



# Impact Of Soil Physico-Chemical Variability On The Incidence And Population Build-Up Of Brown Planthopper (*Nilaparvata Lugens Stål*) In Paddy Fields Of Kafen, Muzaffarpur, Bihar

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## ABSTRACT

The brown planthopper (*Nilaparvata lugens* Stål), belonging to the family Delphacidae, is recognized as one of the most serious insect pests limiting rice (*Oryza sativa* L.) production across South and Southeast Asia. Its impact is particularly severe in the Indo-Gangetic plains, including the rice-growing regions of Bihar, where it poses a persistent threat to crop productivity and farmer livelihoods. As a phloem-feeding insect, the pest not only weakens plants through continuous sap extraction but also contributes to large-scale yield losses under favourable conditions. The recurring nature of its outbreaks highlights the need to better understand the ecological and agronomic factors influencing its population dynamics. In this context, the present study was undertaken during the Kharif cropping seasons of 2022 and 2023 in farmers' paddy fields located in Kafen village of Muzaffarpur district, Bihar. The primary objective of the investigation was to evaluate how variations in soil physico-chemical properties affect both the incidence and seasonal population fluctuations of brown planthopper under field conditions. Given that soil acts as the foundation of crop growth, influencing plant nutrition and physiological responses, it is essential to examine its role in shaping plant-insect interactions in rice ecosystems.

To account for spatial variability within the study area, three distinct field sites were selected based on their historical levels of pest infestation. These were categorized as Plot A (high infestation), Plot B (moderate infestation), and Plot C (low infestation). This stratification allowed for a comparative assessment of soil conditions and their relationship with pest abundance. Soil samples from each plot were systematically collected and analysed for a range of physico-chemical parameters, including soil reaction (pH), organic carbon content, available nitrogen, phosphorus, and potassium levels, as well as cation exchange capacity, moisture status, and textural composition. These parameters are known to influence nutrient availability, plant growth, and ultimately the suitability of the host plant for insect feeding and reproduction. Simultaneously, the population dynamics of brown planthopper were monitored throughout the crop growth period. Observations were recorded at weekly intervals using standard hill-count methods to ensure consistency and accuracy. Both nymphal and adult stages were included in the counts to capture the overall population trend across different growth stages of the crop. This systematic monitoring enabled the identification of peak infestation periods and provided insights into the temporal progression of pest populations. By integrating soil analysis with field-based pest observations, the study aimed to establish a clear linkage between soil variability and pest behaviour. Understanding these relationships is critical for developing more effective and sustainable pest management strategies that go beyond conventional chemical control. The findings are expected to contribute towards the formulation of site-specific nutrient

management practices that can help regulate pest populations while maintaining soil health and crop productivity in rice-based farming systems.

**Keywords:** *Brown Planthopper, Nilaparvata lugens, soil nitrogen, pH variability, Kharif rice, Bihar, Muzaffarpur, integrated pest management*

## INTRODUCTION

Rice (*Oryza sativa* L.) plays a central role in ensuring food security in India, occupying a vast cultivated area and contributing substantially to total grain production. Among the major rice-growing regions, Bihar holds a significant position within the Indo-Gangetic plains, where districts such as Muzaffarpur are well known for intensive rice cultivation. Despite its importance, rice productivity in this region is frequently challenged by insect pest pressures, of which the brown planthopper (*Nilaparvata lugens* Stål) is one of the most persistent and damaging. This pest inflicts injury primarily through continuous extraction of phloem sap, resulting in a characteristic condition known as hopper burn, where affected plants rapidly dry and collapse. In addition to direct feeding damage, the insect also serves as a vector for viral diseases such as rice grassy stunt and rice ragged stunt, both of which can cause severe yield reductions. Economic losses due to BPH outbreaks are substantial, not only globally but also within Bihar, where yield reductions can vary widely depending on infestation severity and varietal response. The interaction between soil properties and pest dynamics is increasingly recognized as a key factor influencing crop health. Soil physico-chemical characteristics determine nutrient availability and plant growth conditions, which in turn shape host plant quality for herbivorous insects. Among the various nutrients, nitrogen has a particularly strong influence on plant-insect relationships. Elevated nitrogen levels in soil tend to promote vigorous vegetative growth, increase the concentration of soluble nitrogen compounds in plant tissues, and produce softer plant structures—all of which favour the feeding and multiplication of sap-sucking pests like BPH. Soil reaction (pH) further regulates nutrient transformations and microbial activity within the soil environment. In relatively acidic conditions, the availability of certain nitrogen forms may increase, potentially enhancing plant growth in a way that supports pest development. Previous studies conducted in other rice-growing regions have indicated that higher nitrogen availability combined with lower pH levels can accelerate BPH population growth. However, similar detailed studies focusing on the agro-ecological conditions of north Bihar, particularly Muzaffarpur, remain limited. In addition to nitrogen and pH, soil organic carbon also plays a critical role in determining soil fertility and plant vigor. Higher organic matter content improves water retention, enhances microbial activity, and supports nutrient cycling processes, which can indirectly influence pest incidence by modifying plant nutritional status. Likewise, soil moisture and texture contribute to the microenvironment within the crop canopy, affecting insect settlement, survival, and reproductive behaviour. Although these relationships have been explored in various contexts, there is a lack of location-specific understanding of how soil variability influences BPH outbreaks in the rice ecosystems of Kafen village in Muzaffarpur district. Therefore, the present study was undertaken to address this gap by (i) analysing the physico-chemical properties of soils under different levels of BPH infestation, (ii) examining the seasonal fluctuation of pest populations across crop growth stages, and (iii) quantifying the relationship between soil characteristics and BPH abundance to support the development of sustainable and site-specific pest management strategies.

## 1. MATERIALS AND METHODS

### 1.1 Study Area and Experimental Design

The field study was carried out over two successive Kharif seasons, spanning from June to November in the years 2022 and 2023, in farmers' rice fields situated in Kafen village of Muzaffarpur district, Bihar (26°07' N latitude, 85°21' E longitude; elevation 52 m above mean sea level). The study area lies within Agro-climatic Zone II of Bihar, commonly referred to as the North Bihar Alluvial Plains. This region experiences a humid subtropical climate characterized by pronounced monsoonal rainfall, with an average annual precipitation of approximately 1,100 mm. The soils are predominantly alluvial in origin, derived from the Gangetic river system. Based on prior field surveys and historical records provided by farmers, three experimental sites of approximately 0.5 hectare each were selected to represent varying levels of brown planthopper (BPH) incidence. Plot A was identified as a high-infestation zone and had been under organic cultivation practices for the past three years. Plot B represented a moderately affected area where fertilization followed recommended NPK doses with an additional 50% nitrogen input. Plot C exhibited relatively low pest incidence and was managed using balanced fertilization along with integrated nutrient management practices. To eliminate varietal influence on pest dynamics, all plots were cultivated with the same susceptible rice variety, MTU-7029 (Swarna). Except for differences in nutrient management practices, all other agronomic operations were maintained uniformly across the experimental sites throughout the study period.

### 1.2 Soil Sampling and Analysis

Soil sampling was carried out within the rhizosphere region (0–15 cm depth) of each experimental unit at three important crop growth phases: prior to transplanting (baseline stage), during the peak tillering phase (35 days after transplanting), and at the onset of panicle formation (55 days after transplanting). From every plot, ten cores of 2.5 cm diameter were randomly collected and thoroughly blended to produce a single composite sample representative of that plot. The collected soil was allowed to dry naturally under ambient conditions, followed by gentle crushing to break aggregates without altering mineral composition. The processed material was then passed through a 2 mm sieve to obtain a uniform sample suitable for analytical work. Analytical determinations were performed using well-established laboratory procedures. Soil acidity/alkalinity (pH) was measured in a suspension prepared by mixing soil and distilled water in a 1:2.5 ratio, using a calibrated electronic pH meter. Organic carbon content was evaluated through wet oxidation based on the dichromate method. The availability of nitrogen was assessed using an alkaline permanganate distillation approach, whereas plant-available phosphorus was extracted and quantified using the Bray and Kurtz procedure. Exchangeable potassium was estimated after extraction and subsequent measurement with a flame photometric system.

The soil's capacity to retain and exchange nutrient cations was determined through the ammonium acetate saturation technique for cation exchange capacity (CEC). Textural classification, reflecting the relative proportions of sand, silt, and clay, was established using the hydrometer method.

To ensure analytical precision and reproducibility, each parameter was measured in triplicate at the Soil Testing Laboratory of Rajendra Agricultural University.

### 1.3 BPH Population Monitoring

The population of brown planthopper (BPH), including both nymphs and adults, was recorded at weekly intervals starting from 7 days after transplanting (DAT) until crop maturity at 105 DAT.

Observations were made using the standard hill-count technique. For each plot, twenty rice hills were selected randomly with the help of a quadrat measuring 25 × 25 cm. BPH individuals, comprising both

brachypterous and macropterous forms along with nymphal stages, were carefully counted by gently separating the tillers near the base of the plants. To ensure accuracy of field observations, periodic validation was carried out at three-week intervals using a D-vac suction sampling device. The population data were subsequently expressed as the average number of insects (nymphs + adults) per hill for each observation period. The intensity of infestation was evaluated using the Standard Evaluation System (SES) developed by IRRI (2014), based on a numerical rating scale ranging from 0 to 9. In this scale, a score of 0 indicates the absence of damage, values between 1 and 3 represent mild infestation, 4 to 6 correspond to moderate damage, and scores from 7 to 9 denote severe infestation characterized by hopper burn symptoms.

## 1.4 Statistical Analysis

All experimental observations generated during the study were subjected to appropriate statistical analysis to ensure the reliability and validity of the results. The primary analytical approach involved the use of analysis of variance (ANOVA), which was performed using SPSS statistical software (version 26.0). This method enabled the identification of significant differences among treatments by comparing variability within and between experimental groups. To further distinguish the differences among treatment means, Duncan's Multiple Range Test (DMRT) was applied at a significance level of  $p \leq 0.05$ , allowing for a detailed comparison of individual treatment effects. To better understand the association between soil properties and pest dynamics, correlation analysis was carried out using Pearson's correlation coefficient ( $r$ ). This statistical tool helped quantify the strength and direction of relationships between various soil physico-chemical parameters—such as nitrogen, organic carbon, pH, and moisture—and the population density of brown planthopper (BPH). Such analysis provided valuable insights into how specific soil factors contribute to variations in pest incidence under field conditions. In addition to correlation analysis, regression techniques were employed to develop predictive models describing the relationship between soil variables and BPH population levels. Multiple regression analysis was used to evaluate the combined influence of different soil parameters, while stepwise regression was specifically applied to identify the most significant contributors among them. This approach allowed for the determination of the relative importance of individual soil characteristics in explaining variations observed in pest population dynamics. The statistical outputs were further supported through visual representation to enhance clarity and interpretation. Graphs and charts illustrating key trends and relationships were prepared using Microsoft Excel (2019), providing an accessible means of presenting complex data. In addition, conceptual flow diagrams were developed using CorelDRAW X8 to visually depict the interactions between soil parameters, plant responses, and pest population behaviour.

Overall, the integration of statistical analysis and graphical visualization ensured a comprehensive understanding of the experimental data, facilitating accurate interpretation and supporting the development of scientifically sound conclusions.

## 2. RESULTS

### 2.1 Soil Physico-Chemical Properties of Experimental Plots

The physico-chemical properties of soils across the three experimental plots exhibited notable variation (Table 1). Among the sites, Plot A was characterized by relatively acidic conditions, recording the lowest pH value ( $5.8 \pm 0.21$ ), along with the highest levels of available nitrogen ( $342 \pm 18.4 \text{ kg ha}^{-1}$ ) and organic carbon ( $2.85 \pm 0.14\%$ ). In contrast, Plot C displayed comparatively neutral soil conditions with the highest pH ( $7.1 \pm 0.15$ ), while also having the lowest concentrations of available nitrogen ( $198 \pm 10.2 \text{ kg ha}^{-1}$ ) and organic carbon ( $1.43 \pm 0.09\%$ ). An inverse relationship was observed between nitrogen and potassium availability across the plots. Potassium levels were lowest in Plot A ( $118 \pm 8.2 \text{ kg ha}^{-1}$ ), where nitrogen content was highest, whereas Plot C exhibited the highest potassium concentration ( $171 \pm 11.3 \text{ kg ha}^{-1}$ ) along with lower nitrogen levels. Additionally, cation exchange capacity (CEC) was found to be greatest in Plot A ( $22.4 \text{ cmol kg}^{-1}$ ), which can be attributed to its relatively higher clay fraction and organic matter content.

**Table 1: Soil Physico-Chemical Properties of Paddy Fields with Differential BPH Infestation Levels, Kafan, Muzaffarpur, Bihar (Mean  $\pm$  SE, n = 6, pooled across 2022–2023)**

Soil Parameter	t A (High BPH)	Plot B (Moderate BPH)	t C (Low BPH)	Critical Threshold
Soil pH	$5.8 \pm 0.21$	$6.4 \pm 0.18$	$7.1 \pm 0.15$	6.5–7.5
Organic Carbon (%)	$2.85 \pm 0.14$	$2.12 \pm 0.11$	$1.43 \pm 0.09$	< 0.75 (low)
Available N (kg/ha)	$342 \pm 18.4$	$287 \pm 14.6$	$198 \pm 10.2$	> 280 (high)
Available P (kg/ha)	$24.6 \pm 1.8$	$19.4 \pm 1.4$	$14.2 \pm 0.9$	< 11 (low)
Available K (kg/ha)	$118 \pm 8.2$	$142 \pm 9.1$	$171 \pm 11.3$	< 108 (low)
Soil Moisture (%)	$48.2 \pm 3.1$	$38.6 \pm 2.8$	$29.4 \pm 2.2$	25–40 (opt.)
CEC (cmol/kg)	$22.4 \pm 1.6$	$18.9 \pm 1.3$	$14.7 \pm 1.1$	> 20 (high)
Sand : Clay ratio	40:48	45:38	52:30	Clay > 35% (rice)

*Note: Values are mean  $\pm$  standard error. DAT = Days after transplanting. Means within rows with different superscripts differ significantly (DMRT,  $p \leq 0.05$ ).*

## 2.2 Seasonal Population Dynamics of BPH

The population dynamics of brown planthopper (BPH) across the three experimental plots exhibited a well-defined seasonal trend. In all plots, pest numbers gradually increased from the initial stages following transplanting, reached a maximum during the heading phase, and subsequently declined as the crop approached maturity (Table 2). Among the treatments, Plot A consistently supported the highest BPH population throughout the cropping period, with a peak density of  $46.8 \pm 4.2$  individuals per hill recorded during the heading stage (Week 9). In comparison, Plot B showed moderate infestation levels, attaining a maximum population of  $24.6 \pm 3.1$  individuals per hill. Plot C, on the other hand, maintained relatively low pest pressure, with peak values limited to  $11.4 \pm 1.8$  individuals per hill. The progression of damage symptoms also varied among plots. In Plot A, hopper burn symptoms became evident from the panicle initiation stage and intensified significantly during the heading to grain-filling period. Plot B exhibited only partial signs of hopper burn, whereas no such symptoms were observed in Plot C throughout the cropping cycle. Statistical evaluation confirmed that the differences in seasonal mean BPH population among the plots were highly significant ( $F = 184.6$ ;  $df = 2, 39$ ;  $p < 0.001$ ). The highest average population was recorded in Plot A ( $21.5 \pm 2.0$  individuals per hill), followed by Plot B ( $12.0 \pm 1.6$  individuals per hill), while Plot C registered the lowest mean density ( $5.8 \pm 0.9$  individuals per hill). A similar pattern was observed in infestation severity ratings based on the IRRI Standard Evaluation System (SES). At the heading stage, Plot A showed severe infestation (score 8.2), Plot B exhibited moderate damage (score 5.6), and Plot C reflected only slight infestation (score 2.8).

**Table 2: Weekly BPH (*Nilaparvata lugens*) Population Dynamics (Nymphs + Adults / Hill) at Different Crop Growth Stages, Kafan, Muzaffarpur, Bihar (Pooled Mean  $\pm$  SE, 2022–2023)**

Week	Stage / Week	Plot A (High N)	Plot B (Mod. N)	Plot C (Low N)	Infestation Level	Hopper Burn?	Correlation (r)
	Transplanting (W1)	$1.2 \pm 0.3$	$0.9 \pm 0.2$	$0.6 \pm 0.1$	Trace	No	0.62
	Tillering (W3)	$4.8 \pm 0.7$	$3.2 \pm 0.5$	$1.9 \pm 0.4$	Low	No	0.74
	Max. Tillering (W5)	$12.6 \pm 1.4$	$8.4 \pm 1.1$	$4.2 \pm 0.8$	Moderate	No	0.81
	Panicle Init. (W7)	$28.4 \pm 2.8$	$16.2 \pm 2.1$	$7.6 \pm 1.2$	High	Partial	0.88
	Heading (W9)	$46.8 \pm 4.2$	$24.6 \pm 3.1$	$11.4 \pm 1.8$	Very High	Yes	0.91
	Grain Filling (W11)	$38.2 \pm 3.8$	$19.8 \pm 2.6$	$9.2 \pm 1.4$	High	Yes	0.89
	Maturity (W13)	$18.6 \pm 2.1$	$11.2 \pm 1.7$	$5.8 \pm 0.9$	Moderate	Residual	0.79
	Seasonal Mean (nymphs+adults/hill)	$21.5 \pm 2.0$	$12.0 \pm 1.6$	$5.8 \pm 0.9$	—	—	0.86**

Note: \*\* = Correlation significant at  $p < 0.01$ . W = Week after transplanting. Values are pooled mean  $\pm$  SE across both seasons.

### 2.3 Correlation Between Soil Parameters and BPH Population

Correlation patterns derived from Pearson's correlation coefficient revealed strong and statistically robust associations between brown planthopper (BPH) population density and multiple soil attributes (Table 3). Among these, available nitrogen exhibited the strongest positive relationship ( $r = 0.91$ ,  $p < 0.01$ ), followed by soil organic carbon ( $r = 0.86$ ,  $p < 0.01$ ) and soil moisture status ( $r = 0.82$ ,  $p < 0.01$ ). Moderate yet significant positive correlations were also observed with cation exchange capacity (CEC) ( $r = 0.74$ ,  $p < 0.01$ ) and available phosphorus ( $r = 0.63$ ,  $p < 0.01$ ), indicating that nutrient-enriched and moisture-retentive soils tend to favor BPH proliferation.

Conversely, soil reaction (pH) demonstrated a pronounced negative association with pest incidence ( $r = -0.78$ ,  $p < 0.01$ ), suggesting that relatively alkaline conditions may act as a limiting factor for BPH population buildup. Available potassium similarly exhibited a significant inverse relationship ( $r = -0.52$ ,  $p < 0.05$ ), implying a potential suppressive influence of potassium-rich soils on pest dynamics. This inhibitory effect may be linked to enhanced plant structural integrity, possibly mediated through increased silica deposition in cell walls, thereby reducing feeding efficiency and pest establishment.

Subsequent modeling using stepwise multiple linear regression identified available nitrogen, soil pH, and organic carbon as key predictors collectively explaining a substantial proportion of the variation in BPH population density ( $R^2 = 0.894$ ,  $F = 62.4$ ,  $p < 0.001$ ). The resulting regression equation is as follows:

$$\text{BPH (nymphs + adults per hill)} = -14.62 + 0.081 (\text{Available N}) - 3.24 (\text{pH}) + 4.18 (\text{Organic C})$$

highlights the dominant and interactive influence of these key soil parameters in determining pest population dynamics.

**Table 3: Pearson's Correlation Coefficient (r) Between Soil Physico-Chemical Parameters and BPH Population Density, Kafan, Muzaffarpur, Bihar (n = 18, pooled 2022–2023)**

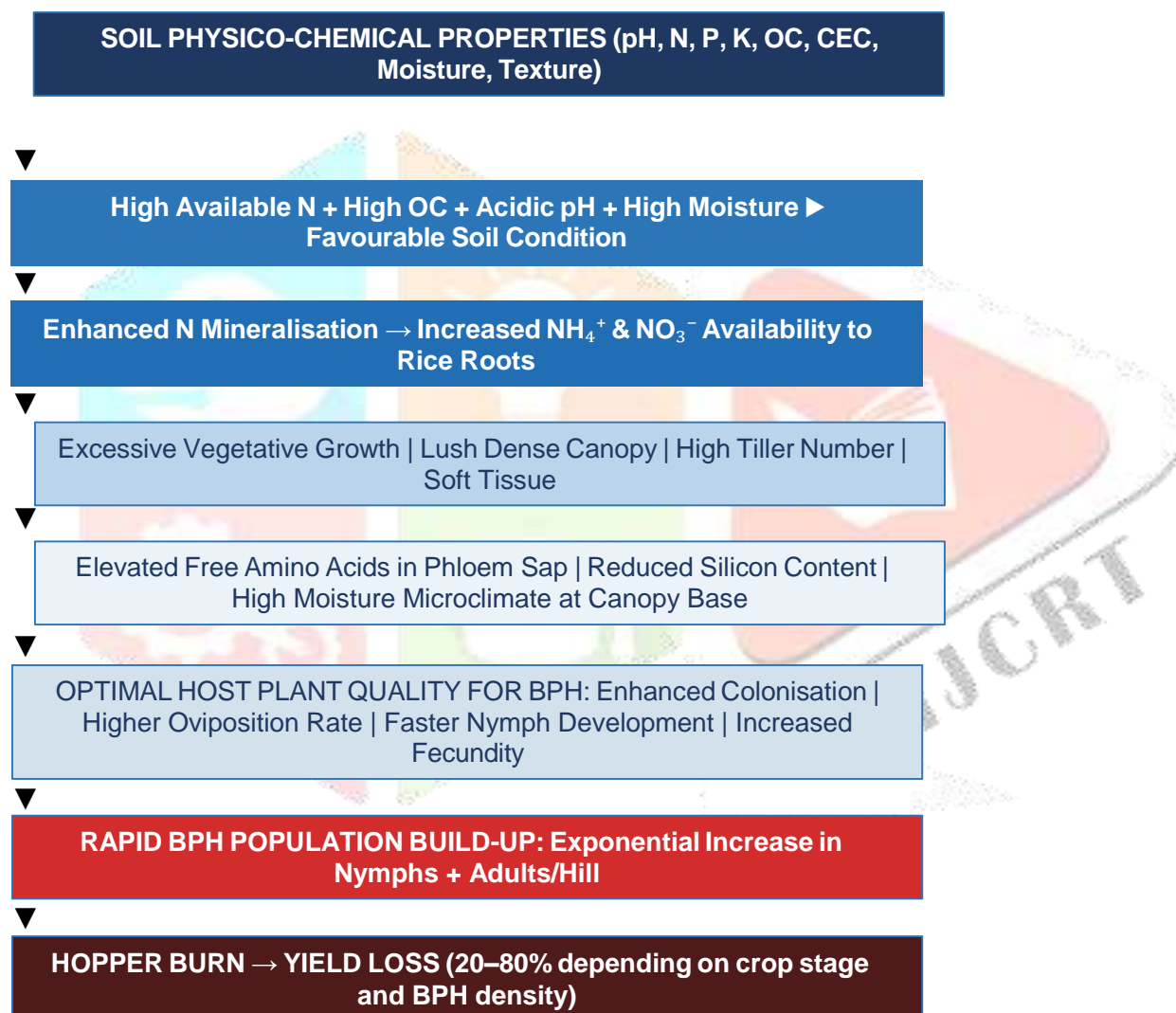
Soil Parameter	BPH Pop. (r)	Pestation Index	Available N (r)	Soil pH (r)	Organic C (r)	Sig.
Available N (kg/ha)	0.91**	0.88**	1.00	-0.64*	0.79**	p<0.01
Organic Carbon (%)	0.86**	0.82**	0.79**	-0.71**	1.00	p<0.01
Soil pH	-0.78**	-0.74**	-0.64*	1.00	-0.71**	p<0.01
Moisture (%)	0.82**	0.79**	0.68**	-0.58*	0.73**	p<0.01
CEC (cmol/kg)	0.74**	0.70**	0.81**	-0.62*	0.68**	p<0.01
Available K (kg/ha)	-0.52*	-0.48*	-0.56*	0.44*	-0.49*	p<0.05
Available P (kg/ha)	0.63**	0.61**	0.72**	-0.51*	0.61**	p<0.01

Note: \* Significant at  $p < 0.05$ ; \*\* Significant at  $p < 0.01$ . Values indicate Pearson's  $r$ . Infestation index based on IRRISSES scale (0–9).

## 2.4 Conceptual Framework: Soil-Mediated BPH Epidemiology (Flow Diagram 1)

The following flow diagram illustrates the conceptual pathway through which soil physico-chemical variability mediates BPH population build-up in paddy ecosystems, integrating findings from the present study with published literature.

### Flow Diagram 1: Conceptual Pathway of Soil Physico-Chemical Variables Mediating BPH (*Nilaparvata lugens*) Incidence in Rice Ecosystems



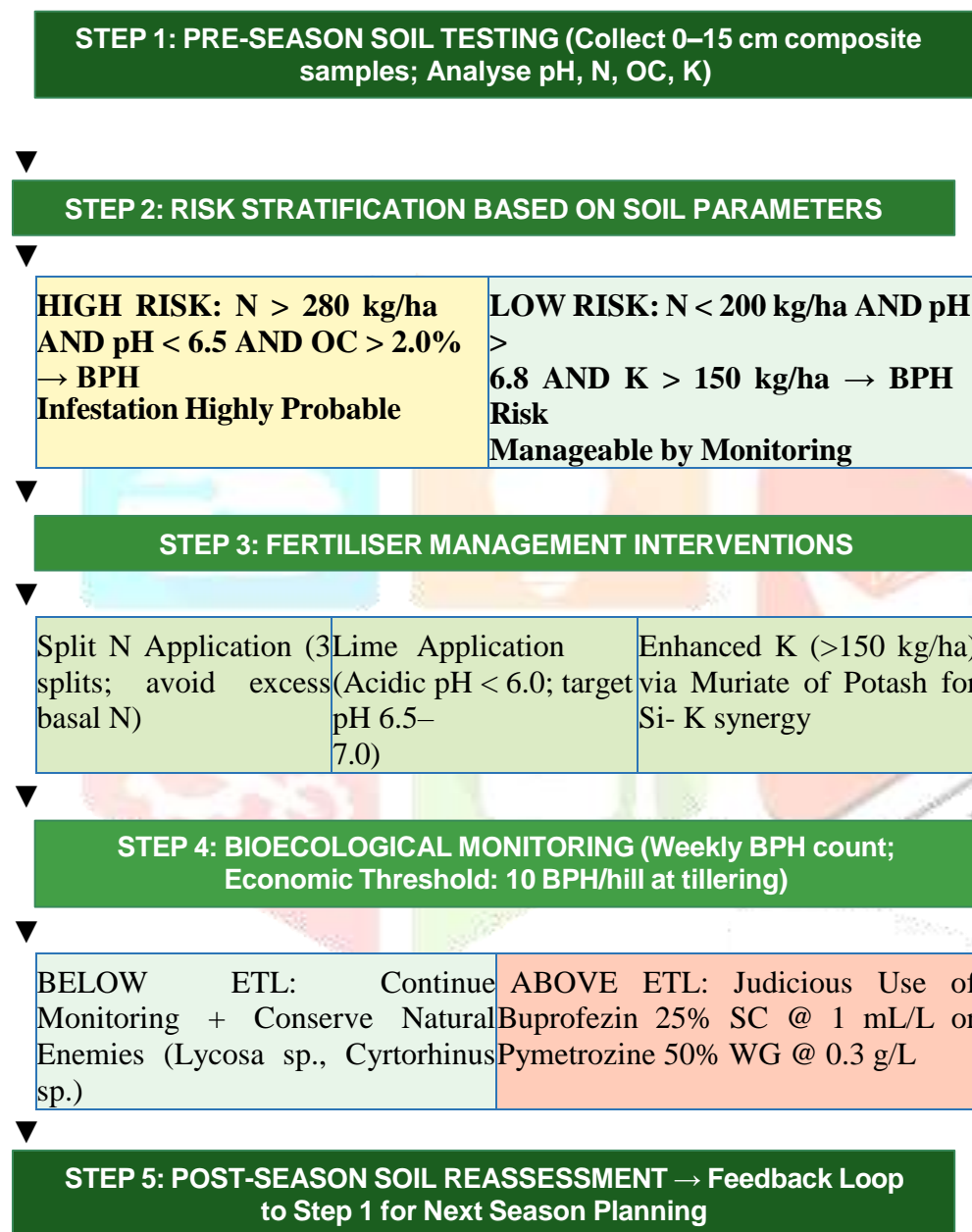
Flow Diagram 1 illustrates the soil-mediated cascade from nutrient-rich, acidic, and moisture-retentive soils through enhanced host plant quality to exponential BPH population build-up and ultimately hopper burn. The diagram integrates primary findings of this study with mechanistic evidence from Xiao et al. (2020), Liu et al. (2022), and Tanaka et al. (2017).

### Management Decision Framework Based on Soil Parameters (Flow Diagram 2)

Based on the relationships identified between soil properties and brown planthopper (BPH) incidence, a practical decision-making framework has been developed to guide nutrient-based pest management

strategies. This framework translates the scientific findings into an applied approach that links soil nutrient status with appropriate management interventions. The proposed flow diagram is designed to support extension personnel and farmers in making informed, evidence-based decisions for effective BPH management under the agro-ecological conditions of north Bihar. By integrating soil analysis with pest monitoring, it provides a structured pathway for implementing timely and site-specific control measures.

### Flow Diagram 2: Decision Framework for BPH (*Nilaparvata lugens*) Management Based on Soil Physico- Chemical Assessment in Paddy Fields of Muzaffarpur, Bihar



### 3. DISCUSSION

The findings of the present study clearly demonstrate that variations in soil physico-chemical properties, particularly available nitrogen, organic carbon, and soil pH, play a decisive role in influencing the incidence and population dynamics of brown planthopper (BPH) in the rice fields of Kafan, Muzaffarpur. These observations are in agreement with recent global studies that emphasize the importance of soil nutrient status in regulating planthopper outbreaks in rice-based ecosystems. The strong positive relationship observed between available soil nitrogen and BPH population density ( $r = 0.91$ ,  $p < 0.01$ ) supports the widely accepted nitrogen–herbivore interaction concept. In Plot A, elevated nitrogen availability resulted in vigorous vegetative growth of the Swarna variety, which likely enhanced the

concentration of free amino acids such as asparagine, glutamine, and proline in the phloem sap. These compounds serve as essential nutritional resources for BPH, thereby promoting its growth and reproductive potential. Similar findings have been reported in controlled studies, where increased nitrogen supply led to higher amino acid concentrations and significantly larger pest populations, thereby reinforcing the results obtained under field conditions in the present study. The inverse relationship between soil pH and BPH abundance ( $r = -0.78$ ,  $p < 0.01$ ) can be attributed to the influence of pH on nutrient transformations and availability. In relatively acidic soils, such as those observed in Plot A, nitrogen tends to accumulate in ammoniacal forms under waterlogged conditions, which are readily absorbed by rice plants. This results in increased nitrogen content within plant tissues, indirectly favouring pest development. Additionally, acidic conditions may limit the availability of silicon, an important element contributing to structural defence in rice plants. Reduced silicon levels weaken plant resistance, thereby facilitating easier feeding and oviposition by BPH. The negative association between available potassium and pest population ( $r = -0.52$ ,  $p < 0.05$ ) further highlights the importance of balanced nutrition. Potassium is known to enhance plant structural integrity and may contribute to improved resistance against insect feeding, possibly through its interaction with silicon in strengthening cell walls. This combined effect can reduce the suitability of the host plant for BPH colonization. A significant positive correlation between soil organic carbon and BPH population ( $r = 0.86$ ,  $p < 0.01$ ) was also observed. Higher organic carbon levels generally support increased microbial activity and nutrient mineralisation, leading to enhanced nitrogen availability and improved plant growth. While such conditions may initially favour pest development, it is also important to consider that long-term organic management systems can enhance biological control through increased diversity of natural enemies, an aspect that may not be fully reflected within the duration of the present study. The observed peak in BPH population during the heading stage across all plots is consistent with established patterns reported in earlier studies. This growth stage represents a period of maximum plant biomass and active nutrient flow, providing an ideal environment for pest multiplication. The marked difference in peak population between Plot A (46.8 individuals per hill) and Plot C (11.4 individuals per hill), despite cultivation of the same susceptible variety, clearly demonstrates the influence of soil-mediated plant quality on pest outbreak intensity. The regression analysis, which showed that available nitrogen, soil pH, and organic carbon together accounted for nearly 90% of the variation in BPH population ( $R^2 = 0.894$ ), offers a practical tool for predicting pest risk based on soil parameters. Compared to earlier models that incorporate climatic variables, this soil-focused approach is relatively simple and more applicable under field conditions where access to weather data may be limited. From a management perspective, the results underline the importance of maintaining balanced soil fertility. Avoiding excessive nitrogen application through split dosing, correcting soil acidity through liming, and ensuring adequate potassium supply emerge as key strategies for reducing BPH incidence. These practices align with the broader principle that maintaining soil health is fundamental to improving plant resistance and minimizing pest outbreaks, thereby supporting sustainable rice production systems.

#### 4. CONCLUSION

The present investigation elucidates that spatiotemporal variability in soil physico-chemical attributes, notably available nitrogen, soil organic carbon, and soil reaction (pH), exerts a governing influence on the population ecology and infestation dynamics of brown planthopper (BPH) within rice agroecosystems of Kafen village. Among the evaluated variables, available nitrogen emerged as the most influential driver of pest proliferation ( $r = 0.91$ ), followed by organic carbon ( $r = 0.86$ ) and soil moisture ( $r = 0.82$ ). In contrast, soil pH demonstrated a pronounced negative association ( $r = -0.78$ ), indicating a potential regulatory effect of relatively alkaline conditions on pest abundance. The multivariate statistical model developed through stepwise multiple linear regression accounted for a substantial proportion of variance in BPH population density ( $R^2 = 0.894$ ), underscoring its robustness and predictive capability for early-season pest risk forecasting and site-specific management decisions. These findings substantiate the integration of soil health diagnostics into Integrated Pest Management (IPM) frameworks for sustainable suppression of BPH in north Bihar. Strategic emphasis should be placed on soil-mediated interventions, including optimized and split nitrogen fertilization regimes, amelioration of soil acidity through liming, and maintenance of adequate potassium status. Such approaches are expected to enhance host plant resilience, thereby curbing

pest outbreaks while minimizing reliance on chemical control measures.

For broader applicability, future investigations should prioritize multi-location validation across diverse agro-ecological gradients within Bihar. Furthermore, elucidation of soil microbiome-mediated plant–insect interactions may provide mechanistic insights into induced resistance and ecological pest regulation. The incorporation of advanced geospatial technologies, including GIS-enabled decision support systems and high-resolution digital soil health mapping, holds considerable promise for refining precision-based advisory services and strengthening climate-resilient pest management strategies.

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## REFERENCES

1. Babu, T. R., Reddy, G. V. P., & Rao, N. H. P. (2021). Influence of soil nitrogen levels on brown planthopper incidence and yield losses in coastal Andhra Pradesh rice ecosystem. *Journal of Entomological Research*, 45(2), 214–221. <https://doi.org/10.5958/0974-4517.2021.00031.6>
2. Bentur, J. S., Viraktamath, C. A., & Pasalu, I. C. (2016). Brown planthopper: Challenges and management strategies in Indian rice. In B. P. Singh & R. K. Malik (Eds.), *Advances in Insect Pest Management of Rice* (pp. 112–143). New India Publishing Agency, New Delhi.
3. Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., & Clark, F. E. (1965). *Methods of Soil Analysis, Part 1: Physical and Mineralogical Properties*. American Society of Agronomy, Madison, Wisconsin.
4. Bottrell, D. G., & Schoenly, K. G. (2012). Resurrecting the ghost of green revolutions past: The brown planthopper as a recurring threat to high-yielding rice production in tropical Asia. *Journal of Asia-Pacific Entomology*, 15(1), 122–140. <https://doi.org/10.1016/j.aspen.2011.09.004>
5. Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*, 54(5), 464–465. <https://doi.org/10.2134/agronj1962.00021962005400050028x>
6. Bray, R. H., & Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science*, 59(1), 39–45.
7. FAOSTAT. (2023). Rice area harvested and production data, India 2022. Food and Agriculture Organization of the United Nations. Retrieved from <https://www.fao.org/faostat/en/#data/QCL>
8. Guntzer, F., Keller, C., & Meunier, J. D. (2012). Benefits of plant silicon for crops: A review. *Agronomy for Sustainable Development*, 32(1), 201–213. <https://doi.org/10.1007/s13593-011-0039-8>
9. Heong, K. L., Hardy, B., & IRRI. (2013). *Planthoppers: New Threats to the Sustainability of Intensive Rice Production Systems in Asia*. International Rice Research Institute (IRRI), Los Baños, Philippines. 490 pp.
10. IRRI (International Rice Research Institute). (2014). *Standard Evaluation System (SES) for Rice* (5th ed.). IRRI, Los Baños, Philippines.

11. Jackson, M. L. (1973). *Soil Chemical Analysis*. Prentice-Hall of India, New Delhi.
12. Jena, M., Mohapatra, S., & Sahoo, M. R. (2018). Soil physico-chemical parameters influencing brown planthopper population in rice ecosystems of Odisha. *Oryza*, 55(3), 312–319.
13. Krishnaiah, N. V., Lakshmi, V. J., & Pasalu, I. C. (2020). Soil organic carbon and brown planthopper dynamics in organic rice: Field observations from Andhra Pradesh. *Indian Journal of Plant Protection*, 48(1), 61–67.
14. Liu, Y., Chen, J., Zhu, Z., Zhang, Y., & Cheng, J. (2022). Nitrogen fertilisation enhances brown planthopper fitness through altered rice plant quality: Insights from phloem metabolomics. *Pest Management Science*, 78(4), 1452–1463. <https://doi.org/10.1002/ps.6764>
15. Singh, R. N., Yadav, M. K., & Pandey, A. K. (2019). Population dynamics of brown planthopper in relation to weather parameters and soil nitrogen in Kharif rice of eastern Uttar Pradesh. *Journal of Applied and Natural Science*, 11(4), 834–840. <https://doi.org/10.31018/jans.v11i4.2160>
16. Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25(8), 259–260.
17. Tanaka, K., Namba, S., Toyoda, H., & Akagi, H. (2017). Silicon-mediated resistance mechanisms of rice to brown planthopper: A review of field and controlled environment studies. *Silicon*, 9(4), 539–547. <https://doi.org/10.1007/s12633-016-9448-9>
18. Xiao, H., Liu, Y., Zhang, Q., & Cheng, J. (2020). Effect of elevated soil nitrogen on host plant quality and performance of brown planthopper (*Nilaparvata lugens*): Roles of free amino acids and phloem characteristics. *Arthropod-Plant Interactions*, 14(2), 231–243. <https://doi.org/10.1007/s11829-020-09748-5>

