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Changes in soil faunal pattern as influenced by novel insecticides in Assam

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Abstract

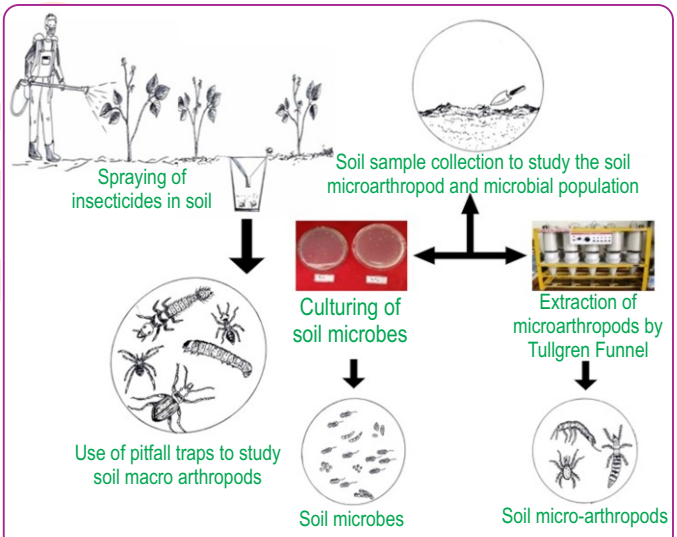
Aim: Studying the influence of certain novel insecticides on soil faunal communities.

Methodology: Soil micro and macroarthropods, total bacterial and fungal population as well as the key soil enzyme activities were studied prior to and after application of insecticides at every 15 days interval to establish their impact.

Results: Prior to the application of insecticides, Hymenoptera was recorded to be the most dominant order (54.74%) among the soil macroarthropods followed by Coleoptera (13.68%) and Araneae (11.57%) whereas Collembola and Oribatida were recorded as soil microarthropods registering 64.72 and 35.28 per cent, respectively. All the insecticidal treatments recorded a significant reduction (p=0.05) in the soil macroarthropod, bacterial and fungal population as well as soil enzymatic activities up to 75 days of application indicating the detrimental effects of insecticides as compared to the untreated plots, which showed more stable habitats for the soil fauna. On the contrary, the insecticidal treatments did not exhibit any significant impact (p=0.05) on the population of soil microarthropods during the study period.

Interpretation: Adoption of ecofriendly pest management practices relying on balance dose of insecticides with proper application methodologies may give insight in maintaining the ecological balance of soil biota in agroecosystems.

Key words: Chlorantraniliprole, Collembola, Insecticides, Soil biota



The present study clearly indicated that the novel insecticides exhibit significant negative impact on soil macro arthropods and microbial communities indicating their detrimental effects as compared to the soil microarthropods during the initial period of application which could be overcome by the soil fauna after certain time period.

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Introduction

Soil is the most dynamic platform for any kind of biological interactions in nature. Among the soil biota, the soil dwelling arthropods are one of the major group which provides many services towards the sustainability of an ecosystem (Menta and Remelli, 2020). These soil arthropods play a pivotal role in the decomposition and humification process of organic matter, thereby maintaining the nutrient quality of the soil (Lavelle *et al.,* 2006; Bagyaraj *et al.,* 2017). They also act as a potential bioindicator in the soil ecosystem due to their great diversity as well as prompt response towards the environmental variations (Menta, 2012; Suheriyanto *et al.,* 2019). In addidtion, different soil microbes also act as chemical engineers, biological regulators and ecosystem engineers (Nadeu *et al.,* 2023). However, the scenario of soil biota in agricultural fields is quite different as compared to natural ecosystems like forest soils (Postma-Blaauw *et al.,* 2010). Many agricultural activities starting from cleaning of land, ploughing, harrowing and harvesting exert significant influence on the soil biota, including their activities as well as their diversity (Menta, 2012). The agricultural practices use high amount of external inputs, of which, a plenty amount of chemicals and their degraded products gets accumulated at the top 10-15 cm layer of soil, thereby changing the physico-chemical properties which ultimately influences the biological properties including metabolic activity of soil microbial and macrobial communities and the overall soil fauna (Blasco and Pico, 2009; Filimon *et al.,* 2015).

In modern agriculture, the use of pesticides is considered as indispensable and its widespread use has greatly benefitted the farming communities of the country. Most of the conventional insecticides like organochlorines, organophosphates, carbamates and synthetic pyretrhroids having broad spectrum of activity has resulted in the development of pest resistance to insecticides, outbreak of secondary pests, pesticide residues, direct hazard to the users and adverse effect on environment and non-target organisms (Kodandaram *et al.,* 2010). In the recent past, many new insecticide groups *viz.,* neonicotinoids, phenylpyrazoles, oxadiazines, diamides, ketoenols, pyridines etc. have been developed having quite different chemical structures over the existing groups and target alternate physiological and biochemical effects with novel mode of action to combat the problems associated with the conventional insecticides (Gavkare *et al.,* 2013; Deep *et al.,* 2018). Although the use of new insecticides have shown encouraging results in managing various insect pest problems in recent years, but a clear gap still exists related to the impact of residual toxicity of these novel insecticides on the density of soil arthropods and microbial communities. Hence, the present study was undertaken to investigate the ecotoxicological effects of certain new insecticides on soil fauna to maintain sound ecological niches.

Materials and Methods

Study area: Field experiment was carried out during 2021 in the Horticultural Experimental Farm, followed by laboratory studies at the Soil Arthropod Pests, Department of Entomology, Nanotechnology Laboratory, Department of Plant Pathology and Farming System Research laboratory, Department of Soil Science, Assam Agricultural University, Jorhat, Assam, India.

Experiment description and application of treatments: French bean crop (Variety: *Sunheri*) was grown as a test crop by following the standard practices due to its high susceptibility towards many soil insect pests (Devi and Bhattacharyya, 2022; Sreedevi *et al.,* 2021). Six new insecticides *viz.,* clothianidin 50 WDG @ 120 g *a.i.* ha^{-1}, fipronil 0.3 G @ 50 g *a.i.* ha^{-1}, thiamethoxam 25 WG @ 80 g *a.i.* ha^{-1}, imidacloprid 70 WG @ 300 g *a.i.* ha^{-1}, chlorantraniliprole 0.4 GR @ 100 g *a.i.* ha^{-1} and fipronil 40%+ imidacloprid 40% WG @ 300 g *a.i.* ha^{-1} were selected for conducting the experiment. These insecticides have novel chemical structures which affect various physiological and biochemical target sites. The neonicotinoid group of insecticides, *i.e.,* clothianidin 50 WDG, thiamethoxam 25 WG and imidacloprid 70 WG acts as antagonist to the nicotinic acetyl choline receptor (nAChR) whereas phenylpyrazole (fipronil 0.3 G) blocks GABA (Gamma Aminobutyric acid) gated chloride channels in the central nervous system. Being diamide group of insecticides, chlorantraniliprole 0.4 GR opens the muscular calcium channels more particularly the ryanodine receptors. These insecticides and their doses were selected based on their previous reports on soil insect pests in different crop ecosystems (Bhagawati *et al.,* 2017; Kumar and Pandey, 2022, 2023) to ensure exposure of the insecticides towards soil fauna. The granular form of insecticides, *i.e.,* fipronil 0.3 G and chlorantraniliprole 0.4 GR were mixed with pulverized soil and applied in the furrows whereas the required amount of remaining insecticides were mixed with water and sprayed in seed furrows during evening hours (4-5PM) prior to sowing. Untreated control plot was also kept for comparison.

Sampling of soil macroarthropods: Soil macro arthropods were sampled through pitfall traps (Make: Rescholar Equipment; 15 cm height and 10 cm diameter). Individual plots measuring 9 m^2 were equally divided in to four blocks and in each block one pitfall trap was placed in a way that the upper rims of the traps were at the top soil surface level (Melbourne, 1999). Ethyl alcohol (70%) was used as a preservative fluid (Goncalves and Pereira, 2012) and the number of macroarthropods captured in each trap was recorded at pre-treatment and at each fortnight intervals after application of insecticides up to 75 days.

Collection and extraction of soil microarthropods: Soil samples were collected without disturbing the profile at pre-treatment and at each fortnight intervals after insecticide application till 75 days with a rectangular soil sampler (30 cm × 11 cm × 8 cm) at a constant depth of 0-10 cm (Paul *et al.,* 2011). Microarthropod population from the collected soil lots were then sampled through Tullgren Funnel (Akoijam and Bhattacharyya, 2012). Soil microarthropods collected in the tubes (40 ml size containing 70 per cent ethyl alcohol as preservative) were further cleaned, categorized and counted with the help of a Stereozoom Microscope (Model: Carl Zeiss Stemi 2000-C) and finally

estimated in numbers per square metre (Singh *et al.,* 1978).

Assessment of soil bacterial and fungal population: While collecting the soil samples for sampling of soil arthropods, alongside another set of samples were also drawn to study the total bacterial and fungal population by following serial dilution technique (10^{-3} concentration) and pour plate method (Sanders, 2012). The Petri plates were incubated at 28±1°C in BOD (Make: Labfit L-475) and the number of colonies were counted (cfu/g) after 48 hr of incubation (Ghosal *et al.,* 2018).

Soil enzymatic activities: Activities of key soil enzymes *viz.,* fluorescein diacetate hydrolysis (FDH), dehydrogenase (DH) and phosphomonoesterase (PMEase) under insecticide stress conditions were deciphered at 75 days after application of insecticides as µg product formed per g of soil per hour. The FDH, DH and PMEase were estimated by following the method of Adam and Duncan, 2001; Casida *et al.,* 1964; Tabatabai and Bremner, 1969, respectively.

Statistical analysis: The experiment was conducted in a Randomized Block Design with three replications with individual plot size of 9 m^2. Data obtained from the experiments were subjected to Fisher's method of analysis of variance for Randomized Block Design. The significance and non-significance of mean values among the treatments in different days intervals were ascertained at 5 per cent level of significance (Panse and Sukhatme, 1985).

Results and Discussion

Among different soil macroarthropods observed prior to the application of insecticides, Hymenoptera was recorded to be the most dominant order (54.74%), followed by Coleoptera (13.68%) and Araneae (11.57%). The other orders like Hemiptera (5.26%), Orthoptera (4.21%), Neuroptera (3.16%), Isoptera (2.80%), Dermaptera (2.47%) and Lepidoptera (2.11%) were found to be less abundant (Table 1). On an average, 453.66 numbers of soil microarthropods were observed in each plot before treatment, out of which the abundance of Collembola and Oribatida was recorded to be 64.72 and 35.28 per cent, respectively. In the present study, comparatively higher abundance of the order Hymenoptera, especially ants, among the macroarthropods and Collembola among the microarthropods in the pretreated plots has been noticed. Ants were captured in more numbers in the pitfall traps which might be related to their unique characteristics of widescale foraging into the soil. Recognizing this behaviour of ants along with their higher abundance and sensitivity towards anthropogenic changes, ants are often undertaken for environmental monitoring studies (Mahon *et al.,* 2017). In the present study, microarthropods were extracted from the top soil layer (up to 10 cm), which may be related to the aggregating behaviour of collembolans in the top soil due to availability of sufficient amount of soil organic matter and moisture making the niche ideal for their growth and development (Bhagawati *et al.,* 2021).

While assessing the effect of newer insecticides on the population of soil macroarthropods, the data in Table 2 revealed that the population of soil macroarthropods in different plots prior to the application of insecticides ranged between 89.00 and 95.33, which showed statistical parity with each other. However, the data pertaining to the number of soil macroarthropods per plot recorded at each fortnightly interval after application of different insecticides (47.33-52.67 at 15 DAT, 52.67-59.00 at 30 DAT, 60.67-65.67 at 45 DAT, 69.33-74.33 at 60 DAT and 77.00-81.33 at 75 DAT) revealed a significant decrease in the population as compared to the untreated plots (89.33, 97.67, 101.33, 99.00 and 106.33 at 15, 30, 45, 60 and 75 DAT, respectively). The population of soil macroarthropods in all the insecticidal treated plots registered statistical parity with each other at each fortnight intervals. This indicates comparatively similar effects of the tested insecticides on the soil macroarthropod population. Among

Table 1: Abundance of different soil arthropods recorded in the pretreated plots

Soil Arthropods	Order	Number of individuals/ plots	Accumulative frequency (%)	Cumulative frequency (%)
	Hymenoptera	50.28	54.74	54.74
	Coleoptera	12.57	13.68	68.42
	Hemiptera	4.83	5.26	73.68
	Orthoptera	3.87	4.21	77.89
Macroarthropods	Neuroptera	2.90	3.16	81.05
	Isoptera	2.57	2.80	83.85
	Dermaptera	2.27	2.47	86.32
	Lepidoptera	1.94	2.11	88.43
	Araneae	10.63	11.57	100
Total		**91.86**		
Microarthropods	Collembola	293. 64	64.72	64.72
	Oribatida	160. 02	35.28	100
Total		**453. 66**		

Data are mean of 21 observations

Table 2: Effect of certain newer insecticides on soil macroarthropod population (numbers/plot) at different days intervals

Treatments	Pre-treatment	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Clothianidin 50 WDG	93.67±7.57	50.33±7.23	57.67±6.81	64.00±7.21	73.67±6.66	80.67±7.57
Fipronil 0.3 G	91.67±6.51	47.67±6.03	53.00±6.24	61.33±7.57	70.00±7.21	77.33±5.51
Thiamethoxam 25 WG	89.33±7.09	49.67±6.66	56.33±7.23	62.00±6.56	72.33±6.03	79.33±7.02
Imidacloprid 70 WG	89.00±6.24	48.33±7.37	54.67±6.11	61.67±7.64	71.67±5.86	78.67±6.66
Chlorantraniliprole 0.4 GR	94.33±6.03	52.67±7.57	59.00±7.21	65.67±6.81	74.33±7.09	81.33±8.08
Fipronil 40% + Imidacloprid 40% WG	89.67±6.35	47.33±6.81	52.67±6.11	60.67±6.66	69.33±7.37	77.00±6.24
Control	95.33±7.37	89.33±7.23	97.67±7.09	101.33±6.51	99.00±6.56	106.33±7.02
Sed(±)	2.96	2.56	2.94	2.31	2.33	2.45
CD (p=0.05)	6.44	5.59	6.41	5.02	5.08	5.33
CV	NS	27.07	25.46	21.27	13.21	12.05

Values are mean of three replicates ± S.D.; DAT: Days after treatment, NS: Non-significant

different treatments, the maximum number of soil macroarthropods was recorded in chlorantraniliprole 0.4 GR treated plots (52.67, 59.00, 65.67, 74.33 and 81.33), followed by clothianidin 50 WDG (50.33, 57.67, 64.00, 73.67 and 80.67) and thiamethoxam 25 WG (49.67, 56.33, 62.00, 72.33 and 79.33) at 15, 30, 45, 60 and 75 days after treatment, respectively. The number of soil macroarthropods per plot recorded at each fortnightly interval after application of tested insecticides revealed a significant decrease in the population as compared to the untreated plots. The significant reduction may be due to quick knockdown effects of synthetic insecticides which often come in contact with the macroarthropod fauna during the time of their foraging (El-Naggar and Zidan, 2013).

However, among different insecticides tested, relative toxicity of chlorantraniliprole 0.4 GR was recorded to be minimum against macroarthropods at each fortnight intervals, which confirms the findings of Ghosal and Hati (2019) and Rahaman and Stout (2019). It was important to notice in the present study that the soil macroarthropod population exhibited a gradual recovery in all insecticide treated plots from 30 days onwards up to 75 days after treatment. This gradual recovery of the soil macroarthropod population in the insecticidal treated plots may be due to the loss of effectiveness of the insecticides after a particular time period which can be ascertained by the concept of half-life of the tested insecticides (Abdullah *et al.,* 2009). All the tested insecticides in the present study possess short half-life period *viz*., 8, 15, 20, 28 and 43 days for chlorantraniliprole 0.4 GR, clothianidin 50 WDG, thiamethoxam 25 WG, imidacloprid 70 WDG and fipronil 0.3 G, respectively, as reported earlier by Mandal and Singh (2013); Kumar *et al.* (2014); Sharma *et al.* (2014); Bansal *et al.* (2019) and Zhang *et al.* (2022).

The number of soil microarthropods per square metre of soil, prior to the application of insecticides in different plots ranged between 458.33 to 555.56, which were statistically at par with each other (Table 3). When the soil microarthropods were studied at 15, 30, 45, 60 and 75 days after insecticidal treatments, the population in different plots ranged between 597.22-694.44, 666.67-763.89, 708.33-791.67, 958.33-1041.67 and 1027.78-1111.11, respectively. All treatments were statistically at par with each other. It is evident from the experimental results that all the tested insecticides in the present study did not exhibit any significant negative impact on the soil microarthropod population during the study period. Additionally, a progressive rise in the total number of soil microarthropods per square meter was recorded from 15 days onwards up to 75 days after insecticidal application as compared to the pretreated plots. Another key result obtained from the present study showed that the tested insecticides did not exhibit any significant negative impact on soil microarthropod population, and additionally a progressive rise in the population level was recorded at each fortnight interval of insecticide application as compared to the pretreatment.

The insignificant effect may be attributed to the fact that insecticides did not translocate to soil zone where the microarthropods are present, in lethal concentrations as in case of the macroarthropods having larger body size and exhibiting above ground foraging activity. Moreover, in the present study, the tested insecticides also affected the potential predatory macroarthropod fauna which can also be cited as one of the possible reason for the insignificant impact of tested insecticides on soil microarthropod (Frampton and Van den Brink, 2007; El-Naggar and Zidan, 2013). Comparatively lower microarthropods were extracted during the initial period which might be due to the vertical migration behaviour as influenced by soil moisture. During subsequent period of the study, the population of soil microarthropods gradually increased which might be related to the availability of moisture content in the upper surface layer of the soil as a result of regular irrigation and continuous rain. The role of soil moisture in significantly increasing the diversity of microarthropods has been reported earlier (Moitra, 2017; Bhagawati *et al.,* 2021).

The population of total soil bacteria (cfu×10^4 g^{-1} of soil) in all the treatments prior to the application of insecticides ranged between 95.67 to 104.67, which was statistically at par with each other (Table 4). It is clear from the results that all the six tested insecticides significantly reduced (58.67-62.67, 68.00-71.67, 75.33-78.33, 79.00-82.67 and 87.33-90.67) the population of

Table 3: Effect of certain newer insecticides on soil microarthropod population (numbers sq m^{-1}) at different days intervals

Treatments	Pre-treatment	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Clothianidin 50 WDG	541.67±125.00	680.56±104.86	694.44±127.29	750.00±110.24	1041.67±110.24	1097.22±104.86
Fipronil 0.3 G	513.89±120.28	611.11±63.65	666.67±110.24	736.11±127.29	958.33±83.33	1041.67±125.00
Thiamethoxam 25 WG	486.11±63.65	625.00±83.33	736.11±96.23	763.89±86.74	986.11±120.28	1055.56±96.23
Imidacloprid 70 WG	458.33±110.24	638.89±127.29	680.56±127.29	708.33±83.33	1027.78±127.29	1069.44±63.65
Chlorantraniliprole 0.4 GR	472.22±127.29	694.44±104.86	750.00±83.33	777.78±104.86	972.22±104.86	1111.11±104.86
Fipronil 40% + Imidacloprid 40% WG	555.56±86.74	597.22±96.23	722.22±104.86	722.22±48.11	1000.00±72.17	1027.78±127.29
Control	500.00±83.33	652.78±63.65	763.89±86.74	791.67±72.17	1013.89±86.74	1083.33±83.33
Sed(±)	45.36	45.66	44.78	40.02	40.59	40.47
CD (p=0.05)	98.84	99.50	97.58	87.20	88.44	88.19
CV	NS	NS	NS	NS	NS	NS

Values are mean of three replicates ± S.D.; DAT: Days after treatment, NS: Non-significant

Table 4: Effect of certain newer insecticides on total bacterial population (cfu×10^4 g^{-1} of soil) at different days intervals

Treatments	Pre-treatment	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Clothianidin 50 WDG	102.33±9.29	62.00±8.66	71.00±5.20	77.67±5.77	82.00±5.57	90.33±6.43
Fipronil 0.3 G	98.67±7.51	59.33±10.21	68.67±8.33	75.67±8.50	79.67±6.11	88.00±4.36
Thiamethoxam 25 WG	103.00±8.54	61.33±7.37	70.33±7.23	77.00±5.29	81.67±6.81	89.33±6.81
Imidacloprid 70 WG	95.67±8.50	60.00±9.64	69.67±3.21	76.33±4.62	81.00±7.81	88.67±7.23
Chlorantraniliprole 0.4 GR	97.00±9.85	62.67±8.50	71.67±5.51	78.33±8.39	82.67±5.03	90.67±8.39
Fipronil 40% + Imidacloprid 40% WG	104.67±9.71	58.67±9.87	68.00±8.66	75.33±4.73	79.00±7.55	87.33±6.66
Control	101.33±9.07	98.67±7.23	89.33±4.62	96.00±7.81	100.33±7.57	106.33±5.51
Sed(±)	4.16	1.85	1.82	1.52	1.71	1.60
CD (p=0.05)	9.06	4.02	3.96	3.30	3.73	3.49
CV	NS	21.57	9.80	8.97	8.50	6.93

Values are mean of three replicates ± S.D.; DAT: Days after treatment, NS: Non-significant

total bacteria in soil at 15, 30, 45, 60 and 75 days after application of insecticides, as compared to the control (98.67, 89.33, 96.00, 100.33 and 106.33 at 15, 30, 45, 60 and 75 DAT). The population of bacteria in all the insecticidal treated plots was statistically at par with each other at each fortnight observation indicating almost similar impact of all six tested insecticides on the total soil bacteria. It is evident from the results that the total bacterial population in all the insecticidal treated plots registered a gradual increase at 30 days after treatments up to 75 days as compared to the population recorded at 15 days after treatment.

The results displayed in Table 5 showed that the population of fungi (cfu×10^4 g^{-1} of soil) in all the plots before application of insecticides ranged between 78.00-85.33, which were statistically at par with each other. The present investigation also showed that the fungal population significantly reduced (48.00-51.67, 51.33-55.00, 57.33-62.67, 65.67-69.00 and 71.00-75.33) in all the insecticidal treated plots at 15, 30, 45, 60 and 75 days after application of insecticides, respectively, as compared to control (91.67, 102.33, 96.33, 104.33 and 99.00 at 15, 30, 45, 60 and 75 DAT, respectively) representing the relative toxicity of the tested insecticides. Furthermore, the population of total soil fungi registered a gradual recovery in each insecticidal treated plots in the subsequent period of the experiment.

The present investigation revealed a significant decrease in the total bacterial and fungal population (cfu×10^4 g^{-1} of soil) in all the insecticide treated plots at 15, 30, 45, 60 and 75 days after application of insecticides as compared to control, which might be due to direct toxicity of insecticides or due to indirect effect by changing the soil physico-chemical properties and soil key enzymes after application of insecticides (Filimon *et al.,* 2015). Total soil bacterial and fungal communities registered a gradual recovery from each insecticidal treated plots in the subsequent period of the present study, which might be due to the utilization of concerned insecticides or their degraded products as a sole source of nutrients like carbon and nitrogen (Shahi *et al.,* 2007). Soil inhabiting microbes, especially bacteria and fungi explore a series of enzyme mediated physiological and biochemical reactions for utilization of carbon which ultimately resulted in the development of non-toxic or less toxic by-products of the insecticides (Tang *et al.,* 2018). The steady rise in the population of soil microbes after a particular time period of insecticide application has previously been reported (Pandey and Singh, 2003; Ahmed and Ahmed, 2006; Ghosal *et al.,* 2018). In the present study, it was observed that among all the insecticides

Table 5: Effect of certain newer insecticides on total fungal population (cfu×10^4 g^{-1} of soil) at different days intervals

Treatments	Pre-treatment	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Clothianidin 50 WDG	83.33±6.11	51.00±5.57	53.67±5.13	62.00±6.56	68.33±8.50	75.00±6.56
Fipronil 0.3 G	85.33±4.93	48.67±4.04	52.00±7.00	58.33±5.86	66.00±6.56	72.67±8.14
Thiamethoxam 25 WG	78.00±7.81	50.33±8.02	53.00±4.58	61.33±5.13	67.33±9.29	74.67±6.66
Imidacloprid 70 WG	79.33±9.29	49.67±8.62	52.67±6.66	59.67±6.66	67.00±5.57	73.67±5.69
Chlorantraniliprole 0.4 GR	80.67±7.77	51.67±4.04	55.00±7.81	62.67±4.73	69.00±5.29	75.33±8.50
Fipronil 40% + Imidacloprid 40% WG	78.33±8.50	48.00±7.21	51.33±9.45	57.33±8.50	65.67±4.04	71.00±5.29
Control	84.00±4.58	91.67±6.51	102.33±6.66	96.33±7.57	104.33±4.73	99.00±7.81
Sed(±)	3.43	2.00	1.88	2.64	1.81	2.02
CD (p=0.05)	7.48	4.35	4.10	5.74	3.95	4.41
CV	NS	28.02	30.94	20.50	19.17	12.09

Values are mean of three replicates ± S.D.; DAT: Days after treatment, NS: Non-significant

Table 6: Effect of certain newer insecticides on key soil enzyme activities at 75 days after insecticide application

Treatments	FDH (µg fluorescein g^{-1} soil hr^{-1})	DH (µg TPF g^{-1} soil hr^{-1})	PMase (µg p-nitrophenol g^{-1} soil hr^{-1})
Clothianidin 50 WDG	94.661±6.79	13.955±1.48	199.279±8.64
Fipronil 0.3 G	75.500±6.75	9.435±1.30	98.138±6.83
Thiamethoxam 25 WG	92.613±7.00	12.873±1.30	174.715±5.51
Imidacloprid 70 WG	88.274±7.08	10.840±1.42	165.502±6.73
Chlorantraniliprole 0.4 GR	95.043±7.37	18.253±1.08	200.113±8.93
Fipronil 40% + Imidacloprid 40% WG	69.356±7.84	7.685±1.28	94.789±6.31
Control	116.114±7.04	21.074±1.04	251.208±5.48
Sed(±)	2.48	0.58	2.98
CD (p=0.05)	5.41	1.27	6.50
CV	16.44	35.26	33.40

Values are mean of three replicates ± S.D.; DAT: Days after treatment, NS: Non-significant

tested, chlorantraniliprole 0.4 GR treated plots registered highest total soil bacteria and fungi population at each fortnight interval after application of insecticides, respectively. Ghosal *et al.* (2018) have reported comparatively less toxicity of chlorantraniliprole towards the non-target soil fauna.

The soil enzymes *viz.,* FDH, DH and PMEase assessed 75 days after application of insecticides revealed a significant decrease in the activities in all the insecticidal treated plots as compared to the untreated plots (Table 6) showing definite toxicity of insecticides towards the soil microbiological processes. However, among different insecticides tested, the maximum activities of all the soil enzymes were recorded in the chlorantraniliprole 0.4 GR treated plots (95.043 µg fluorescein, 18.253 µg Triphenyl Formazan (TPF) and 200.113 µg p nitrophenol per g of soil per hour, respectively) followed by clothianid in 50 WDG (94.661 µg fluorescein, 13.955 µg TPF and 199.279 µg p-nitrophenol, respectively) and thiamethoxam 25 WG (92.613 µg fluorescein, 12.873 µg TPF and 174.715 µg p-nitrophenol, respectively) treated plots. Soil enzymatic activities are real-time indicator of the functional potentiality of microorganisms. These enzymes can be used as an early indicative sign of changes in soil quality because of their prompt responses towards anthropogenic changes (Puglisi *et al.,* 2006). In the present study, soil enzymes like Fluorescein di-acetate hydrolysis, Dehydrogenase and Phosphomonoesterase activities were significantly affected due to the application of different insecticides as compared to the untreated soils. Application of synthetic chemical pesticides exerts an inhibitory effect on the metabolic processes of soil microbial population, especially the nitrifying bacterial communities due to which the key soil enzymatic activities are reduced significantly (Filimon *et al.,* 2015). The efforts made to understand the ecotoxicological effects of newer insecticides on soil faunal diversity revealed that the tested insecticides showed a negative effect on the soil macroarthropods along with the total soil inhabiting bacteria and fungi. However, this negative impact was highly observed during the initial period of experiment and gradually decreased during the subsequent period, enabling different groups of soil fauna to recover progressively. Furthermore, the current study did not exhibit any distinct significant impact of the tested insecticides on soil microarthropod populations.

These findings are important for the farming and scientific communities of the globe to select a suitable insecticide for a sustainable Integrated Pest Management (IPM) strategies against various soil dwelling insect pests, keeping the beneficial and non target soil fauna safe. Further, there is a need to conduct residue analysis of the tested insecticides which will provide more supplementary information on the insecticide persistence in soil as well as in crops. Analysis of soil physico-chemical properties after application of these insecticides will give more insights about their possible impact on soil macro, meso and microfauna.

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