. The collected data weresubjected to statistical

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analysis using Duncan’s Multiple Range Test (DMRT) to compare the specific difference among means with the help of SPSS (26) software.

Results and Discussion

The soil under investigation hosts a diverse assemblage of arthropods, predominantly from the class Insecta, which represents 83.54% of the total population. Within this collection, collembola (springtails) were the most abundant, comprising 42.57% of the total soil arthropod collected from the field.Followed by this, IsopteraFollowingcollembola, isoptera(termites) constituted 29.32%, and hymenoptera(ants) made up 7.23%. Other insect orders include coleoptera(beetles) at 3.21% and dermaptera(earwigs) at 1.21%. The class Arachnida, accounted arachnida, accounting for 7.23% of the total, and was predominantly represented by oribatida(mites) at 5.62%, and Araneaewitharaneae(spiders) contributing 1.61%. Diplopoda (millipedes) represented 4.83%, chilopoda(centipedes) 2.01%, and annelida(earthworms) 2.41% were the other members of the Phylum Arthropoda. 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 soil environment.

Results indicated significant reductions in collembolan populations across all treated groups compared to the control. The most pronounced reductions wasobserved in the combination treatments of fipronil 15 +imidacloprid 5 SC and fipronil 15 + indoxacarb 5% SC, with mean populations of 2.71 and 2.75 individuals per 500g of soil, respectively. These treatments showed the highest percent reduction of 51.74% and 50.98% over control. Conversely, chlorantraniliprole 20 SC and flubendamide 480 SC showed relatively lower reductions, with mean populations of 4.06 and 3.95 individuals/ 500g of soil and percentage reductions of 27.56% and 29.62%, respectively. The control group exhibited a stable mean population of 5.61 individuals/ 500g of soil throughout the study period, emphasizing the natural resilience of the collembolan population in untreated soil.

The results suggested that the combination insecticides, particularly those containing fipronil, have a significant detrimental effect on the collembolan population. This could be attributed to the synergistic effects of the combined active ingredients, leading to relatively highertoxicity and subsequent reductionin soil-dwelling arthropods. These findings align with previous studies that have highlighted the broad-spectrum activity of fipronil-based insecticides

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and their impact on non-target soil organisms **(Kim *et al.*, 2014; Oliver *et al.*, 2016).** 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 harmful impact observed due to various insecticides underscores careful consideration for selection ofpest control strategies in agricultural ecosystems.

Despite importance ofeffective pest management in any agricultural ecosystem, itspotential adverse effects on beneficial soil organisms must be weighed to maintain ecological balance. Further, the current experimentis warranted to explore the recovery dynamics of collembolan populations post-insecticide application and to investigate alternative pest management practices that mitigate the harm to soil biodiversity **(Pisa *et al.*, 2015).**

Table 1. Relative abundance of soil arthropods found in the experimental location

Class	Order	Individuals	Relative Abundance (%)
Insecta	Coleoptera (beetles)	8	3.21
	Collembola (Springtail)	106	42.57
	Hymenoptera (Ant)	18	7.23
	Isoptera (Termite)	73	29.32
	Dermaptera (Earwigs)	3	1.20
Total Insecta		**208**	**83.53**
Arachnida	Oribatida (Mite)	14	5.62
	Araneae (Spider)	4	1.61
Diplopoda	Millipedes	12	4.82
Chilopoda	Centipedes	5	2.01
Annelida	Earthworms	6	2.41
Grand Total		**249**	**100**

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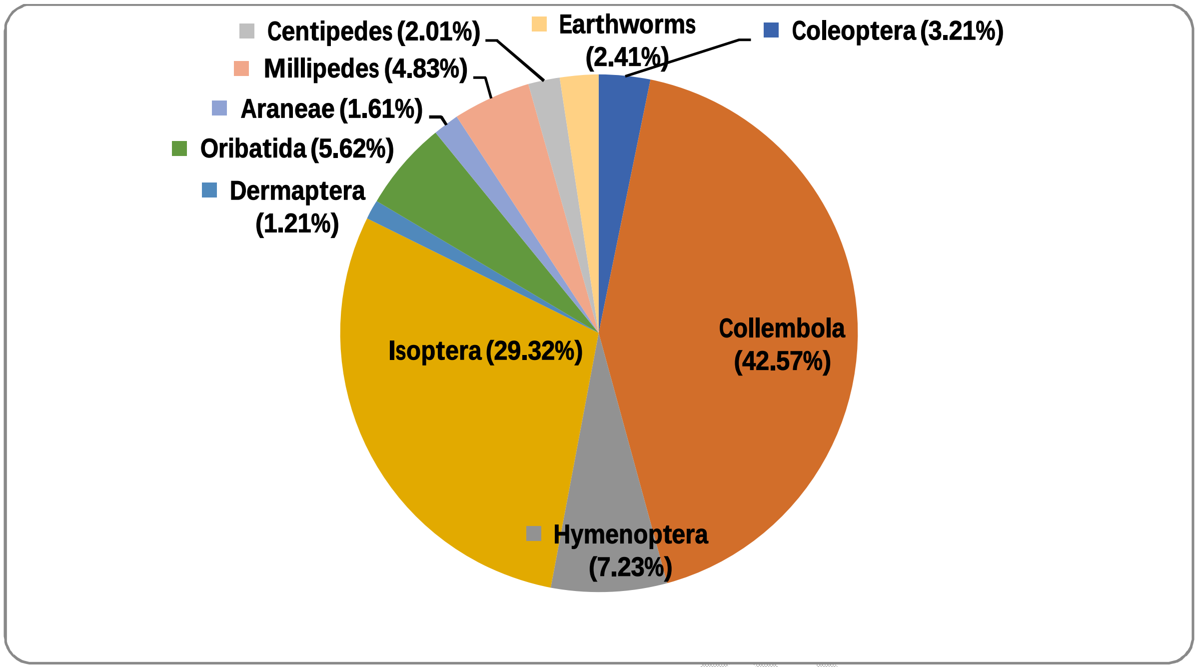

Fig 1. Abundance of soil arthropods found in the experimental location

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

Diversity Index	**Value**
Shannon Diversity Index (H)	1.498
Simpson Diversity Index (1-D)	0.723
Pielou's Evenness Index (J)	0.651
Berger–Parker Index (1/d)	2.35

Table 3. Effect of insecticides on collembolan populationat different interval

Treatment No.	**Pre-treatment**	**15DAS**	**30DAS**	**75DAS**	**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
SEm(±)	0.06	0.04	0.07	0.06		
CD @5%	0.19	0.12	0.20	0.20		

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Treatment No.	Pre-treatment	15DAS	30DAS	75DAS	Mean	% ROC
CV%	13.00	50.16	41.26	32.16		

*T_1= Chlorantraniliprole 20 SC, T_2= Fipronil % 5 SC, T_3= Cartap Hydrochloride 50 SP (T3), T_4= Flubendamide 480 SC (T4), T_5= Indoxacarb 14.5% SC (T5), T_6= Fipronil 15%+ Imidacloprid 5% SC, T_7= Fipronil 15%+Indoxcarb 5 SC, T_8= Control

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

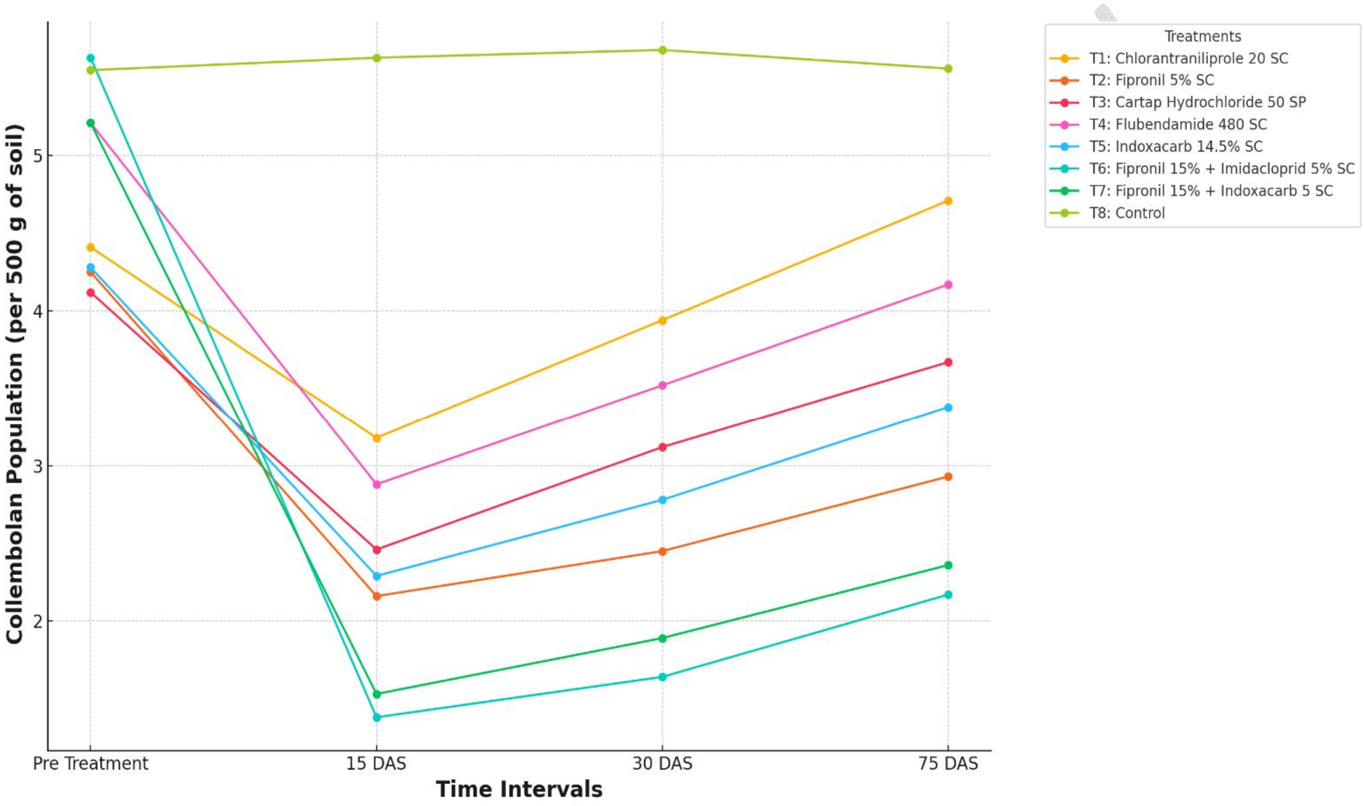

Fig 2. Effect of insecticides on collembolan population at different intervals

Conclusion:

This study demonstrates that the application of various insecticides, particularly those containing fipronil in combination with imidacloprid or indoxacarb, significantly reducedthe 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.

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