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Effect of foliar spray of different doses of selected insecticides on soil enzyme activity under brinjal cultivation

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Abstract

A field experiment was conducted at the PG Research Block, College of Agriculture, KSNUAHS, Navile, Shivamogga to study the effect of foliar spray of different doses of acephate and lambda-cyhalothrin on soil enzyme activity under brinjal cultivation. The experiment was laid out in a randomized complete block design with seven treatments and three replications. The treatments consisted of different doses of acephate 75 SP and lambda-cyhalothrin 5% EC along with an absolute control (water spray). Soil enzyme activities such as dehydrogenase, acid phosphatase and urease were assessed at 0, 8 and 15 days after spray (DAS) during two consecutive insecticide applications using standard procedures. The results revealed that enzyme activities were significantly influenced by insecticide type, concentration and duration after spray. Initially, at 0th day (2 hours after spray), enzyme activities showed non-significant differences among treatments. However, a significant reduction in enzyme activities was observed at 8 DAS in insecticide treated soils compared to the control. The reduction was more pronounced with increasing dose of acephate, particularly at 1120 g a.i. ha⁻¹, whereas lambda-cyhalothrin treated soils recorded comparatively higher enzyme activity. Partial recovery of enzyme activity was observed at 15 DAS in all treatments, indicating microbial adaptation and degradation of insecticide residues over time. During the second spray, enzyme inhibition was relatively greater, suggesting the cumulative effect of repeated insecticide application. Overall, acephate exerted stronger inhibitory effects on soil enzymatic activities than lambda-cyhalothrin. The study indicated that higher doses of insecticides can temporarily suppress soil biological activity, while lower doses cause comparatively lesser impact, emphasizing the need for judicious use of insecticides to maintain soil health and microbial functioning in brinjal cultivation.

Keywords: Brinjal, acephate, lambda-cyhalothrin, soil enzyme activity, soil health

Introduction

To ensure food safety around the world, it is important to build up all necessary measures to boost crop production. Crop loss due to pests is the biggest challenge our agriculture sector faces today. A decrease in crop yield from pest damage is one of the significant errands to guarantee crop productivity. Pesticides help farmers to overcome work costs by diminishing the measure of time required to control weeds and pests from fields. "Pesticides are chemicals to control a variety of pests that can damage crops and livestock and reduce farm productivity". The pesticides cover a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematocides, plant growth regulators and others. Herbicides account for 42%, insecticides 27%, fungicides 22% and disinfectants and other agrochemicals 9% of global pesticide sales whereas, in India 76% of the pesticide used is insecticide and use of herbicides and fungicides is correspondingly less heavy (Mathur, 1999) [28]. Vegetables consume 14% of the total pesticides used in India, in which the share of different types of pesticides in Indian agriculture market shows that organophosphorus (50%) ranked first, followed by pyrethroids (19%), organochlorines (18%), carbamates (4%) and biopesticides (1%) (Dhaliwal and Singh, 2000) [12].

Brinjal (*Solanum melongena* L.) is a popular solanaceous and economically important vegetable and is native to India. India is the second largest producer of brinjal after China with a 27.55 per

cent world production share. It contributes 8.1% of the total vegetable production of the country (Anonymous, 2011) [3]. Brinjal is attacked by a number of insect pests from seedling to fruiting stage affecting its growth and productivity. Major insect-pests of brinjal are fruit and shoot borer *Leucinodes orbonalis*, beetles *Henosepilachna vigintioctopunctata*, jassids *Amrasca devastans*, brinjal stem borer *Euzophera perticella* and aphids *Aphis gossypii* (Walia *et al.*, 2010) [40]. Fruit and shoot borer (*Leucinodes orbonalis*) is the most devastating pest causing a significant yield loss of 60-70% in India (Kumar *et al.*, 2011) [25]. This crop is sprayed heavily with insecticides to protect it from the attack of pests. On an average, 4.6 kg of active ingredient of the insecticide per hectare per season is applied on brinjal (Walia *et al.*, 2010) [40]. Different insecticides are approved and recommended against insect-pests of various crops. However, the recommended use of these insecticides and their effectiveness on a wide range of pests, provoke the farmers to use them against pests of other crops also, on which they are not recommended. Improper and injudicious use of pesticide, besides posing health threat to the farm workers, also leaves harmful pesticide residues on the crop and soil and causes development of pest resistance leading to the losses to the crops (Kumar and Singh, 2014) [24].

Acephate (O, S-dimethyl acetylphosphoramidothioate) is an important systemic organophosphate insecticide, introduced by Chevron Chemical in 1971 (Magee, 1973) [26] and first time registered for use by the United States Environmental Protection Agency in 1973. It has been observed that, after decomposition acephate generally converts into highly toxic methamidophos. According to the National Pesticide Information Center, the half-life of acephate ranged from 4.5 to 32 days in soil.

Lambda cyhalothrin [α -cyano-3-phenoxybenzyl-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethyl cyclopropanecarboxylate] is one of the well known synthetic pyrethroids. It is a non-systemic insecticide with contact and stomach action as well as repellent properties. It is most commonly used against both sap sucking and chewing insects and mites due to its contact and acaricidal action. The half-life of lambda-cyhalothrin on plant surfaces is 5 days (Knisel, W. G, 1993) [23]. Soil half-life for lambda-cyhalothrin is 30 days with values ranging from 28-84 days (Hornsby *et al.*, 1995) [18]. In a field study, lambda-cyhalothrin degraded with a half-life of approximately 9 days (Hill and Inaba, 1991) [17]. Lambda-cyhalothrin has a low potential to contaminate ground water due to its low water solubility and high potential to bind to soil.

The application of insecticides in agricultural fields can influence soil biological properties, particularly soil enzyme activity. Soil enzymes such as dehydrogenase, urease, phosphatase, and catalase play an important role in nutrient cycling and maintaining soil fertility. When insecticides are applied as foliar sprays in crops like brinjal, a portion of the chemicals may reach the soil through spray drift, plant wash-off or residue fall. These residues can interact with soil microorganisms that produce enzymes. At higher doses, insecticides may inhibit microbial growth and reduce enzyme activity, leading to temporary suppression of processes such as organic matter decomposition and nutrient mineralization. However, at recommended or lower doses, the effect may be minimal or short-lived because soil microorganisms can adapt and degrade pesticide residues over time. Therefore, the impact of insecticides on soil enzyme activity largely depends on the type of insecticide, application rate, persistence in soil, and environmental conditions, which ultimately influence soil health and microbial functioning under brinjal cultivation.

Materials and Methods

Details of the experiment

Location	PG Research block, College of Agriculture, KSNUAHS, Navile, Shivamogga
Crop	Brinjal
Variety	Lalitha F1
Spacing	120 cm x 60 cm
Plot size	4 m x 5 m
RDF	125:100:50 kg ha ⁻¹ of N, P ₂ O ₅ , K ₂ O
FYM	25 t ha ⁻¹
Design	RCBD
Treatment	7
Replication	3

Treatment details

T₁- Absolute control (Water spray)

T₂-Foliar spray of acephate 75 SP @ 560 g a.i. ha⁻¹ (RD)

T₃-Foliar spray of acephate 75 SP @ 840 g a.i. ha⁻¹

T₄-Foliar spray of acephate 75 SP @ 1120 g a.i. ha⁻¹

T₅-Foliar spray of lamda-cyhalothrin 5% EC @ 15 g a.i. ha⁻¹ (RD)

T₆-Foliar spray of lamda-cyhalothrin 5% EC @ 22.5 g a.i. ha⁻¹

T₇-Foliar spray of lamda-cyhalothrin 5% EC @ 30 g a.i. ha⁻¹

Note: RD- Recommended dose

Assessment of soil enzyme activity

The soil enzyme like dehydrogenase activity, phosphatase activity, urease activity were assessed by adopting standard procedures.

Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ day}^{-1}$)

Three grams of air-dried soil was thoroughly mixed with 0.2 g of CaCO₃. To each sample tube, 1 ml of 3% aqueous solution of 2, 3, 5-triphenyl tetrazolium chloride (TTC) and 2.5 ml of distilled water was added. The contents of each tube were mixed using a vortex mixer and the tubes were incubated at 37 °C. After 24 hours, 10 ml of methanol was added to the tube and shaken for one minute. Then, the suspension was filtered through a glass funnel plugged with absorbent cotton into a 100 ml volumetric flask. The soil in the tube was washed repeatedly with methanol till the filtrate coming from the tip of the funnel was colorless. Then, the volume was made to 100 ml with methanol. The intensity of the reddish color was read using a spectrophotometer at a wavelength of 485 nm with methanol as the blank. The amount of TPF (2, 3, 5-triphenyl formazan) produced was calculated using a standard graph prepared by using different concentrations of TPF standards. For this, 10 ml of the TPF standard solution containing 1000 $\mu\text{g ml}^{-1}$ was diluted to 100 ml with methanol (100 μg of TPF ml^{-1}). Aliquots of 5, 10, 15 and 20 ml were pipetted into 100 ml volumetric flasks (500, 1000, 1500 and 2000 μg of TPF 100 ml^{-1}). The volume was made to 100 ml with methanol and mixed thoroughly. Then, the intensity of the red color formed by TPF was measured as described earlier (Casida *et al.*, 1964) [6]. Finally, the Dehydrogenase activity was calculated using the following formula;

$$\text{Dehydrogenase activity } (\mu\text{g TPFg}^{-1} \text{ day}^{-1}) = \frac{S - C}{W} \times 100 (\text{dilution factor})$$

Where,

S - Concentration of TPF in samples

C - Concentration of TPF in control

W - Dry weight of soil (g)

Acid and Alkaline Phosphatase activity ($\mu\text{g PNP g}^{-1} \text{h}^{-1}$)

The acid and alkaline phosphatase activity was estimated as per the procedure given by Eivazi and Tabatabai (1977) [14]. For this, one gram of each of the soil samples (<2 mm) was placed in a wide mouth test tube and 0.2 ml of toluene, 4 ml of modified universal buffer (pH 6.5 for acid phosphatase and pH 11.5 for alkaline Phosphatase) and 1 ml of p-nitro phenol (PNP) phosphatase solution made in the same buffer were added. Tubes were swirled for a few seconds to mix the contents. Tubes were then stopped with a rubber cork and placed in an incubator at 37 °C. After one hour stopper were removed and 1 ml of 0.5 M CaCl_2 and 4 ml of 0.5 M NaOH were added. The suspension was centrifuged at 3000 rpm, filtered and the intensity of the yellow color of the supernatant was measured using a spectrophotometer at 420 nm wavelength. The PNP content of the filtrate was obtained by reference to a calibration graph plotted from the results obtained with standards containing 0, 10, 20, 30, 40, 50 μg of PNP. The control was performed with each soil analysed to allow for color not derived from PNP released by phosphatase activity.

$$\text{Acid and Alkaline phosphatase activity}(\mu\text{g PNP g}^{-1}\text{h}^{-1}) = \frac{S - C}{W} \times 100 (\text{dilution factor})$$

Where,

S- Concentration of PNP in samples

C- Concentration of PNP in control

W- Dry weight of soil (g)

Urease activity ($\mu\text{g NH}_4\text{-N g}^{-1} \text{soil hr}^{-1}$)

Five grams of fresh soil was taken in a 50 mL volumetric flask. To this 0.2 mL of toluene and 9 mL of tris-hydroxymethyl amino methane buffer (THAM-0.05M, pH 9.0) was added and swirled the flask for few seconds, followed by the addition of 1 mL of 0.2 M urea solution, and incubated for 2 hours at 37 °C. Then 35 mL of $\text{KCl-Ag}_2\text{SO}_4$ solution was added and mixed by shaking immediately and allowed to cool to room temperature. The volume was made up to 50 mL by addition of $\text{KCl-Ag}_2\text{SO}_4$, stoppered and mixed thoroughly. From this solution, 20 mL aliquot was pipetted out into 100 mL distillation flask and steam distilled with 0.2 g of MgO for 6 minutes. Then 25 mL of the distillate was collected in 50 mL Erlenmeyer flask containing 5 mL of 2% boric acid with double indicator solution. Ammonium N concentration of distillate was estimated by titrating with standard acid (0.02 N H_2SO_4) with the color change from blue to pink as the end point. A control was also maintained and the same procedure was followed with the addition of 1 mL of 0.5 M urea solution after the addition of 35 mL of $\text{KCl-Ag}_2\text{SO}_4$ solution (Tabatabai and Bremner, 1969) [39].

$$\text{Urease activity}(\mu\text{g NH}_4\text{ g}^{-1} \text{soil hr}^{-1}) = \frac{(\text{Blank value} - T.V) \times \text{Factor} \times \text{Vol.Extract}}{\text{Aliquot} \times \text{Weight of soil} \times \text{Time of incubation}}$$

Statistical analysis

The analysis and interpretation of the data was done using Fisher's method of analysis of variance (ANOVA) as given by Gomez and Gomez (1984) [16]. Significance between the treatments was tested by F test. Whereas, difference between the treatments mean were tested by critical difference (CD) at 5% level of significance.

Results and Discussion

The data clearly indicated that the soil enzyme activity is mainly

dependent on the insecticide spray concentration and duration or days after spray (DAS). Accordingly, in either the first or second spray of insecticide (acephate and lambda-cyhalothrin) the highest enzyme activity was recorded at 0th day (2 hour after spray) and gradually decreased at 8 DAS and a slight increase was observed at 15 DAS in brinjal cultivated soil. Higher soil enzyme activity was recorded in lambda-cyhalothrin sprayed plot compared to acephate.

Effect of foliar spray of different doses of acephate and lambda-cyhalothrin on dehydrogenase activity in soil under brinjal cultivation

The results on dehydrogenase activity as influenced by varying doses of foliar spray of acephate and lambda-cyhalothrin after the first and second spray on brinjal are presented in Table 1. The enzyme activity showed marked variation among treatments and time intervals, indicating that insecticide application altered soil biological activity in a dose and frequency dependent manner.

During the first spray, dehydrogenase activity at 0th day (2 hour after spray) recorded a statistically non significant effect among treatments, indicating uniform enzyme activity before insecticide exposure, with the control recording higher (38.02 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$) and lowest in T_4 (acephate @ 1120 g a.i. ha^{-1}) with 35.44 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$. At 8 days after spray (DAS), a significant reduction in dehydrogenase activity was recorded across all treated soils compared to the control (38.96 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$). Among insecticide treated plots, application of lambda-cyhalothrin @ 15 g a.i. ha^{-1} (33.56 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$) recorded significantly higher activity followed by 22.5 g a.i. ha^{-1} (30.77 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$) and 30 g a.i. ha^{-1} (28.01 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$). In contrast, acephate spray treatments showed a significant decline with increasing concentration which recorded 26.03, 24.15 and 22.87 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$ in T_2 (acephate @ 560 g a.i. ha^{-1}), T_3 (acephate @ 840 g a.i. ha^{-1}) and T_4 (acephate @ 560 g a.i. ha^{-1}), respectively. The lowest enzyme activity was noted in T_4 , suggesting stronger inhibition at higher doses of acephate. At 15 DAS, enzyme activity exhibited partial recovery in all the treatments but remained significantly lower than the control (41.34 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$). Among treated plots, the lambda-cyhalothrin applied soils recorded significantly higher activity, with 35.99 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$ (15 g a.i. ha^{-1}) and 32.86 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$ (22.5 g a.i. ha^{-1}), showing greater recovery than the acephate treated soils.

During the second spray, a similar declining trend in enzyme activity was observed, indicating the cumulative effect of repeated insecticide application. At 0 DAS, the dehydrogenase activity recorded significantly lower in acephate @ 1120 g a.i. ha^{-1} (T_4) with 25.11 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$, while higher activity was noticed in the control (T_1) with 43.11 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$. Among acephate spray treatments, enzyme activity decreased progressively with increasing dose, whereas lambda-cyhalothrin treated plots exhibited significantly higher enzyme activity, showing 36.93, 34.90 and 31.96 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$ in T_5 (lambda-cyhalothrin @ 15 g a.i. ha^{-1}), T_6 (lambda-cyhalothrin @ 22.5 g a.i. ha^{-1}) and T_7 (lambda-cyhalothrin @ 30 g a.i. ha^{-1}), respectively. At 8 DAS, a marked decline in dehydrogenase activity occurred across all insecticide treated soils. The highest activity was maintained in the control (43.91 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$), while the lowest was recorded in acephate @ 1120 g a.i. ha^{-1} (19.05 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$). Lambda-cyhalothrin @ 15 g a.i. ha^{-1} (32.49 $\mu\text{g TPF g}^{-1} \text{soil hr}^{-1}$) recorded the highest microbial

activity, indicating a lesser degree of suppression compared to acephate treatments. At 15 DAS, enzyme activity showed slight recovery in all treatments but continued to remain significantly lower than the control. The activity ranged from 20.65 $\mu\text{g TPF g}^{-1} \text{ soil hr}^{-1}$ in acephate @ 1120 g a.i ha^{-1} to 44.67 $\mu\text{g TPF g}^{-1} \text{ soil hr}^{-1}$ in control. The lambda-cyhalothrin treated soils exhibited significantly higher activity compared to acephate, with 34.18 $\mu\text{g TPF g}^{-1} \text{ soil hr}^{-1}$ in T_5 (15 g a.i ha^{-1}) and 31.76 $\mu\text{g TPF g}^{-1} \text{ soil hr}^{-1}$ in T_6 (22.5 g a.i ha^{-1}) showing better recovery.

Effect of foliar spray of different doses of acephate and lambda-cyhalothrin on acid phosphatase activity in soil under brinjal cultivation

The data summarized in Table 2 depicted the response of soil acid phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) to varying doses of acephate (75 SP) and lambda-cyhalothrin (5% EC) following two consecutive sprays in brinjal cultivation.

The data recorded at 0th day after the first spray, the differences among treatments in acid phosphatase activity of soil were statistically non significant, with the control recording higher (79.62 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) and lowest in T_4 (acephate @ 1120 g a.i ha^{-1}) with 75.06 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$. At 8 days after spray (DAS), a significant reduction in acid phosphatase activity was observed across all insecticide treated soils compared to the control (80.45 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$). Among acephate treatments, enzyme activity declined progressively with increasing dose, ranging from 67.52 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$ in acephate @ 560 g a.i ha^{-1} to 62.07 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$ in acephate @ 1120 g a.i ha^{-1} , with the latter showing the lowest value among all treatments. In contrast, higher values were recorded in lambda-cyhalothrin @ 15 g a.i ha^{-1} and 22.5 g a.i ha^{-1} (75.96 and 73.28 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$, respectively), reflecting lower toxicity of the pyrethroid compared to the organophosphate compound. By 15 DAS, a partial recovery in enzyme activity was noted across all treatments, although the values remained lower than that of the control (82.00 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$). The lowest activity (63.51 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) was again recorded in acephate @ 1120 g a.i ha^{-1} , while the highest among the treated plots was observed in lambda-cyhalothrin @ 15 g a.i ha^{-1} (77.03 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$). The results indicated that acephate at higher concentrations exerted a stronger inhibitory effect on acid phosphatase activity compared to lambda-cyhalothrin.

During the second spray, acid phosphatase activity followed a similar declining trend. Significantly the highest activity was recorded in the control (83.15 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$). But the spray of lambda-cyhalothrin @ 15 g a.i ha^{-1} recorded 78.95 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$ and 22.5 g a.i ha^{-1} recorded 76.34 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$ at 0th DAS. The lowest enzyme activity was found in acephate @ 1120 g a.i ha^{-1} (65.98 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$). A consistent decline was noted with increasing acephate dosage, whereas lambda-cyhalothrin treatments retained higher activity levels. At 8 DAS, the enzyme activity decreased further across all treatments, with the highest recorded in the control (84.02 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) and in treated soils, lambda-cyhalothrin @ 15 g a.i ha^{-1} (73.49 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) maintained relatively higher enzyme activity, followed by lambda-cyhalothrin @ 22.5 g a.i ha^{-1} (70.98 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$), indicating that lambda-cyhalothrin was less suppressive to soil enzymatic activity than acephate. By 15 DAS, a slight recovery in enzyme activity was evident, though the control (84.84 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) still maintained the highest value. Among insecticide treatments, the significantly higher activity (75.08 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) was

found in lambda-cyhalothrin @ 15 g a.i ha^{-1} , while the lowest activity (61.59 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) persisted in acephate @ 1120 g a.i ha^{-1} .

Effect of foliar spray of different doses of acephate and lambda-cyhalothrin on urease activity in soil under brinjal cultivation

The influence of foliar application of acephate 75 SP and lambda-cyhalothrin 5% EC on soil urease activity in brinjal cultivation was assessed at 0, 8 and 15 days after spray (DAS) during two successive sprays and the results are presented in Table 3.

During the first spray, urease activity at 0th day showed no significant difference among treatments, indicating that initial application of the insecticides did not cause any immediate alteration in soil enzymatic activity. By 8 DAS, a marked and statistically significant decline in urease activity was observed in all treated plots compared to the control. The control maintained the highest urease activity (26.98 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$), while a sharp decline was evident with increasing acephate concentration, reaching the lowest value in acephate @ 1120 g a.i. ha^{-1} (8.87 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$). Similarly, lambda-cyhalothrin treatments showed a dose dependent decrease in activity, with 15 g a.i. ha^{-1} recording 21.05 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ and 30 g a.i. ha^{-1} showed the lowest activity (15.96 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$). At 15 DAS, the inhibitory trend persisted, with urease activity in the control further increasing to 28.11 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$, while a sharp reduction continued in acephate and lambda-treated soils. The significantly lower activity occurred in acephate @ 1120 g a.i. ha^{-1} (10.01 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$). Among the lambda-cyhalothrin treatments, 15 g a.i. ha^{-1} maintained significantly higher activity (22.96 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$) and lowest in 30 g a.i. ha^{-1} (17.47 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$).

In the second spray, urease activity followed a similar pattern, though the values were slightly higher across all treatments compared to the first spray, suggesting partial recovery of microbial function between applications. At 0th day, the control recorded significantly highest activity (30.66 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$), while acephate treated soils exhibited dose dependent reduction, from 17.63 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ in 560 g a.i. ha^{-1} to 12.34 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ in 1120 g a.i. ha^{-1} . Among lambda-cyhalothrin treatments, 15 g a.i. ha^{-1} maintained 25.00 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$, while 30 g a.i. ha^{-1} showed 20.13 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$. At 8 DAS, urease activity continued to decline in all treated soils. The control recorded 31.86 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$, while the lowest value among acephate treatments was 7.26 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ in 1120 g a.i. ha^{-1} . For lambda-cyhalothrin, the enzyme activity declined from 20.11 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ in 15 g a.i. ha^{-1} to 14.95 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$ in 30 g a.i. ha^{-1} . At 15 DAS, the trend remained consistent, with the control recording the highest urease activity (33.02 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$), followed by 15 g a.i. ha^{-1} (22.76 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$) and 22.5 g a.i. ha^{-1} (19.03 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$) among lambda-cyhalothrin treatments. The lowest enzyme activity was observed in acephate @ 1120 g a.i. ha^{-1} (8.32 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$).

Soil enzymes are among the most sensitive biological indicators of soil health and fertility, as they mediate key biochemical transformations essential for nutrient cycling (Nannipieri *et al.*, 2002) [31]. Enzymes such as dehydrogenase, acid phosphatase and urease play vital roles in microbial oxidative metabolism, phosphorus mineralization and nitrogen transformation,

respectively. Their activities are closely linked to the abundance, composition and metabolic vigor of soil microorganisms and are highly responsive to xenobiotic inputs, including pesticides (Ahemad and Khan, 2011) ^[1].

In the present investigation, the application of acephate (75 SP) and lambda-cyhalothrin (5% EC) significantly influenced soil enzymatic activities in brinjal rhizosphere soil in a dose and time dependent manner. During the first spray, enzyme activities recorded at 0th day after spraying (2 hour after spray) were statistically non-significant among treatments, suggesting that the initial microbial equilibrium remained unaffected immediately after insecticide application. Similar findings were reported by Rangaswamy and Venkateswarlu (1992) ^[34] in groundnut and Das and Debnath (2006) ^[8] in rice soils, where organophosphate applications did not immediately impact enzymatic activities, indicating that microbial populations initially tolerated the pesticide stress before metabolic disruption occurred. However, by 8 DAS, a marked decline in dehydrogenase, acid phosphatase and urease activities was observed across all insecticide treated soils relative to the control, clearly reflecting the inhibitory effect of insecticide residues on soil microbial metabolism. The inhibition was more severe in acephate treated soils, especially at higher doses (1120 g a.i. ha⁻¹), than in lambda-cyhalothrin treated soils. This differential response is largely attributed to the contrasting chemical nature and persistence of the two insecticides. Acephate, being an organophosphate, interferes with essential sulfhydryl (-SH) groups of enzymes, thereby disrupting microbial respiration and energy metabolism (Kandeler *et al.*, 1996; Zhang *et al.*, 2014) ^[21, 41]. In contrast, lambda-cyhalothrin, a pyrethroid, primarily affects microbial cell membrane integrity and induces oxidative stress, but undergoes rapid degradation in soil (Cycon and Piotrowska-Seget, 2016) ^[7].

Dehydrogenase activity, an important indicator of microbial respiratory potential (Casida *et al.*, 1964) ^[6], exhibited a sharp reduction at 8 DAS following acephate treatment, suggesting suppression of oxidative metabolism and microbial respiration. Comparable inhibitory patterns were reported by Dey and Pal (2011) ^[11] in tomato soils treated with monocrotophos and chlorpyrifos and by Sannino and Gianfreda (2001) ^[37] in soils treated with various organophosphates, confirming that pesticide exposure limits microbial respiration by reducing oxidative enzymatic capacity. The results of the present study also agree with Jilani and Khan (2004) ^[19], who observed that organophosphate insecticides significantly reduced dehydrogenase activity in brinjal soils. In contrast, lambda-cyhalothrin at lower doses (15 g a.i. ha⁻¹) maintained relatively higher dehydrogenase activity, indicating mild and transient microbial stress. Similar reversible inhibition trends were noted by Das *et al.* (2015) ^[9] in cabbage and Rahman *et al.* (2017) ^[32] in chilli soils treated with pyrethroids.

Acid phosphatase activity followed a similar inhibitory trend. At 8 DAS, enzyme activity decreased progressively with increasing acephate dose, while lambda-cyhalothrin treated soils maintained comparatively higher activity. The stronger suppression in acephate treatments may be due to its higher affinity for phosphate ester bonds, causing competitive inhibition of phosphatase enzymes (Sannino and Gianfreda,

2001) ^[37]. Parallel results were observed by Devi and Rangaswamy (2013) ^[10] in tomato and brinjal soils, where repeated organophosphate applications significantly reduced phosphatase activity, while pyrethroids exhibited only transient inhibition. The partial recovery at 15 DAS observed in the present study indicates possible microbial adaptation or degradation of pesticide residues by tolerant microbial consortia, which is consistent with reports of Cycon and Piotrowska-Seget (2016) ^[7] and Khan *et al.* (2018) ^[22], who documented recovery of phosphatase activity after microbial acclimatization to pyrethroid residues.

Similarly, urease activity exhibited a dose dependent reduction after acephate and lambda-cyhalothrin application. At 8 DAS, urease activity decreased sharply under acephate @ 1120 g a.i. ha⁻¹, whereas lambda-cyhalothrin @ 15 g a.i. ha⁻¹ maintained higher activity. This decline may be due to pesticide interference with nickel dependent ureolytic enzymes and suppression of urease producing microbes (Martinez-Toledo *et al.*, 1998) ^[27]. Similar results were reported by Mukherjee and Gopal (1994) ^[30] and Rangaswamy *et al.* (1994) ^[35] in groundnut soils, where urease activity declined with increasing insecticide concentration. The partial restoration at 15 DAS may be attributed to microbial degradation of insecticide residues, leading to the revival of enzyme producing populations, which aligns with the findings of Ahemad (2012) ^[2] in chickpea and Awasthi *et al.* (2015) ^[5] in cotton soils.

During the second spray, all enzyme activities showed more pronounced and prolonged inhibition, indicating cumulative toxic effects of repeated pesticide applications. The persistence of acephate and its metabolite methamidophos likely intensified the suppression of microbial respiration and nutrient turnover, whereas lambda-cyhalothrin treated soils recovered faster due to rapid microbial hydrolysis and photodegradation (Fenner *et al.*, 2013) ^[15]. The extended suppression under acephate corroborates findings of Zhang *et al.* (2014) ^[41] and Khan *et al.* (2018) ^[22], who reported long term inhibition of dehydrogenase and urease activities following organophosphate exposure.

The comparative analysis clearly revealed that acephate caused stronger and longer inhibition across all enzyme systems due to its solubility, persistence and systemic mode of action, whereas lambda-cyhalothrin exerted moderate and transient inhibition, allowing quicker microbial recovery. Similar comparative observations were made by Singh and Kumar (2008) ^[38], Devi and Rangaswamy (2013) ^[10] and Cycon and Piotrowska-Seget (2016) ^[7] in brinjal and lettuce soils.

The present results are in close agreement with several other field studies, including Kabadad and Gali (2018) ^[20] who reported pesticide-induced reductions in dehydrogenase and phosphatase activities in vegetable soils, Anuradha *et al.* (2015) ^[4] in groundnut soils who found dose dependent suppression of enzymatic activity under chlorpyrifos stress, Sahu *et al.* (2014) ^[36] and Raju and Venkateswarlu (2013) ^[33] in cotton soils where organophosphates reduced microbial activity and enzyme function; Mohiddin *et al.* (2011) ^[29] in groundnut who observed reversible inhibition of phosphatase and urease due to pesticide dissipation and Du *et al.* (2013) ^[13] in paddy, who reported transient inhibition of dehydrogenase following pyrethroid exposure.

Table 1: Effect of foliar spray of different doses and frequency of selected insecticide on soil dehydrogenase activity under brinjal cultivation

Treatment details	Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil hr}^{-1}$)					
	First spray			Second spray		
	0 th day	8 DAS	15 DAS	0 th day	8 DAS	15 DAS
T ₁ - Absolute control (Water spray)	38.02	38.96	41.34	43.11	43.91	44.67
T ₂ -Foliar spray of acephate 75 SP @ 560 g a.i. ha ⁻¹	36.52	26.03	28.29	29.48	24.38	26.40
T ₃ -Foliar spray of acephate 75 SP @ 840 g a.i. ha ⁻¹	35.87	24.15	26.35	27.01	21.89	22.98
T ₄ -Foliar spray of acephate 75 SP @ 1120 g a.i. ha ⁻¹	35.44	22.87	23.93	25.11	19.05	20.65
T ₅ -Foliar spray of lambda cyhalothrin 5% EC @ 15 g a.i. ha ⁻¹	37.92	33.56	35.99	36.93	32.49	34.18
T ₆ -Foliar spray of lambda cyhalothrin 5% EC @ 22.5 g a.i. ha ⁻¹	37.15	30.77	32.86	34.00	29.71	31.76
T ₇ -Foliar spray of lambda cyhalothrin 5% EC @ 30 g a.i. ha ⁻¹	36.88	28.01	30.99	31.96	27.2	29.07
S.Em. $\pm$	1.45	0.40	0.58	0.58	0.75	0.72
CD at 5%	NS	1.22	1.77	1.78	2.30	2.22

Note: DAS-Days After Spray, NS- Non Significant

Table 2: Effect of foliar spray of different doses and frequency of selected insecticide on soil acid phosphatase activity under brinjal cultivation

Treatment details	Acid phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$)					
	First spray			Second spray		
	0 th day	8 DAS	15 DAS	0 th day	8 DAS	15 DAS
T ₁ - Absolute control (Water spray)	79.62	80.45	82.00	83.15	84.02	84.84
T ₂ -Foliar spray of acephate 75 SP @ 560 g a.i. ha ⁻¹	76.15	67.52	69.95	71.56	65.36	66.98
T ₃ -Foliar spray of acephate 75 SP @ 840 g a.i. ha ⁻¹	75.73	64.93	66.82	68.79	62.57	64.37
T ₄ -Foliar spray of acephate 75 SP @ 1120 g a.i. ha ⁻¹	75.06	62.07	63.51	65.98	60.00	61.59
T ₅ -Foliar spray of lambda cyhalothrin 5% EC @ 15 g a.i. ha ⁻¹	79.16	75.96	77.03	78.95	73.49	75.08
T ₆ -Foliar spray of lambda cyhalothrin 5% EC @ 22.5 g a.i. ha ⁻¹	78.92	73.28	75.42	76.34	70.98	72.43
T ₇ -Foliar spray of lambda cyhalothrin 5% EC @ 30 g a.i. ha ⁻¹	77.85	70.63	72.18	73.50	68.26	69.64
S.Em. $\pm$	4.44	0.81	0.51	0.84	0.74	0.84
CD at 5%	NS	2.49	1.56	2.59	2.28	2.60

Note: DAS-Days after Spray, NS- Non Significant

Table 3: Effect of foliar spray of different doses and frequency of selected insecticide on soil urease activity under brinjal cultivation

Treatment details	Urease activity ($\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil hr}^{-1}$)					
	First spray			Second spray		
	0 th day	8 DAS	15 DAS	0 th day	8 DAS	15 DAS
T ₁ - Absolute control (Water spray)	26.02	26.98	28.11	30.66	31.86	33.02
T ₂ -Foliar spray of acephate 75 SP @ 560 g a.i. ha ⁻¹	21.98	13.49	15.18	17.63	12.34	13.54
T ₃ -Foliar spray of acephate 75 SP @ 840 g a.i. ha ⁻¹	21.04	11.17	12.68	14.89	9.73	10.85
T ₄ -Foliar spray of acephate 75 SP @ 1120 g a.i. ha ⁻¹	20.68	8.87	10.01	12.34	7.26	8.32
T ₅ -Foliar spray of lambda cyhalothrin 5% EC @ 15 g a.i. ha ⁻¹	25.97	21.05	22.96	25.00	20.11	22.76
T ₆ -Foliar spray of lambda cyhalothrin 5% EC @ 22.5 g a.i. ha ⁻¹	24.82	18.45	20.34	22.29	17.47	19.03
T ₇ -Foliar spray of lambda cyhalothrin 5% EC @ 30 g a.i. ha ⁻¹	22.56	15.96	17.47	20.13	14.95	16.25
S.Em. $\pm$	1.46	0.72	0.67	0.68	0.75	0.81
CD at 5%	NS	2.23	2.06	2.10	2.31	2.51

Note: DAS-Days after Spray, NS- Non Significant

Conclusion

Overall, the observed enzyme inhibition may be attributed to pesticide induced microbial stress, denaturation of enzyme proteins and disruption of cofactor availability, while the subsequent recovery reflects microbial adaptation and enzymatic resilience once the toxic residues degraded. Thus, these findings confirm that enzyme activities serve as reliable bioindicators of soil quality under pesticide stress and highlight the need for judicious pesticide use to maintain soil biochemical health and microbial functionality.

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