J. Appl. Biosci., 51(2): 198-206, December, 2025
doi: 10.61081/joab/51v2i108

ISSN (Print) 0975-685X
ISSN (Online) 0975-864X

RESEARCH ARTICLE

Soil Nutrient Enrichment Alters Trophic Linkages and Predator Efficiency in Cowpea-Aphid-Ladybird Systems

Gaurvanvita Singh[1], Praveen C Verma[2] and Geetanjali Mishra[1]
[1]Ladybird Research Laboratory, Department of Zoology, University of Lucknow, Lucknow-226007, UP, India
[2]Department of Molecular Biology & Biotechnology, CSIR-National Botanical Research Institute, Lucknow-226001, UP, India

ABSTRACT

Soil nutrient management can strongly influence interactions among plants, herbivores, and natural enemies. This study examined how organic and inorganic soil amendments affect tritrophic interactions among cowpea (*Vigna unguiculata* L. Walp.), the aphid *Aphis craccivora* Koch, and the predatory ladybird *Cheilomenes sexmaculata* Fabricius under semi-field conditions. Plants were grown in control, vermicompost, and NPK-treated soil to evaluate plant growth, aphid fitness, development of predator and its performance. Vermicompost significantly increased the number of leaflets per plant which reflected enhanced vegetative growth, while differences in leaflet shape were qualitative. It also enhanced the aphid fitness due to improved host quality. The total developmental period was significantly shortened and predation efficiency was highest at various prey densities in vermicompost treatment. Overall, vermicompost improved plant vigour and predator performance through improved prey quality, demonstrating a cascade effect across trophic levels. These results highlight vermicompost as a sustainable alternative to chemical fertilizers for promoting natural pest regulation and maintaining ecological balance in cowpea agroecosystems.

KEY WORDS: Tritrophic interactions, Soil fertilization, Vermicompost, NPK, *Cheilomenes sexmaculata*

INTRODUCTION

Fertilizers play a crucial role in maintaining soil fertility (de Oliveira *et al*., 2023; Liu *et al*., 2023) and sustaining agricultural productivity (Liu *et al*., 2021; Krasilnikov *et al*., 2022). They provide adequate soil nutrition which support plant growth (Leghari *et al*., 2016; Muhammad *et al*., 2022), yield (dos Santos Sousa *et al*., 2022; Tang, 2025), and resilience to pest attack (Altieri *et al*., 2012; Gómez-Trejo *et al*., 2021; Rajareddy *et al*., 2024). However, the type and source of nutrients supplied to the soil can determine not only plant performance but also the interactions between herbivorous pests and their natural enemies (Pekas & Wäckers, 2020; Horgan *et al*., 2022). In tritrophic systems, the plants, herbivores, and predators are interconnected and fertilizer-induced changes at the soil level are capable of influencing biological processes across all three trophic levels (Zhu *et al*., 2020; Gorji *et al*., 2023). Among various soil amendments, organic and inorganic fertilizers are the most widely used (Hernandez *et al*., 2021; Garbowski *et al*., 2023; Prashar *et al*., 2025). Organic fertilizers, such as vermicompost are known to improve soil structure, water-holding capacity, and microbial activity (Chatterjee *et al*., 2020; Oyege & Balaji Bhaskar, 2023). They release nutrients slowly and promote balanced plant growth (Iqbal *et al*., 2024; Hossain *et al*., 2025). In contrast, inorganic fertilizers, such as NPK formulations provide nutrients rapidly but alter soil chemistry (Liu *et al*., 2017; Mi *et al*., 2018) and plant physiology differently (Liu *et al*., 2024; Sai & Paswan, 2024).

The contrasting nutrient release patterns and effects of these fertilizers can lead to substantial differences in plant vigour, leaf structure, and biochemical composition. Such variations are especially relevant for cowpea (*Vigna unguiculata* L. Walp.), a major leguminous crop grown throughout tropical and subtropical regions (Vendramini *et al*., 2012; Sindha *et al*., 2024), which is highly responsive

---

*Corresponding author email: mishra_geeta@lkouniv.ac.in

to soil nutrient management (Aechra *et al*., 2017; Abd El Lateef *et al*., 2018). The morphological traits of plants; such as the number of leaves and the leaf length-to-width ratio, reflect its overall vigour (Sibhatu, 2016; Jagadale *et al*., 2017) and influence the feeding behaviour and reproductive potential of herbivorous insects (Agrawal, 2004; Ruhnke *et al*., 2009; Chaudhary *et al*., 2018; Münzbergová & Skuhrovec, 2020; González-Carrera *et al*., 2025). Improved nutrient availability generally promotes lush plant growth (Nadeem *et al*., 2018; Kafle *et al*., 2023), but it may also make plants more suitable hosts for sap-feeding pests by enhancing nutrient quality in the phloem (Joern & Behmer, 2012; Ebeling *et al*., 2022).

Among these pests, the cowpea aphid, *Aphis craccivora* Koch (Hemiptera: Aphididae) is one of the most destructive species which causes leaf curling, stunted growth, and substantial yield losses in cowpea (Choudhary *et al*., 2017; Ghosh, 2020; Mohamed *et al*., 2021). Its development, fecundity, and longevity are closely tied to host plant quality (Borowiak-Sobkowiak *et al*., 2017; Ríos Martínez & Costamagna, 2018). Plants grown in nutrient-rich soil, particularly under high nitrogen availability support faster aphid reproduction and longer survival (Gao *et al*., 2018; Mousa *et al*., 2019). Thus, fertilizer-induced changes in plant quality can directly alter aphid population dynamics and pest pressure in the agricultural fields.

The consequences of soil fertility also extend to higher trophic levels particularly to predatory ladybird beetles (Hosseini *et al*., 2018; Aguilera *et al*., 2021), such as *Cheilomenes sexmaculata* Fabricius (Coleoptera: Coccinellidae), which are key biological control agents of aphids. The growth of predator and its feeding efficiency depend on the abundance and nutritional quality of its prey (Zhu *et al*., 2020). High-quality aphids supported by nutrient-enriched plants may accelerate predator development and increase the consumption rate. Conversely, nutrient imbalances can prolong the developmental period or reduce the feeding efficiency. Assessing parameters such as the total developmental period (TDP) and percent prey consumption provides a clear measure of how soil nutrient amendments influence biological control potential through tritrophic interactions.

The present study evaluates the impact of two types of soil amendments; vermicompost (organic) and NPK (inorganic) on the performance of cowpea *V. unguiculata*, its pest *A. craccivora*, and the predator *C. sexmaculata*. It aims to understand how differences in soil nutrient sources shape plant growth, aphid fitness, development of the predator and its predation efficiency within a tritrophic framework.

MATERIALS AND METHODS

Experimental design

The study was conducted under semi-field conditions in University of Lucknow (26.86° N, 80.93° E) area to evaluate the influence of soil nutrient amendments on cowpea (*V. unguiculata*) growth, aphid (*A. craccivora*) performance, and development of predator (*C. sexmaculata*) and its predation efficiency. Experiments were carried out in cubical mesh cages (250 µm; 0.5×0.5 m) under natural photoperiod 11.5L: 12.5D with recorded temperature and relative humidity 26.8 ± 2°C and 63.4 ± 5%, respectively during the experimental duration from October 2022 to April 2023 .

Assessment of various trophic levels

Plant growth assessment : *Vigna unguiculata* seeds were individually sown in plastic pots (8 × 6 inches) filled with autoclaved sterile soilrite to prevent microbial and pest contamination. Plants were maintained under natural environmental conditions and grown to the third or fourth trifoliate stage for the experiments. Treatments included control, vermicompost (1.8 t/ha), and NPK (131.6 kg/ha) amendments (TNAU Agritech portal, 2022) in soilrite. All plants were watered daily to maintain uniform soil moisture. Plant growth was evaluated by recording the number of leaves (compound leaflets) per plant and the leaflet length-to-width (L: W) ratio as an indicator of vegetative growth. The L: W ratio is measured using ImageJ (version 1.52a) software. Each treatment was replicated thirty times. Total 90 replicates were used.

Aphid fitness evaluation : *Aphis craccivora* individuals were collected from local *Lablab purpureus* (L.) Sweet fields and maintained on cowpea plants to establish clonal colonies. Offspring from a single gravid aphid were used for all experiments to ensure uniformity.

Fecundity: A single gravid aphid (30 per treatment) was confined to a target leaflet using fine mesh insect-rearing bags. The total number of offspring produced over seven consecutive days was recorded to assess reproductive potential under different plant nutrient conditions. Total 90 replicates were used.

Longevity: First instar aphids were individually confined to leaflets using fine mesh insect rearing bag and monitored daily until death. The experiment was replicated 30 times for each treatment (n=90).

These parameters provided insights into how plant nutritional status affects aphid population growth and survival.

Development and Predation efficiency

Adult *C. sexmaculata* were collected from *L. purpureus* plants from the local agricultural fields of Barabanki, India (26°93' N, 81°18' E). The collected adults were paired and reared for three successive generations in plastic beakers (14.5 × 10.5 cm^2) covered with muslin cloth fastened with rubber bands. The rearing was carried out under natural environmental conditions corresponding to the experimental period within cubical mesh cages. They were provided with an *ad libitum* supply of *A. craccivora* reared on *V. unguiculata* maintained under the identical semi-field conditions to establish the stock culture. Eggs were collected daily and the resulting neonates were reared to adulthood. Periodic introduction of wild beetles was performed to maintain genetic diversity and prevent inbreeding. All the requisite stages used in the experiments were obtained from these established colonies.

Developmental period

The developmental period of *C. sexmaculata* was recorded for each treatment to assess the influence of prey availability and plant nutrient status on predator growth. The duration of the eggs (incubation period), larvae (from first instar to fourth instar), pre-pupal and pupal stages (immature developmental period) were monitored individually. Eggs (E), first instar (L1), and second instar (L2) larvae were maintained on leaves of *V. unguiculata* plants infested with *A. craccivora* enclosed inside insect-rearing bags to prevent larval dispersal due to their small sizes within cubical mesh cages. The third (L3) and fourth (L4) instar larvae being highly voracious and mobile were reared directly on aphid-infested *V. unguiculata* plants within cubical mesh cages. Throughout the experiment, predators were provided with an *ad libitum* supply of *A. craccivora* reared on *V. unguiculata* plants from the corresponding soil treatment. Subsequently, the total developmental period (TDP) from egg to newly emerged adult was calculated for each treatment. The experiment was replicated 30 times per treatment (n=90).

Percent prey consumption

Prior to the experiment, adult beetles were starved for 24 hours to standardize hunger. Five different densities of third instar *A. craccivora* nymphs (50, 100, 200, 300, and 400) were applied to leaflets of *V. unguiculata* plants within cubical mesh cages. Third instar aphids were used to minimize reproduction during the 24-hour predation period. After introducing the requisite number of aphids, a single adult beetle was released into each cage. After 24 hours, beetles were removed and the remaining live aphids were counted. The number of aphids consumed was recorded and percent prey consumption was calculated for each adult beetle at each aphid density. The experiment was replicated 20 times (n=100) for each aphid density. Total replicates were 300 for all treatments.

Statistical analyses

Data on plant growth (number of leaflets per plant and length-to-width ratio of leaflets), aphid fitness (fecundity and longevity), along with growth of predator (immature developmental durations and TDP) and its performance (percent predation at different aphid densities) were tested for normality using the Shapiro-Wilk test. All the datasets were found to be non-normally distributed. Differences among soil treatments (control, vermicompost, and NPK) were analysed using the Kruskal-Wallis H test. Pairwise comparisons were conducted for significant differences using the Bonferroni post hoc test. All analyses and graphical outputs were conducted using IBM SPSS (Version 27.0) software.

RESULTS

Effects of soil treatment on *V. unguiculata* growth

The number of leaflets per plant varied significantly among soil treatments ($H = 48.948$, $df = 2$, $p < 0.001$). Plants grown in vermicompost-amended soil showed the highest number of leaflets followed by NPK-treated and control plants (Fig. 1). In contrast, although the leaflet length-to-width ratio did not differ significantly among treatments ($H = 3.849$, $df = 2$, $p = 0.146$), yet noticeable differences in leaflet shape were observed. Leaflets of control plants were slightly more elongated *i.e.* lanceolate (1.88 ± 0.06), whereas those of NPK (1.76 ± 0.07) and vermicompost (1.75 ± 0.07) treatments appeared broader and more ovate in shape (Fig. 2).

Effect of soil treatment on *A. craccivora* fitness

Aphid fecundity differed significantly among soil treatments ($H = 240.405$, $df = 2$, $p < 0.001$). The highest fecundity was observed in aphids reared on vermicompost-grown plants, followed by those on NPK-treated and control plants (Fig. 3). Similarly, aphid longevity also varied significantly among treatments ($H = 63.056$, $df = 2$, $p < 0.001$), with the longest lifespan recorded in the vermicompost treatment, followed by NPK and control. (Fig. 4).

Effect of soil treatment on development and predation efficiency of *C. sexmaculata*

The developmental durations of the immature stages of *C. sexmaculata* showed minor variations among soil treatments, although most differences were statistically non-significant. The egg stage (incubation period) was shortest in the vermicompost treatment, followed by NPK

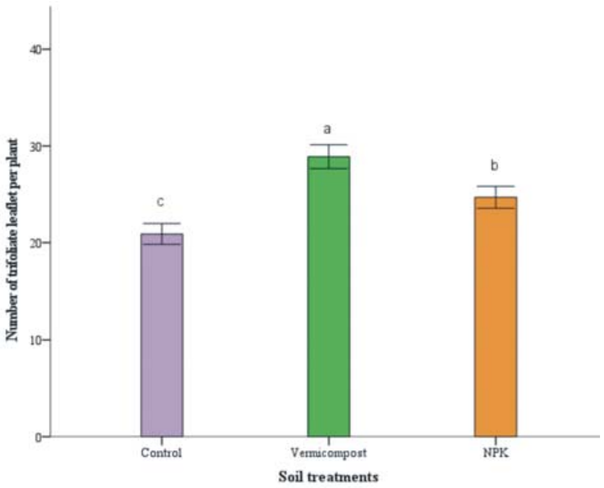

Fig. 1: Number of trifoliate leaflets per *V. unguiculata* plant grown under control, vermicompost-amended, and NPK-amended soils. Bars represent mean ± SE. Different letters above the bars indicate significant differences among treatments (p<0.05).

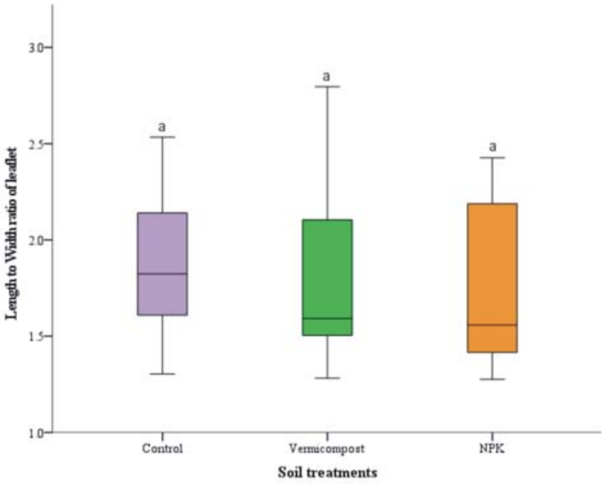

Fig. 2: Box plots showing the leaflet length-to-width ratio for *V. unguiculata* plants grown under control, vermicompost-amended, and NPK-amended soils. The centre line within each box represents the median, the box shows the interquartile range, and whiskers extend to the full data range. Similar letters denote no significant difference.

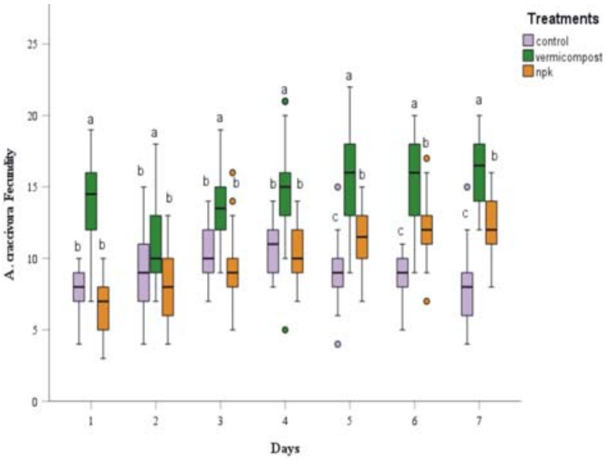

Fig. 3: Box plots showing aphid *A. craccivora* fecundity in control, vermicompost-amended, and NPK-amended soil treatments. The centre line within each box represents the median, the box indicates the interquartile range, and whiskers extend to the full data range. Circles represent outliers. Different letters above the boxes denote significant differences among treatments (p<0.05), whereas similar letters indicate no significant difference.

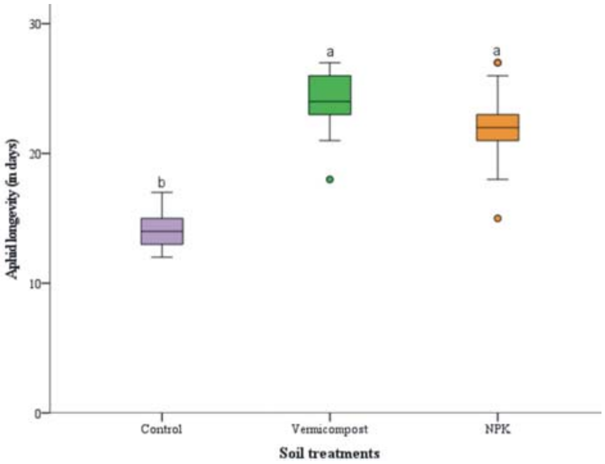

Fig. 4: Box plots showing aphid *A. craccivora* longevity in control, vermicompost-amended, and NPK-amended soil treatments. The centre line within each box represents the median, the box indicates the interquartile range, and whiskers extend to the full data range. Circles represent outliers. Different letters above the boxes denote significant differences among treatments (p<0.05), whereas similar letters indicate no significant difference.

and control, but this variation was not significant (H = 4.628, df = 2, p = 0.099). Similarly, the first, second, third, and fourth-instar larval durations did not differ significantly among treatments (H = 1.171 - 4.684, df = 2, p > 0.05). The pre-pupal (H = 2.000, df = 2, p = 0.368) and pupal (H = 2.866, df = 2, p = 0.239) durations also exhibited no significant variation (Fig. 5). However, the total developmental period (egg-to-adult) varied significantly among treatments (H = 10.850, df = 2, p = 0.004) where vermicompost had the shortest total developmental period (35.73 days), followed by NPK (43.87 days) and control (56.90 days) (Fig. 6).

The predation efficiency (percent consumption) at individual prey densities showed clear variation across treatments. At prey density 50, the percent consumption was highest under vermicompost, followed by NPK and control, with a significant difference among treatments (H = 6.310, df = 2, p = 0.043). A similar trend was evident at prey density 200 (H = 7.613, df = 2, p = 0.022), 300 (H = 13.004, df = 2, p = 0.002), and 400 aphids (H = 12.291, df = 2, p = 0.002), whereas at 100 aphids, the difference among treatments was not significant (H = 5.466, df = 2, p = 0.065). Although the cumulative percent consumption at all the prey densities of *C. sexmaculata* was recorded to be non-significant (H = 5.069, df = 2, p = 0.079) yet the overall trend indicated that soil enrichment enhanced the predator's feeding efficiency in vermicompost treatment from NPK and control (Fig. 7).

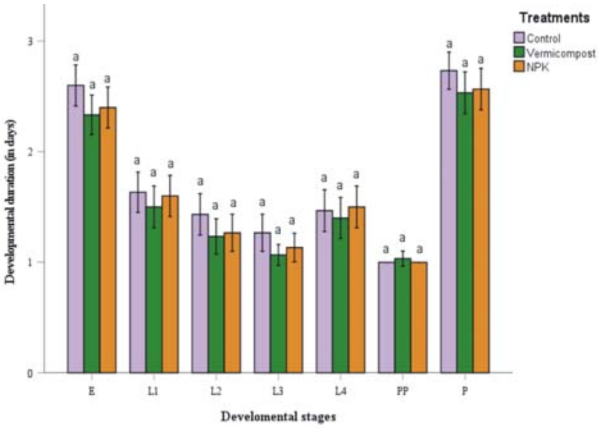

Fig. 5: Duration of immature developmental stages (E-egg, L1 to L4- larval instars, PP- pre-pupa, P- Pupa) of *C. sexmaculata* reared on *A. craccivora* from control, vermicompost-amended, and NPK-amended soils. Bars represent mean ± SE. Similar letters above bars denote no significant difference.

DISCUSSION

This study highlights the effects of soil nutrient management in tritrophic interactions among the leguminous crop *V. unguiculata*, the aphid *A. craccivora*, and the predatory ladybird beetle *C. sexmaculata*. The results clearly indicate that organic amendment via vermicompost enhanced plant morphological traits, improved aphid fitness, shortened predator developmental period and increased the percent consumption. Ecological theory predicts that changes in resource availability at the plant level can propagate upward through trophic levels and influence herbivore and natural-enemy dynamics (Price *et al*., 1980). In this system, vermicompost appears to promote a more favourable tritrophic linkage than conventional NPK fertilizer highlighting to its potential role in ecologically grounded pest management strategies.

The significant increase in the number of leaflets per plant in vermicompost-amended soil reflects improved nutrient availability (Adiloðlu *et al*., 2018), microbial activities (Arancon *et al*., 2004) and soil structure (Ceritoðlu *et al*., 2018) compared to chemical fertilizer (NPK) or control conditions. Vermicompost is known to enhance plant vegetative growth through the slow release of plant growth promoting substances, such as humic acids (Rehman *et al*., 2023) and phytohormones (Arancon *et al*., 2004). The improved root-shoot balance due to better soil structure, microbial activities and nutrient uptake likely

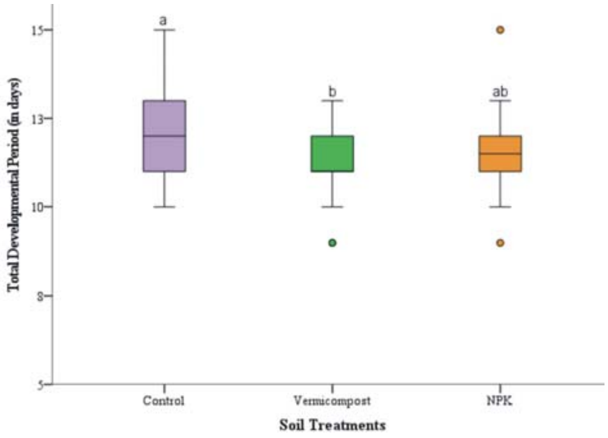

Fig. 6: Box plots showing total developmental duration (from egg to newly emerged adult) of *C. sexmaculata* reared on *A. craccivora* from control, vermicompost-amended, and NPK-amended soils The centre line within each box represents the median, the box indicates the interquartile range, and whiskers extend to the full data range. Circles represent outliers. Different letters above the boxes denote significant differences among treatments (p<0.05), whereas similar letters indicate no significant difference.

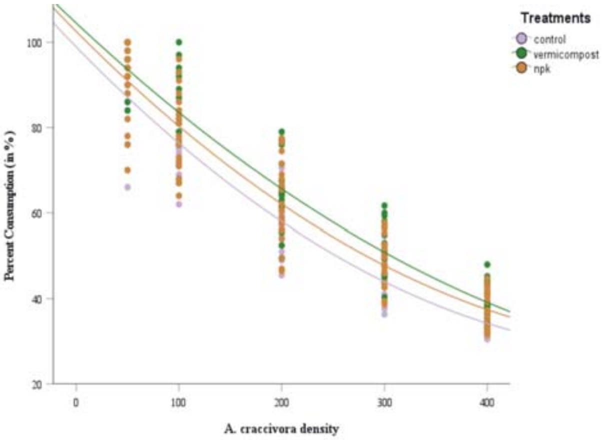

Fig.7: Percent consumption of *C. sexmaculata* at varying *A. craccivora* densities under control, vermicompost-amended, and NPK-amended soil treatments. Each point represents mean ± SE.

contributed to the higher leaflet production observed in this treatment.

Although the leaflet length-to-width (L: W) ratios were non-significant between treatments yet there were noticeable morphological differences present *viz.* control plants produced slightly more elongated and lanceolate leaflets, while NPK and vermicompost treatments had somewhat broader and ovate leaflets. Such shape trends can indicate phenotypic plasticity in response to nutrient regimes. Broader ovate leaflets under enriched soils may increase light capture and photosynthetic efficiency (Niinemets & Sack, 2006; Shi, Yu & Niinemets, 2020), which in turn could indirectly influence the herbivore quality (Campo & Dirzo, 2003).

Aphid fecundity and longevity were significantly enhanced on vermicompost-grown plants which validates the notion that host plant nutritional status is a key determinant of herbivore performance (Awmack & Leather, 2002; Züst & Agrawal, 2017). Plants with superior nitrogen content promote aphid reproduction by improving phloem sap quality (Rousselin *et al.*, 2016). Vermicompost treatment at the soil level likely elevated soluble nitrogen levels and amino acids in cowpea phloem, thereby enhancing aphid reproductive potential and survival. Hosseini *et al*. (2018) found that increasing nitrogen fertilization of cucumber increased the nutritional content of aphids and altered predator foraging responses. The shorter aphid lifespan on control plants suggests suboptimal nutrition or increased plant defensive compounds under nutrient-limited conditions. Moreover, organic amendments (including vermicompost) and organic management frequently improve plant vigour and nutrient availability and these factors can increase herbivore performance in some systems (Blouin *et al.*, 2019), however effects are species and context-dependent (Arancon *et al.*, 2004). In the present study, vermicompost likely created a more balanced nutritional environment that supported aphid fecundity and longevity better than NPK and control condition, while sustaining higher predator efficiency indicating a stabilizing effect across trophic levels.

The development and predation efficiency of *C. sexmaculata* were influenced by soil enrichment, though the degree of impact varied among parameters. Immature developmental durations exhibited small variations across treatments, with non-significant differences in egg, larval, pre-pupal or pupal stages. However, the slight reductions across multiple immature stages under vermicompost treatment likely accumulated and resulted in a significantly shorter total developmental period (Farhadi *et al.*, 2010). Such bottom-up effects, where soil amendments influence plant vigour and consequently herbivore and predator fitness, have been widely documented in tritrophic systems (Fallahpour *et al.*, 2020; Aguilera *et al.*, 2021). The shorter total developmental period in vermicompost-treated plants aligns with the earlier reports which indicate that organically enriched soils enhance plant nutritional quality and secondary metabolites which promote aphid growth and provide superior prey for predatory coccinellids (Chen *et al.*, 2010; Hosseini *et al.*, 2018). Conversely, the longer developmental period observed in the control treatment reflects nutrient limitation at the base trophic level, which propagates upward through the food chain and delays predator maturation (Chen *et al.*, 2015).

The predation efficiency of *C. sexmaculata* varied among soil treatments with the highest consumption recorded on aphids from vermicompost-treated plants, followed by NPK and control. Significant differences at most prey densities (50, 200, 300, and 400 aphids) indicate that organic amendments can enhance predator foraging efficiency by improving prey availability and host-plant nutrient status (Patel *et al.*, 2014; Blouin *et al.*, 2019). At the intermediate density of 100 aphids, consumption did not differ significantly, likely due to behavioural adjustments such as altered search patterns or patch switching, and moderate prey densities reducing effective encounters through aggregation or refuges (Jeschke *et al.*, 2002)

Vermicompost enhances plant nitrogen and amino acid content (Arancon *et al.*, 2004) due to its richness in humic substances and microbial metabolites which likely improves aphid nutritional quality and consequently, predator feeding efficiency. Although cumulative consumption across all densities was not statistically significant, yet the overall trend clearly favoured vermicompost over NPK and control. These results are consistent with previous studies showing that nutrient-enriched host plants produce higher-quality prey (Nevo & Coll, 2001), which increases prey consumption (Hosseini *et al*., 2018) and supports better developmental and reproductive performance of coccinellids (Obrycki *et al*., 2009; Shah & Khan, 2014). In the present study, the moderate increase observed under NPK treatment suggests that inorganic enrichment can also enhance predator performance, though not as effectively as vermicompost, possibly due to differences in nutrient balance and soil microbial activity (Arancon *et al*., 2004).

CONCLUSIONS

This study establishes that soil nutrient management plays a pivotal role in shaping tritrophic interactions. Vermicompost significantly enhanced *V. unguiculata* growth and supported effective biological control of *A. craccivora* through improved performance of *C. sexmaculata*. Although NPK fertilization also enhanced plant, pest, predators development and performance but its overall ecological benefits were limited compared to vermicompost.

Hence, vermicompost emerges as an ecologically sustainable soil fertilizer that strengthens plant health, maintains predator efficiency, and facilitates natural pest suppression. Promoting organic nutrient sources such as vermicompost can reduce dependence on chemical fertilizers which also aligns with integrated pest management (IPM) principles, and contribute to resilient agroecosystems.

REFERENCES

Abd El Lateef, E.M., Abd El-Salam, M.S., Elewa, T.A., & Wali, A.M. (2018). Effect of organic manures and adjusted N application on cowpea (*Vigna unguiculata* L. Walp) yield, quality and nutrient removal in sandy soil. *Middle East J. App. Sci.*, 8(1): 7-18.

Abd El-Zaher, T.R., El-Zoghby, I.R.M., & Hassan, G.M. (2016). Impact of host plant on the population growth rate and nymphal durations of *Aphis craccivora* and using plant extract for aphid control. *Middle East J. Agri. Res.*, 5(4): 611-619.

Adiloðlu, S., Eryýlmaz Açýkgöz, F., Solmaz, Y., Çaktü, E., & Adiloðlu, A. (2018). Effect of vermicompost on the growth and yield of lettuce plant (*Lactuca sativa* L. var. *crispa*). *Intern. J. Pl. Soil Sci.*, 21(1): 1-5.

Aechra, S., Yadav, B.L., Ghosalya, B.D., & Bamboriya, J.S. (2017). Effect of soil salinity, phosphorus and biofertilizers on physical properties of soil, yield attributes and yield of cowpea [*Vigna unguiculata* (L.) Wilczek]. *J. Pharma. Phytochem.*, 6(4): 1691-1695.

Agrawal, A.A. (2004). Plant defense and density dependence in the population growth of herbivores. *The Amer. Natur.*, 164(1): 113-120.

Aguilera, G., Riggi, L., Miller, K., Roslin, T., & Bommarco, R. (2021). Organic fertilisation enhances generalist predators and suppresses aphid growth in the absence of specialist predators. *J. App. Ecol.*, 58(7): 1455-1465.

Altieri, M.A., Ponti, L., & Nicholls, C.I. (2012). Soil fertility, biodiversity and pest management. Biodiversity and Insect Pests: Key Issues for Sustainable Management, 72-84.

Arancon, N.Q., Edwards, C.A., Bierman, P., Welch, C., & Metzger, J.D. (2004). Influences of vermicomposts on field strawberries: 1. Effects on growth and yields. *Biores. Technol.*, 93(2): 145-153.

Awmack, C.S., & Leather, S.R. (2002). Host plant quality and fecundity in herbivorous insects. *Ann. Rev. Entomol.*, 47(1): 817-844.

Blouin, M., Barrere, J., Meyer, N., Lartigue, S., Barot, S., & Mathieu, J. (2019). Vermicompost significantly affects plant growth. A meta-analysis. *Agron. Sustain. Develop.*, 39(4): 34.

Borowiak-Sobkowiak, B., Durak, R., & Wilkaniec, B. (2017). Morphology, biology and behavioral aspects of *Aphis craccivora* (Hemiptera: Aphididae) on *Robinia pseudoacacia*. *Acta Scientiarum Polonorum. Hortorum Cultus*, 16(1): 39-49.

Campo, J., & Dirzo, R. (2003). Leaf quality and herbivory responses to soil nutrient addition in secondary tropical dry forests of Yucatán, Mexico. *J. Trop. Ecol.*, 19(5): 525-530.

Ceritoðlu, M., Þahin, S., & Erman, M. (2018). Effects of vermicompost on plant growth and soil structure. *Selcuk J. Agricul. Food Sci.*, 32(3): 607-615.

Chatterjee, R., Debnath, A., & Mishra, S. (2020). Vermicompost and soil health. In: *Soil Health* (pp. 69-88). Cham: Springer International Publishing.

Chaudhary, A., Bala, K., Thakur, S., Kamboj, R., & Dumra, N. (2018). Plant defenses against herbivorous insects: a review. *Intern. J. Chem. Stud.*, 6(5): 681-688.

Chen, Y., Olson, D.M., & Ruberson, J.R. (2010). Effects of nitrogen fertilization on tritrophic interactions. *Arthropod-Pl. Interac.*, 4(2): 81-94.

Choudhary, A.L., Hussain, A., Samota, R.G., & Nehra, S. (2017). Effect of biotic and abiotic factors on the incidence of aphid, *Aphis craccivora* Koch on cowpea. *J. Pharmacog. Phytochem.*, 6(4): 1587-1590.

de Oliveira, M.W., Verma, K.K., Bhatt, R., & Oliveira, T.B.A. (2023). Impact of green and organic fertilizers on soil fertility and sugarcane productivity. In Agro-industrial Perspectives on Sugarcane Production under Environmental Stress (pp. 193-213). Singapore: Springer Nature Singapore.

dos Santos Sousa, W., Soratto, R.P., Peixoto, D.S., Campos, T.S., Da Silva, M.B., Souza, A.G.V., Teixeira I.R. & Gitari, H.I. (2022). Effects of *Rhizobium inoculum* compared with mineral nitrogen fertilizer on nodulation and seed yield of common bean. A meta-analysis. *Agron. Sustain. Develop.*, 42(3): 52.

Ebeling, A., Strauss, A.T., Adler, P.B., Arnillas, C.A., Barrio, I.C., Biederman, L.A., & Blumenthal, D.M. (2022). Nutrient enrichment increases invertebrate herbivory and pathogen damage in grasslands. *J. Ecol.*, 110(2): 327-339.

Fallahpour, F., Ghorbani, R., Nassiri-Mahallati, M., & Hosseini, M. (2020). Plant fertilization helps plants to compensate for aphid damage, positively affects predator efficiency and improves canola yield. *J. Pest Sci.*, 93(1): 251-260.

Farhadi, R., Allahyari, H., & Chi, H. (2011). Life table and predation capacity of *Hippodamia variegata* (Coleoptera: Coccinellidae) feeding on *Aphis fabae* (Hemiptera: Aphididae). *Biol. Cont.*, 59(2): 83-89.

Gao, J., Guo, H.J., Sun, Y.C., & Ge, F. (2018). Juvenile hormone mediates the positive effects of nitrogen fertilization on weight and reproduction in pea aphid. *Pest Manag. Sci.*, 74(11): 2511-2519.

Garbowski, T., Bar-Michalczyk, D., Charaziñska, S., Grabowska-Polanowska, B., Kowalczyk, A., & Lochyñski, P. (2023). An overview of natural soil amendments in agriculture. *Soil and Tillage Res.*, 225: 105462.

Ghosh, S.K. (2020). Aphid (*Aphis craccivora* Koch.) Management on groundnut crop (*Arachis hypogaea*) by using bio-pesticides. *Intern. J. Curr. Microbiol. Appl. Sci.*, 9(10): 24-34.

Gómez-Trejo, L.F., Hernández-Acosta, E., & Peralta-Sánchez, M.G. (2021). N, P, K nutrition differentially affects the incidence and severity of the attack of pests and diseases in plants. *Agro Producti.*, 14(5): 121-125.

González-Carrera, S., Fernández-Fuentes, A., Escudero, A., García-Estévez, I., Martínez-Ortega, M., & Mediavilla, S. (2025). Leaf traits and insect herbivory levels in two Mediterranean oaks and their hybrids through contrasting environmental gradients. *Tree Physiol.*, 45(1): tpae170.

Gorji, Z., Mehrparvar, M., & Mansouri, S. M. (2023). Cascading effects of soil organic and inorganic fertilizers on tri-trophic interactions: Plant–aphid–parasitoid wasp as a study system. *J. Appl. Entomol.*, 147(2): 126-139.

Hernandez, T., Berlanga, J. G., Tormos, I., & Garcia, C. (2021). Organic versus inorganic fertilizers: Response of soil properties and crop yield. *AIMS Geosci.*, *7*(3): 415-439.

Horgan, F.G., Crisol-Martínez, E., Stuart, A.M., Villegas, J.M., Peñalver-Cruz, A., Mundaca, E.A., Perez, M.O., Bernal, C.C., Almazan, M.L.P. & Ramal, A.F. (2022). Direct and indirect effects of planting density, nitrogenous fertilizer and host plant resistance on rice herbivores and their natural enemies. *Agricul.*, 12(12): 2053.

Hossain, M.L., Shapna, K.J., Li, J., Kabir, M.H., Siddika, F., Khandker, S., & Beierkuhnlein, C. (2025). Transforming agriculture with vermicompost: 7-year empirical evidence from drought-prone and salinization-affected regions of Bangladesh. *J. Cleaner Prod.*, 145595.

Hosseini, A., Hosseini, M., Michaud, J.P., Modarres Awal, M., & Ghadamyari, M. (2018). Nitrogen fertilization increases the nutritional quality of *Aphis gossypii* (Hemiptera: Aphididae) as prey for *Hippodamia variegata* (Coleoptera: Coccinellidae) and alters predator foraging behavior. *J. Econ. Entomol.*, 111(5): 2059-2068.

Iqbal, A., Khan, R., Hussain, Q., Imran, M., Mo, Z., Hua, T., Adnan, M., Abid, I., Rizwana, H., Elshikh, M. S., Sabagh, A. El., Lal, R., & Tang, X. (2024). Vermicompost application enhances soil health and plant physiological and antioxidant defense to conferring heavy metals tolerance in fragrant rice. *Front. Sustain. Food Syst.*, 8: 1418554.

Jagadale, A., Lahane, G., Bahure, G., Mirza, I., & Ghungarde, S. (2017). Influence of plant geometry and fertilizer levels on growth of cowpea (*Vigna unguiculata* L. Walp). *Advan. Life Sci.*, 5(17): 221-228.

Jeschke, J.M., Kopp, M., & Tollrian, R. (2002). Predator functional responses: discriminating between handling and digesting prey. *Ecol. Monogr.*, 72(1): 95-112.

Joern, A., Provin, T., & Behmer, S.T. (2012). Not just the usual suspects: insect herbivore populations and communities are associated with multiple plant nutrients. *Ecol.*, 93(5): 1002-1015.

Kafle, J., Bhandari, L., Neupane, S., & Aryal, S. (2023). A review on impact of different nitrogen management techniques on maize (*Zea mays* L.) crop performance. *AgroEnviron. Sustain.*, 1: 192-198.

Krasilnikov, P., Taboada, M.A., & Amanullah. (2022). Fertilizer use, soil health and agricultural sustainability. *Agricul.*, 12(4): 462.

Leghari, S.J., Wahocho, N.A., Laghari, G.M., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K. & Lashari, A.A. (2016). Role of nitrogen for plant growth and development: A review. *Advan. Environ. Biol.*, 10(9): 209-219.

Liu, J., Wang, D., Yan, X., Jia, L., Chen, N., Liu, J., Zhao, P., Zhou, L., & Cao, Q. (2024). Effect of nitrogen, phosphorus and potassium fertilization management on soil properties and leaf traits and yield of *Sapindus mukorossi*. *Front. Plant Sci.*, 15: 1300683.

Liu, Q., Xu, H., & Yi, H. (2021). Impact of fertilizer on crop yield and C: N: P stoichiometry in arid and semi-arid soil. *Intern. J. Environ. Res. Public Heal.*, 18(8): 4341.

Liu, W., Cui, S., Wu, L., Qi, W., Chen, J., Ye, Z., Ma, J., & Liu, D. (2023). Effects of bio-organic fertilizer on soil fertility, yield, and quality of tea. *J. Soil Sci. Plant Nutri.*, 23(4): 5109-5121.

Liu, Z., Rong, Q., Zhou, W., & Liang, G. (2017). Effects of inorganic and organic amendment on soil chemical properties, enzyme activities, microbial community and soil quality in yellow clayey soil. *PloS one*, 12(3): e0172767.

Mi, W., Sun, Y., Xia, S., Zhao, H., Mi, W., Brookes, P. C., Liu, Y., & Wu, L. (2018). Effect of inorganic fertilizers with organic amendments on soil chemical properties and rice yield in a low-productivity paddy soil. *Geoderma*, 320: 23-29.

Mohamed, G.S., Allam, R.O.H., Mohamed, H.A., & Bakry, M.M.S. (2021). Impact of certain weather factors and plant age on the population density of *Aphis craccivora* (Koch) on faba bean plants. *SVU-Intern. J. Agricul. Sci.*, 3(4): 84-104.

Mousa, K.M., Gawad, A.A., Shawer, D.M., & Kamara, M.M. (2019). Drought stress and nitrogen fertilization affect cereal aphid populations in wheat fields. *J. Plant Protec. Pathol.*, 10(12): 613-619.

Muhammad, I., Yang, L., Ahmad, S., Farooq, S., Al-Ghamdi, A.A., Khan, A., Zeeshan, M., Elshikh, M.S., Abbasi, A.M. & Zhou, X.B. (2022). Nitrogen fertilizer modulates plant growth, chlorophyll pigments and enzymatic activities under different irrigation regimes. *Agron.*, 12(4): 845.

Münzbergová, Z., & Skuhrovec, J. (2020). Data on herbivore performance and plant herbivore damage identify the same plant traits as the key drivers of plant–herbivore interaction. *Insects*, 11(12): 865.

Nadeem, F., Hanif, M.A., Majeed, M.I., & Mushtaq, Z. (2018). Role of macronutrients and micronutrients in the growth and development of plants and prevention of deleterious plant diseases-a comprehensive review. *Intern. J. Chem. Biochem. Sci.*, 13: 31-52.

Nevo, E., & Coll, M. (2001). Effect of nitrogen fertilization on *Aphis gossypii* (Homoptera: Aphididae): variation in size, color, and reproduction. *J. Econ. Entomol.*, 94(1): 27-32.

Niinemets, Ü., & Sack, L. (2006). Structural determinants of leaf light-harvesting capacity and photosynthetic potentials. In *Progress in Botany* (pp. 385-419). Berlin, Heidelberg: Springer Berlin Heidelberg.

Obrycki, J.J., Harwood, J.D., Kring, T.J., & O'Neil, R.J. (2009). Aphidophagy by Coccinellidae: application of biological control in agroecosystems. *Biolo. Cont.*, 51(2): 244-254.

Oyege, I., & Balaji Bhaskar, M.S. (2023). Effects of vermicompost on soil and plant health and promoting sustainable agriculture. *Soil Syst.*, 7(4): 101.

Patel, D.P., Das, A., Kumar, M., Munda, G.C., Ngachan, S.V., Ramkrushna, G.I., Layek, J., Pongla, N., Buragohain, J., & Somireddy, U. (2015). Continuous application of organic amendments enhances soil health, produce quality and system productivity of vegetable-based cropping systems in subtropical eastern Himalayas. *Experim. Agricul.*, 51(1): 85-106.

Pekas, A., & Wäckers, F.L. (2020). Bottom-up effects on tri-trophic interactions: plant fertilization enhances the fitness of a primary parasitoid mediated by its herbivore host. *J. Econ. Entomol.*, 113(6): 2619-2626.

Prashar, D., Singh, A., Dhama, V., Singh, P.K., Kumar, M., Kumar, S., Pandey, D. & Verma, G. (2025). Effect of organic and inorganic fertilizers on crop yield and soil fertility: a comprehensive review. *J. Experim. Agricul. Intern.*, 47(2): 16-22.

Price, P.W., Bouton, C.E., Gross, P., McPheron, B.A., Thompson, J.N., & Weis, A.E. (1980). Interactions among three trophic levels: influence of plants on interactions between insect herbivores and natural enemies. *Ann. Rev. Ecol. System.*, 11: 41-65.

Rajareddy, G., Alekhya, G., Kasa, K.R., Dasari, G., Reddy, K.S., & Reddy, K.S. (2024). Nutrient strategies for pest resilience in plants: a review. *Intern. J. Environ. Clim. Change*, 14(5): 279-291.

Rehman, S. u., De Castro, F., Aprile, A., Benedetti, M., & Fanizzi, F.P. (2023). Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. *Agron.*, 13(4): 1134.

Ríos Martínez, A.F., & Costamagna, A.C. (2018). Effects of crowding and host plant quality on morph determination in the soybean aphid, *Aphis glycines*. *Entomol. Experim. et Appli.*, 166(1): 53-62.

Rousselin, A., Sauge, M.H., Jordan, M.O., Vercambre, G., Lescourret, F., & Bevacqua, D. (2016). Nitrogen and water supplies affect peach tree–green peach aphid interactions: The key role played by vegetative growth. *Agricul. For. Entomol.*, 18(4): 367-375.

Ruhnke, H., Schädler, M., Klotz, S., Matthies, D., & Brandl, R. (2009). Variability in leaf traits, insect herbivory and herbivore performance within and among individuals of four broad-leaved tree species. *Basic and Appl. Ecol.*, 10(8): 726-736.

Sai, R., & Paswan, S. (2024). Influence of higher levels of NPK fertilizers on growth, yield, and profitability of three potato varieties in Surma, Bajhang, Nepal. *Heliyon*, 10(14).

Shah, M.A., & Khan, A.A. (2014). Qualitative and quantitative prey requirements of two aphidophagous coccinellids, *Adalia tetraspilota* and *Hippodamia variegata*. *J. Insect Sci.*, 14: 72.

Shi, P., Yu, K., Niinemets, Ü., & Gielis, J. (2020). Can leaf shape be represented by the ratio of leaf width to length? Evidence from nine species of *Magnolia* and *Michelia* (Magnoliaceae). *Forests*, 12(1): 41.

Sibhatu, B. (2016). Evaluation of cowpea plant density and nitrogen fertilizer for productivity of sorghum/cowpea intercrops at Abergelle, Northern Ethiopia. *J. Nat. Sci. Res.*, 6(3): 112-121.

Sindha, P.M., Patel, H.H., Patel, J.N., Bambhaniya, S.M., & Vaishnav, M.D. (2024). Effect of nutrient management on cowpea [*Vigna unguiculata* (L.) Walp]. *Intern. J.Plant & Soil Sci.*, 36(4): 257-265.

Tamil Nadu Agriculture University. *TNAU Agritech Portal*, https://agritech.tnau.ac.in/agriculture/CropProduction/Pulses/pulses_cowpea.html. Accessed 2 October, 2022.

Tang, L. (2025). Soil fertility, plant nutrition and nutrient management. *Plants*, 14(1): 34.

Vendramini, J.M.B., Arthington, J.D., & Adesogan, A.T. (2012). Effects of incorporating cowpea in a subtropical grass pasture on forage production and quality and the performance of cows and calves. *Grass and For. Sci.*, 67(1): 129-135.

Zhu, P., Zheng, X., Xu, H., Johnson, A.C., Heong, K.L., Gurr, G.M., & Lu, Z. (2020). Nitrogen fertilizer promotes the rice pest *Nilaparvata lugens* via impaired natural enemy, *Anagrus flaveolus*, performance. *J. Pest Sci.*, 93(2): 757-766.

Züst, T., & Agrawal, A.A. (2017). Trade-offs between plant growth and defense against insect herbivory: an emerging mechanistic synthesis. *Ann. Rev. Plant Biol.*, 68(1): 513-534.