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## Preface

We would like to present, with great pleasure, the inaugural volume-10, Issue-11, November 2024, of a scholarly journal, *International Journal of Environmental & Agriculture Research*. This journal is part of the AD Publications series *in the field of Environmental & Agriculture Research Development*, and is devoted to the gamut of Environmental & Agriculture issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Environmental & Agriculture as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Environmental & Agriculture community, addressing researchers and practitioners in below areas.

### **Environmental Research:**

*Environmental science and regulation, Ecotoxicology, Environmental health issues, Atmosphere and climate, Terrestrial ecosystems, Aquatic ecosystems, Energy and environment, Marine research, Biodiversity, Pharmaceuticals in the environment, Genetically modified organisms, Biotechnology, Risk assessment, Environment society, Agricultural engineering, Animal science, Agronomy, including plant science, theoretical production ecology, horticulture, plant, breeding, plant fertilization, soil science and all field related to Environmental Research.*

### **Agriculture Research:**

*Agriculture, Biological engineering, including genetic engineering, microbiology, Environmental impacts of agriculture, forestry, Food science, Husbandry, Irrigation and water management, Land use, Waste management and all fields related to Agriculture.*

Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with *IJOEAR*. We are certain that this issue will be followed by many others, reporting new developments in the Environment and Agriculture Research Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOEAR* readers and will stimulate further research into the vibrant area of Environmental & Agriculture Research.



Mukesh Arora  
(Managing Editor)



Dr. Bhagawan Bharali  
(Chief Editor)

## Fields of Interests

| Agricultural Sciences                                                                                                                                                                          |                                                                                 |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Soil Science                                                                                                                                                                                   | Plant Science                                                                   |
| Animal Science                                                                                                                                                                                 | Agricultural Economics                                                          |
| Agricultural Chemistry                                                                                                                                                                         | Basic biology concepts                                                          |
| Sustainable Natural Resource Utilisation                                                                                                                                                       | Management of the Environment                                                   |
| Agricultural Management Practices                                                                                                                                                              | Agricultural Technology                                                         |
| Natural Resources                                                                                                                                                                              | Basic Horticulture                                                              |
| Food System                                                                                                                                                                                    | Irrigation and water management                                                 |
| Crop Production                                                                                                                                                                                |                                                                                 |
| Cereals or Basic Grains: Oats, Wheat, Barley, Rye, Triticale, Corn, Sorghum, Millet, Quinoa and Amaranth                                                                                       | Oilseeds: Canola, Rapeseed, Flax, Sunflowers, Corn and Hempseed                 |
| Pulse Crops: Peas (all types), field beans, faba beans, lentils, soybeans, peanuts and chickpeas.                                                                                              | Hay and Silage (Forage crop) Production                                         |
| Vegetable crops or Olericulture: Crops utilized fresh or whole (wholefood crop, no or limited processing, i.e., fresh cut salad); (Lettuce, Cabbage, Carrots, Potatoes, Tomatoes, Herbs, etc.) | Tree Fruit crops: apples, oranges, stone fruit (i.e., peaches, plums, cherries) |
| Tree Nut crops: Hazlenuts. walnuts, almonds, cashews, pecans                                                                                                                                   | Berry crops: strawberries, blueberries, raspberries                             |
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|----------------------------------------|------------------------------------|
| Crop Protection Chemicals              | Feed supplements                   |
| Chemical based (inorganic) fertilizers | Organic fertilizers                |
| Environmental Science                  |                                    |
| Environmental science and regulation   | Ecotoxicology                      |
| Environmental health issues            | Atmosphere and climate             |
| Terrestrial ecosystems                 | Aquatic ecosystems                 |
| Energy and environment                 | Marine research                    |
| Biodiversity                           | Pharmaceuticals in the environment |
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# Bridging Knowledge Gaps in Phosphorus Fertilization: Insights into Rice Farmers' Practices and Environmental Sustainability

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**Abstract**— Phosphorus plays a crucial role in agricultural productivity, yet its mismanagement, particularly excessive application, poses significant environmental risks, including water quality degradation and eutrophication. This study aimed to assess rice farmers' knowledge, perceptions, and practices regarding phosphorus fertilization. A structured questionnaire was administered to 210 rice farmers across 18 villages within three states (Anambra, Ebonyi, and Enugu) following a multistage sampling procedure. The survey data were analyzed using IBM-SPSS statistical software. Farmers demonstrate a good understanding of phosphorus's essential role in plant growth, maturity, and resilience, as well as the major symptoms of phosphorus deficiency, such as stunting and reduced tillering. The farmers' fertilizer purchasing behaviour was mostly influenced by price, nutrient content, safety, subsidies, and social influence. The import status of fertilizer is less important in the purchasing decision. Though the results revealed a high level of awareness among farmers regarding the environmental impacts of excessive phosphorus application, gaps were identified, particularly regarding the effects of phosphorus runoff on water bodies, where 22.9% of the farmers were unaware of its detrimental impact on water quality. The study concludes that while rice farmers in Southeastern Nigeria have a significant understanding of the environmental effects of phosphorus use, targeted education and outreach programs are necessary to bridge knowledge gaps and promote sustainable fertilization practices. The study recommends the development of training programs and the promotion of climate-resilient phosphorus management strategies to mitigate environmental risks and enhance sustainable agricultural production in the region/

**Keywords**— *Innovation Diffusion, Rice Farming, Small-Scale Farmers, Soil Nutrient Management, Sustainable Agriculture.*

## I. INTRODUCTION

Phosphorus (P) is one of the most essential nutrients for plant growth and development, second only to nitrogen in its importance for crop productivity. In global agriculture, phosphorus plays a vital role, with its low availability significantly influencing crop yields. Specifically, in rice farming, phosphorus enhances root development, accelerates plant maturity, and boosts grain yield, making it indispensable for sustainable agricultural systems [1,2]. Although phosphorus is abundant in soil, only a small portion is readily accessible for plant uptake, necessitating the addition of phosphorus fertilizers to sustain optimal growth. The derived Guinea Savannah in Nigeria, characterized by severely weathered tropical soils, faces an elevated risk of phosphorus deficiency [3].

*This research was sponsored by TETFund (TETF/DR&D/CE/UNI/NSUKKA/BR/2024/VOL.I)*

In Nigeria, where rice is a staple food crucial to national food security, small-scale farmers, responsible for approximately 80% of rice production [4], face significant challenges in maintaining adequate soil nutrient levels, particularly phosphorus. Low phosphorus availability, coupled with underuse of fertilizers, has been identified as a leading cause of poor agricultural output in the country [5]. Across sub-Saharan Africa, rice farmers encounter phosphorus deficiency due to low fertilizer use, which not only hampers crop yields but also affects long-term soil health and agricultural sustainability [6]. Furthermore, inefficient phosphorus management exacerbates environmental risks, as excessive runoff contributes to eutrophication in water bodies, leading to ecological degradation [7]. As Nigeria struggles to meet domestic rice demand despite being one of Africa's largest producers, the judicious use of phosphorus, a non-replaceable and finite resource, is critical for improving yields and minimizing environmental impacts [2,8].

This study aims to address these challenges by assessing rice farmers' knowledge, perception, and use of phosphorus fertilization in the derived Guinea Savannah agro-ecological zone. Specifically, the study seeks to: (i) identify and characterize the socioeconomic features of rice farmers, (ii) assess their fertilizer-use patterns and purchasing behavior, and (iii) evaluate their knowledge of phosphorus application in rice farming. Understanding these factors is vital for promoting more effective and sustainable nutrient management practices. Although soils may contain phosphorus pools significantly higher than what is required for plant growth, only a small soluble fraction is available for uptake, further complicating nutrient management [9]. This research will contribute to broader efforts aimed at enhancing agricultural productivity, ensuring food security, and protecting the environmental integrity of farming systems through balanced fertilizer application [8].

## **II. METHODOLOGY**

### **2.1 Description of Study Areas:**

The research was undertaken in 18 villages across six local government areas (LGAs) in three states out of the five southeastern states in Nigeria. These areas are typified by the derived Savannah agro-ecological zone, known for its agricultural activities, especially rice farming. The study focuses on Anambra, Ebonyi, and Enugu states, which together contribute significantly to rice production in the region [10]. The respondents were evenly distributed across the three key states, with each contributing 33.3% to the total sample. This balance ensures a representative view across these regions. At the local level, the sample was similarly spread across six LGAs: Abakaliki LGA and Ikwo LGA in Ebonyi State, Awka South LGA and Ayamelum LGA in Anambra State, and Aninri LGA and Uzo-Uwani LGA in Enugu State.

### **2.2 Sampling Procedure:**

A two-stage sampling method was employed for this study. The first step involved selecting the major rice-producing areas within the derived Savannah zone, guided by existing literature [10,11]. Anambra, Ebonyi, and Enugu states were purposively selected due to their high involvement in rice farming. The second stage involved random selection of 210 rice farmers across these three states, with an average of 35 farmers chosen from each LGA. Farmers were included if they had cultivated rice in the previous growing season.

### **2.3 Questionnaire Design and Data Collection:**

Semi-structured questionnaires were designed and pre-tested to gather relevant data from the farmers. The instrument was validated by experts in agricultural extension and agricultural economics at the University of Nigeria, Nsukka. Suggestions were made to refine the wording and sequence of questions to ensure clarity and reliability. A pilot test was conducted, and the

reliability of the instrument was confirmed, yielding a Cronbach's alpha value of 0.88, which is above the acceptable threshold of 0.7 [12].

The questionnaire covered various aspects such as socio-economic characteristics, land ownership, farming experience, fertilizer-use patterns, and knowledge of phosphorus application. Data were collected from March 2024 to May 2024 through in-person interviews conducted in the local Igbo language, using trained enumerators familiar with the region's dialect and customs. In line with ethical procedures laid down by the University of Nigeria, oral informed consent was obtained from all participating farmers prior to data collection. Farmers were briefed about the study objectives, assured of the voluntary nature of their participation, and informed that they could withdraw at any time if they felt uncomfortable. To ensure confidentiality, all personal identifiers were removed before the data analysis stage.

## **2.4 Data Analysis:**

Data collected through the questionnaires were entered into a spreadsheet and analyzed using IBM SPSS version 26. Descriptive statistics, including frequencies and percentages were employed to summarize the data, particularly for farmers' knowledge of phosphorus application and fertilization patterns. The result is presented as graphs and tables.

# **III. RESULT AND DISCUSSION**

## **3.1 Demographic information:**

The data reveals significant demographic patterns. The majority of respondents are male (67.1%), which aligns with the traditional gender roles in farming in many regions (Table 1). The predominant age group is between 41 and 50 years, suggesting that rice farming in these areas is largely managed by middle-aged individuals. Younger participants are notably fewer, with minimal representation from those aged 21 to 30 years. This might point to a generational shift where younger people are not as actively engaged in rice farming, possibly due to migration to urban centers or the pursuit of other career paths. The participants' marital status also provides insight into their social structure, with 73.3% of respondents being married. A smaller proportion are single (14.8%), while divorced (6.2%) and widowed (5.7%) individuals make up the remainder. This demographic distribution could influence household decision-making processes in farming. Notably, 72.9% of the respondents are household heads, indicating that most of these farmers are key decision-makers in their families, which may affect their farming practices and land use strategies.

Education plays a critical role in the effectiveness of agricultural practices, and the data shows that while 75.2% of respondents can read and write; a significant portion (24.8%) cannot. This lack of literacy could be a barrier to the adoption of modern farming techniques that require the understanding of written instructions or technological tools [13]. Most respondents have attained the West African Senior School Certificate (45.7%) or the First School Leaving Certificate (31.4%), with only a few having undergraduate (13.3%) or postgraduate degrees (3.3%). This educational landscape suggests that while there is a foundation of basic education, the overall low level of formal qualifications may limit access to advanced agricultural knowledge and innovations. The occupational background of the respondents is largely agricultural, with 74.8% identifying as farmers. A smaller segment engages in private business or government employment, which might supplement their agricultural income. Interestingly, 7.1% of the sample are students, reflecting some engagement of younger individuals in farming alongside their education. The farming experience of the respondents is significant, with 50% having between 6 to 10 years of experience, and 32.4% having more than 10 years. This wealth of experience suggests a deep understanding of local farming conditions, although it also highlights a potential resistance to adopting new technologies due to established practices.

**TABLE 1**  
**DEMOGRAPHIC INFORMATION OF RICE FARMERS**

|                                           |                       | Frequency | Percent | Cumulative |
|-------------------------------------------|-----------------------|-----------|---------|------------|
| Sex                                       | Female                | 69        | 32.9    | 32.9       |
|                                           | Male                  | 141       | 67.1    | 100        |
| Age Group                                 | 21 – 30 years         | 2         | 1       | 1          |
|                                           | 31 – 40 years         | 7         | 3.3     | 4.3        |
|                                           | 41 – 50 years         | 199       | 94.8    | 99         |
|                                           | 51 – 60 years         | 2         | 1       | 100        |
| Marital status                            | Divorced              | 13        | 6.2     | 6.2        |
|                                           | Married               | 154       | 73.3    | 79.5       |
|                                           | Single                | 31        | 14.8    | 94.3       |
|                                           | Widowed               | 12        | 5.7     | 100        |
| Household head                            | No                    | 57        | 27.1    | 27.1       |
|                                           | Yes                   | 153       | 72.9    | 100        |
| Nationality                               | Nigeria               | 210       | 100     | 100        |
| Ethnicity                                 | Hausa                 | 2         | 1       | 1          |
|                                           | Igbo                  | 207       | 98.6    | 99.5       |
|                                           | Yoruba                | 1         | 0.5     | 100        |
| Can you read and write?                   | No                    | 52        | 24.8    | 24.8       |
|                                           | Yes                   | 158       | 75.2    | 100        |
| Highest educational qualification         | First School Leaving  | 66        | 31.4    | 31.4       |
|                                           | Other qualifications  | 13        | 6.2     | 37.6       |
|                                           | Postgraduate degree   | 7         | 3.3     | 41         |
|                                           | Undergraduate degree  | 28        | 13.3    | 54.3       |
|                                           | WAEC or equivalent    | 96        | 45.7    | 100        |
| Are you the owner of the land?            | No                    | 91        | 43.3    | 43.3       |
|                                           | Yes                   | 119       | 56.7    | 100        |
| What is the size of your rice farm?       | 1 to 3 hectares       | 58        | 27.6    | 27.6       |
|                                           | 4 to 6 hectares       | 101       | 48.1    | 75.7       |
|                                           | 7 to 9 hectares       | 35        | 16.7    | 92.4       |
|                                           | Less than 1 hectare   | 5         | 2.4     | 94.8       |
|                                           | More than 10 hectares | 11        | 5.2     | 100        |
| Occupation                                | Farmer                | 157       | 74.8    | 74.8       |
|                                           | Government employee   | 17        | 8.1     | 82.9       |
|                                           | Others                | 1         | 0.5     | 83.3       |
|                                           | Private business      | 20        | 9.5     | 92.9       |
|                                           | Student               | 15        | 7.1     | 100        |
| Rice cultivation period                   | Both early and late   | 76        | 36.2    | 36.2       |
|                                           | Early                 | 129       | 61.4    | 97.6       |
|                                           | Late                  | 5         | 2.4     | 100        |
| Average rice yield per hectare            | Above 4 tons          | 101       | 48.1    | 48.1       |
|                                           | Between 2 and 4 tons  | 93        | 44.3    | 92.4       |
|                                           | Less than 2 tons      | 16        | 7.6     | 100        |
| No of years of experience in rice farming | 2 to 5 years          | 34        | 16.2    | 16.2       |
|                                           | 6 to 10 years         | 105       | 50      | 66.2       |
|                                           | Less than 2 years     | 3         | 1.4     | 67.6       |
|                                           | More than 10 years    | 68        | 32.4    | 100        |

Land ownership is another crucial factor in the farming dynamics of this population. The majority of the participants (56.7%) own the land they farm, which provides them with the autonomy to make long-term investments in their land. Those who do not own their land (43.3%) may face limitations in making such investments. Farm sizes are relatively moderate, with most farmers managing between 4 to 6 hectares of land, indicating a substantial scale of rice farming. Smaller farms, below 3 hectares, are less common, and only a small percentage (5.2%) manage more than 10 hectares. This distribution of farm sizes points to a semi-commercial scale of farming, where productivity is a central focus. The rice cultivation practices of the respondents show a preference for early cultivation (61.4%), with a smaller portion (36.2%) practicing both early and late cultivation cycles. According to Okeke and Oluka [11], rice farmers in southeast Nigeria plant rice between May and August. The focus on early cultivation may be influenced by environmental factors such as rainfall patterns or market demands. The yield data shows a positive trend, with 48.1% of farmers producing more than 4 tons per hectare, indicating high productivity levels. Only a small portion (7.6%) reports yields below 2 tons per hectare, which may be due to suboptimal farming practices or environmental challenges.

### 3.2 Farmers' fertilizer-use patterns:

The data on farmers' fertilizer-use patterns presents a detailed view of the types of fertilizers and application methods prevalent among the respondents. The findings indicate that the majority of farmers rely heavily on inorganic fertilizers, with 68.6% of them using this type on their cultivated lands (Table 2). Organic fertilizers, although still in use, are applied by only 31.4% of the respondents. This significant inclination towards inorganic fertilizers suggests that farmers in the region may prioritize quick and more consistent nutrient delivery over the longer-term benefits of organic amendments. Simpson, *et al.* [14] indicate that when P inputs are minimal, the soil experiences a net loss of P, leading to unsustainable production over time. This nutrient depletion establishes a lower limit for sustainable soil fertility management. Even in low-yield farming systems, it is essential to provide P inputs that at least match the amount of P removed in harvested products [14]. A striking 99% of the respondents confirmed the use of chemical fertilizers, demonstrating the widespread adoption of these inputs in rice farming. Compound fertilizers (84.8%) was the dominant fertilizer type used by the respondents. The minimal use of straight fertilizers, reported by just 1%, does not reflect a clear preference for nutrient blends that offer balanced nutrition to the crops but an indication of the non-availability of the straight fertilizers in the region. Interestingly, only 13.3% of the farmers report using both organic and inorganic fertilizers, hinting at limited adoption of integrated nutrient management practices, which could otherwise offer sustainable benefits to both crop yield and soil health.

The timing of phosphorus application is critical for crop development, and the data reflects varied practices among farmers. About half (50%) of the farmers apply phosphorus at the planting stage, which is a common practice for ensuring early nutrient availability. A significant number of farmers (39%) also apply phosphorus during the tiller phase, when rice plants begin to develop their vegetative structure. The relatively lower percentage of farmers (6.2%) who apply phosphorus at the grain-filling stage suggests that fewer farmers recognize the importance of this nutrient at later stages of crop development. Meanwhile, only a small fraction (4.8%) apply phosphorus before planting, which may limit the early uptake of nutrients by seedlings. Nasution, *et al.* [15] reported a significant influence of time of P application on the growth, development and yield of rice. In terms of application methods, broadcasting is by far the most common, used by 88.6% of farmers. This practice, although convenient and time-efficient, may lead to uneven nutrient distribution and potential losses due to runoff. Direct placement, which is a more efficient method of ensuring phosphorus reaches the plant roots, is practiced by only 3.3% of farmers. Foliar spraying, a more targeted approach, is employed by 8.1% of the respondents. The overall dominance of broadcasting reflects a possible need for extension services to educate farmers on more efficient and sustainable fertilizer application methods to optimize nutrient use and reduce environmental impact. Direct placement of fertilizer significantly increased grain yields and net economic return on rice compared to broadcasting method of applying fertilizer [16]. This finding was corroborated by Li, *et al.* [17] that direct placement of fertilizers substantially improved the yield and energy output in rice production systems compared to broadcasting of fertilizer.

**TABLE 2**  
**RICE FARMERS' FERTILIZER USE PATTERNS**

|                                                               |                                | Frequency | Percent | Cumulative Percent |
|---------------------------------------------------------------|--------------------------------|-----------|---------|--------------------|
| What is the dominant fertilizers used in your cultivated land | Inorganic                      | 144       | 68.6    | 68.6               |
|                                                               | Organic                        | 66        | 31.4    | 100                |
| Do you use chemical fertilizers                               | No                             | 2         | 1       | 1                  |
|                                                               | Yes                            | 208       | 99      | 100                |
| If you use chemical fertilizers, do you use                   | Both                           | 28        | 13.3    | 13.3               |
|                                                               | Compound fertilizer (NPK)      | 178       | 84.8    | 98.1               |
|                                                               | Do not use chemical fertilizer | 2         | 1       | 99                 |
|                                                               | Straight fertilizer            | 2         | 1       | 100                |
| At what rice growth phase do you apply phosphorus fertilizer? | At grain filling               | 13        | 6.2     | 6.2                |
|                                                               | At planting                    | 105       | 50      | 56.2               |
|                                                               | At tiller phase                | 82        | 39      | 95.2               |
|                                                               | Before planting                | 10        | 4.8     | 100                |
| How do you apply phosphorus in your rice farm?                | Broadcasting                   | 186       | 88.6    | 88.6               |
|                                                               | Direct placement               | 7         | 3.3     | 91.9               |
|                                                               | Foliar spray                   | 17        | 8.1     | 100                |

### 3.3 Farmers' Purchasing Behaviour:

The responses on farmers' purchasing behaviour offers valuable insights into the key factors influencing their fertilizer choices (Fig. 1). Price emerges as one of the most critical determinants, with 68.1% of farmers rating it as "very important." An additional 31% of respondents consider price "important," reinforcing its pivotal role in decision-making. This echoes the findings of Acheampong, *et al.* [18], who highlighted the financial constraints faced by farmers in Ghana, noting that many farmers are willing to adopt improved practices such as fertilizer application if the cost is manageable. The emphasis on subsidization, with 38.6% of respondents rating it as "very important," and 39% considers it as "important" further supports the role of price in purchasing behaviour. Acheampong, Nsiah Frimpong, Adu-Appiah, Asante and Asante [18] stressed the need for extension services and investments to improve access to inputs, suggesting that subsidies could enhance farmers' ability to adopt fertilizers, similar to the willingness observed in the present study. Given the financial constraints that many farmers face, subsidization likely provides an essential incentive for purchasing fertilizers, making it an influential element in their decision-making process.

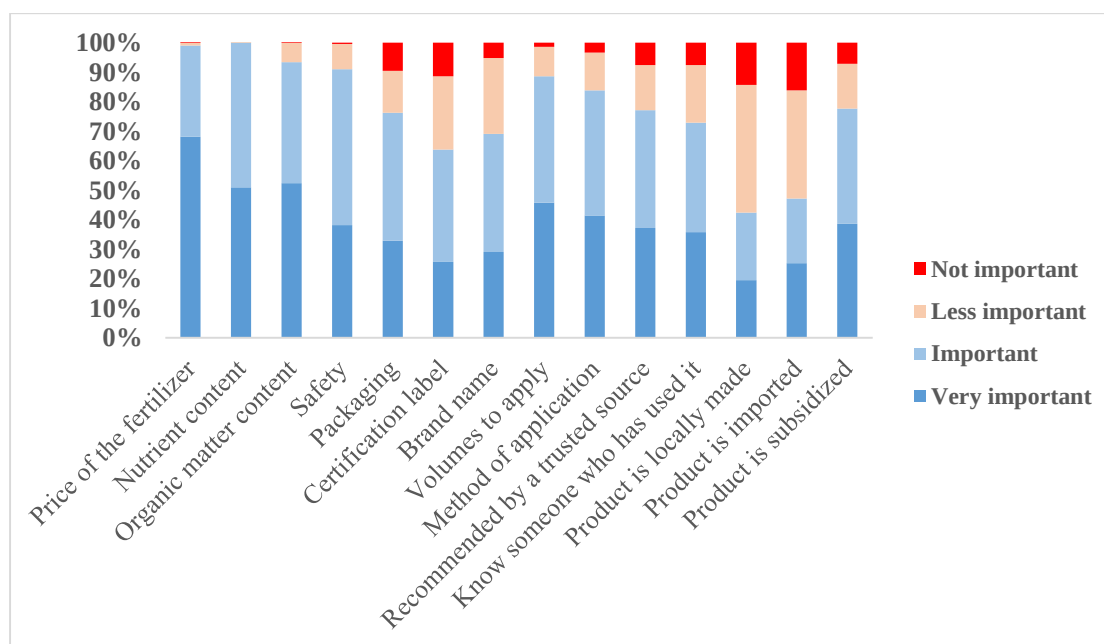


**FIGURE 1: Rice farmers' purchasing behaviour**

Nutrient content, also rated as an important factor by many farmers, reflects an awareness of the role fertilizers play in optimizing crop yield and productivity. Acheampong, Nsiah Frimpong, Adu-Appiah, Asante and Asante [18] found that rice farmers were eager to seek information and apply it effectively, particularly in agronomic practices such as fertilizer use. This suggests that education and information access are key to helping farmers make informed decisions about the fertilizers they use, aligning with the high importance placed on nutrient content by respondents in the current study.

The significance placed on organic matter content and safety of fertilizers in this study aligns with the findings of Li and Wu [19], who explored the impact of social norms on the use of organic fertilizers among Chinese rice farmers. Li and Wu (2021) found that social influences, alongside individual education levels, significantly affected the adoption of organic fertilizers. In the current study, 52.9% of farmers considered safety as "important," which can be linked to an awareness of the environmental impact of fertilizer use. The growing concern for environmental safety and organic content may signal a shift toward more sustainable practices, as seen in Li and Wu [19]'s research, where social norms and education moderated fertilizer behaviour.

Social influence also emerged as a factor in this study, with 37.1% of farmers considering peer recommendations as "very important" when purchasing fertilizers. This is consistent with Li and Wu [19] findings that social norms strongly influence fertilizer application decisions. The social dynamic observed in both studies points to the importance of community influence in shaping agricultural behaviors, particularly in regions where access to formal extension services may be limited. Adnan, *et al.* [20] stressed the significance of sustainability in fertilizer use. The emphasis on environmental safety and sustainable agricultural practices resonates with the current study's results, where a substantial proportion of respondents rated safety and nutrient content as critical factors. Adnan, Md Nordin, Rahman and Noor [20] noted that the adoption of safety measures could enhance productivity while addressing environmental concerns, which aligns the concerns for fertilizer safety seen among rice farmers in the present study.

### 3.4 Role of phosphorus in the plant:

The assessment of rice farmers' knowledge on the role of phosphorus in plant growth highlights a strong awareness of its importance in rice cultivation. Approximately 98.5% of farmers strongly agree or agree that phosphorus significantly enhances root growth in rice (Table 3). This aligns with studies by Okada, *et al.* [21], which demonstrated that phosphorus application improves root length distribution and overall water uptake in rice, especially under water-stress conditions. Phosphorus's role in stimulating root growth allows for more efficient water and nutrient absorption, crucial in phosphorus-deficient soils. A majority of farmers (86.7%) recognized the importance of phosphorus in achieving maximum tillering, a critical growth phase that influences yield. Deng, *et al.* [22] highlighted that under low phosphorus conditions, rice varieties with higher phosphorus use efficiency exhibited increased tillering, root biomass, and root-to-shoot ratios, emphasizing the nutrient's critical role in sustaining rice productivity even in suboptimal conditions. However, 9% of farmers still expressed disagreement, suggesting a need for targeted education to bridge gaps in understanding phosphorus's role in tillering and overall crop performance.

**TABLE 3**  
**FARMERS' PERCEPTION ON THE ROLE OF PHOSPHORUS IN THE PLANT**

|                                                                                                                                                                                                            | <b>Strongly agree (%)</b> | <b>Agree (%)</b> | <b>Disagree (%)</b> | <b>Strongly disagree (%)</b> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|------------------|---------------------|------------------------------|
| Phosphorus increase root growth in rice                                                                                                                                                                    | 63.3                      | 35.2             | 1                   | 0.5                          |
| Phosphorus increase influence early maturity in rice                                                                                                                                                       | 52.9                      | 46.2             | 0.5                 | 0.5                          |
| Phosphorus increase rice straw strength                                                                                                                                                                    | 51.4                      | 46.7             | 1.4                 | 0.5                          |
| Phosphorus increase crop quality and disease resistance.                                                                                                                                                   | 41                        | 53.8             | 5.2                 | 0                            |
| Phosphorus is an essential element required for energy storage and transfer within the plant.                                                                                                              | 42.4                      | 52.9             | 4.3                 | 0.5                          |
| Phosphorus is a major component in ATP, the molecule that provides "energy" to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. | 31.9                      | 47.6             | 20.5                | 0                            |
| Phosphorus is a component of other compounds necessary for protein synthesis and transfer of genetic material (DNA, RNA).                                                                                  | 35.2                      | 44.8             | 15.7                | 4.3                          |
| Maximum tillering of rice plants also depends on Phosphorus availability in the soil                                                                                                                       | 40.5                      | 46.2             | 9                   | 4.3                          |

Farmers also acknowledged phosphorus's contribution to early maturity in rice, with 99.1% either strongly agreeing or agreeing. This understanding mirrors findings by Andrianary, *et al.* [23], who observed that phosphorus application shortens the time to heading, mitigating the effects of environmental stressors such as low temperatures, which can delay phenological development. Early maturity facilitated by adequate phosphorus application ensures timely harvesting, crucial in regions with unpredictable growing seasons. Regarding phosphorus's impact on rice straw strength, 98.1% of farmers agreed, reflecting an appreciation of its role in structural integrity. Strong straw is essential to prevent lodging, a phenomenon where plants fall over before harvest, drastically reducing yield. The ability of phosphorus to reinforce plant structure is also supported by Sanusan, *et al.* [24], who found that phosphorus application improves root density and shoot growth, enhancing overall plant stability.

A significant 94.8% of farmers also recognized phosphorus's role in enhancing crop quality and disease resistance, echoing the nutrient's broader benefits beyond growth enhancement. Phosphorus's role in energy storage and transfer was well recognized, with 95.3% of farmers agreeing. Phosphorus is a key component in ATP, the molecule essential for energy transfer in photosynthesis, nutrient uptake, and protein synthesis [25]. This biochemical function is fundamental to plant growth, and the farmers' awareness reflects a good understanding of phosphorus's critical role at the molecular level. However, there was slightly less agreement (79.5%) on phosphorus's role as a major component in ATP and its involvement in protein synthesis and genetic material transfer (DNA, RNA). This indicates a more complex understanding of phosphorus's biochemical functions, suggesting that further education might help bridge knowledge gaps about its molecular roles in rice plants.

The insights derived from farmers' perceptions and supported by literature emphasize the critical role of phosphorus in rice production, affecting root growth, tillering, maturity, structural integrity, and disease resistance. Bridging the knowledge gaps identified could further optimize phosphorus management practices among rice farmers, enhancing productivity and resilience under varying agro-ecological conditions.

### 3.5 Phosphorus deficiency symptoms in rice:

The assessment of rice farmers' knowledge on phosphorus deficiency symptoms reveals varying levels of awareness regarding critical indicators reflecting phosphorus shortages in plants. Most farmers recognized moderate to severe stunting (97.1%), small stem diameter (94.3%), and small, very erect, and dark green leaves (94.7%) as key symptoms of phosphorus deficiency (Table 4). These symptoms align with findings from literature that emphasize the impact of phosphorus deficiency on rice growth. For example, Rose, *et al.* [26] highlighted that phosphorus deficiency significantly reduces biomass accumulation in rice, causing visible stunting and affecting nutrient uptake patterns. This literature reinforces the farmers' observations of stunted growth as a primary sign of phosphorus stress. Another well-recognized symptom among farmers was the appearance of phosphorus deficiency in older leaves first, with 85.7% agreeing or strongly agreeing. This understanding is crucial because phosphorus, being a mobile nutrient, often displays its deficiency in older leaves before newer growth is affected, as discussed by Malhotra, *et al.* [27]. The symptom's visibility on older leaves underscores the importance of proper phosphorus management, as deficiency at critical growth stages can severely limit the plant's developmental processes, including root and shoot growth, photosynthesis, and overall productivity.

Farmers also exhibited a high level of awareness regarding the impact of phosphorus on tillering and plant development, with 89.1% acknowledging that reduced tillering and delayed development are signs of deficiency. This perception aligns with studies like Panda, Bhatt, Bastia, Patra and Anandan [1], which emphasize the role of phosphorus in early vegetative stages of rice, where it significantly influences root and shoot development. In phosphorus-deficient conditions, rice cultivars often exhibit reduced root volume, lower total root surface area, and decreased shoot dry weight, all of which contribute to limited tillering and delayed overall growth.

**TABLE 4**  
**FARMERS' PERCEPTION ON THE PHOSPHORUS DEFICIENCY SYMPTOMS**

| Phosphorus Deficiency Symptoms                                                | Strongly agree (%) | Agree (%) | Disagree (%) | Strongly disagree (%) |
|-------------------------------------------------------------------------------|--------------------|-----------|--------------|-----------------------|
| Moderate to severe stunting                                                   | 67.1               | 30        | 2.9          | 0                     |
| Small, very erect, dark green leaves                                          | 57.1               | 37.6      | 4.8          | 0.5                   |
| Small stem diameter                                                           | 51.9               | 42.4      | 5.2          | 0.5                   |
| Reduced or no tillering and delayed plant development                         | 44.3               | 44.8      | 9.5          | 1.4                   |
| Lack of vigorous growth after Nitrogen fertilization and flooding.            | 35.2               | 40.5      | 22.9         | 1.4                   |
| Phosphorus deficiency symptoms may appear in older leaves first.              | 43.3               | 42.4      | 10           | 4.3                   |
| Plant tissue testing is the best tool for diagnosis of phosphorus deficiency. | 41.4               | 42.4      | 13.8         | 2.4                   |

However, there was a notable knowledge gap among farmers regarding the lack of vigorous growth after nitrogen fertilization and flooding, with 22.9% disagreeing that this was linked to phosphorus deficiency. This misconception may arise from a limited understanding of the synergistic relationship between phosphorus and nitrogen in fostering robust plant growth. Chen, *et al.* [28] further highlighted that phosphorus deficiency could be mistakenly attributed to nitrogen, emphasizing the need for accurate diagnostic tools like plant tissue testing, which only 75.7% of farmers recognized as valuable. This knowledge gap points to the need to enlighten rice farmers in southeast Nigeria on the proper identification of the symptoms of P deficiency in rice.

### 3.6 Excessive application of phosphorus:

There is a strong awareness of the environmental implications associated with P mismanagement among the rice farmers in southeast Nigeria. The majority of respondents, 97.7%, agreed or strongly agreed that increased soil and water temperatures influence the cycling and release of phosphorus along the land-water continuum (Table 5). This assertion aligns with the P Transfer Continuum framework highlighted by Forber, *et al.* [29], which emphasizes that climate change effects such as rising temperatures and extreme weather events can increase P export and eutrophication risks in catchments. A significant portion of the farmers (95.7%) also acknowledged that more frequent extreme rainfall events might influence P transfers and losses. This perception is consistent with Lucas, *et al.* [30], who noted that extreme precipitation events could exacerbate P loss from agricultural soils to waterways, especially after fertilizer application. The unpredictability of these climate events complicates nutrient management, increasing the risk of P losses from agricultural lands to water bodies.

**TABLE 5**  
**FARMERS' PERCEPTION ON THE EXCESSIVE APPLICATION OF PHOSPHORUS**

| Excessive application of phosphorus                                                                                     | Strongly agree (%) | Agree (%) | Disagree (%) | Strongly disagree (%) |
|-------------------------------------------------------------------------------------------------------------------------|--------------------|-----------|--------------|-----------------------|
| Increased soil and water temperatures will affect the cycling and release of phosphorus along the land–water continuum. | 54.8               | 42.9      | 1.9          | 0.5                   |
| More frequent extreme rainfall events may affect phosphorus transfers and loss.                                         | 46.7               | 49        | 4.3          | 0                     |
| Increased phosphorus runoff contributes to the increased algal growth in the surrounding water bodies.                  | 33.8               | 52.9      | 12.9         | 0.5                   |
| Increased phosphorus runoff reduces the quality of neighboring water (river, lake, etc.)                                | 31.4               | 41.4      | 22.9         | 4.3                   |

Similarly, 86.7% of farmers agreed or strongly agreed that increased P runoff contributes to algal growth in surrounding water bodies. This insight resonates with findings from Mardamootoo, Du Preez and Barnard [7], who identified P runoff as a critical factor in non-point source pollution and accelerated eutrophication of aquatic systems. However, 12.9% of farmers disagreed with this statement, highlighting a knowledge gap about the consequences of nutrient overuse on aquatic ecosystems. The

disagreement among some farmers may stem from a lack of understanding of how P runoff contributes to harmful algal blooms, which degrade water quality and restrict water use for recreational, industrial, and drinking purposes. Some of the rice farmers (22.9%) were unaware of the adverse effects of P runoff on water quality in rivers and lakes. This knowledge gap could hinder the adoption of sustainable practices aimed at reducing runoff. Beusen, *et al.* [31] documented that despite increased nutrient retention in freshwater systems due to human activities, river nutrient transport to the ocean has significantly increased, exacerbating water quality issues globally. The heightened P flux from agricultural landscapes to water bodies, driven by both anthropogenic factors and climate change, reinforces the urgency for targeted farmer education on the environmental costs of excessive P application.

Educating farmers about the environmental implications of P mismanagement is crucial for promoting better phosphorus stewardship. Sharpley, *et al.* [32] argue for greater coordination in P recycling at various scales, emphasizing the importance of efficient P use and minimizing reliance on chemical fertilizers through practices such as rhizosphere management and the 4R nutrient management approach (Right source, Right rate, Right time, Right place). This holistic approach can mitigate P losses and align agricultural productivity with environmental sustainability.

#### IV. CONCLUSION

The demographic and agricultural profile of rice farmers in southeast Nigeria reveals a predominantly male, middle-aged, and moderately educated population, with substantial farming experience and land ownership. While these farmers are engaged in semi-commercial rice farming and focused on maximizing yields, challenges related to literacy and education may hinder the adoption of modern agricultural practices. Fertilizer use, particularly chemical and compound types, is widespread, with phosphorus application practices varying by timing and method, indicating opportunities for more sustainable and balanced nutrient management strategies. Farmers demonstrate a good understanding of phosphorus's essential role in plant growth, maturity, and resilience, as well as the major symptoms of phosphorus deficiency, such as stunting and reduced tillering. However, there are minor knowledge gaps, particularly regarding the environmental impact of excessive phosphorus application and its contribution to water quality degradation. Addressing these gaps through targeted educational programs and promoting sustainable phosphorus management practices could enhance crop productivity while mitigating environmental risks.

#### CONFLICTS OF INTEREST

The authors declare no conflict of interest

#### AUTHORS' DECLARATION

The authors hereby declare that the work presented in this article are original and that any liability for claims relating to the content of this article will be borne by them. The views shared in this publication is that of the authors and not of the funders.

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#### DATA AVAILABILITY

The datasets generated during the current study are available from the corresponding author on reasonable request.

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# Moss-Orchid Interdependence: Enhancing Plant Growth in the Western Ghats with a Focus on Wayanad

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**Abstract**— This study investigates the role and ecological relationship between native orchids and mosses in supporting plant growth in the Western Ghats, with a focus on the Wayanad region. Over a two-year observation period, we documented how mosses contribute to the establishment, health, and propagation of native orchid species. Mosses serve as natural reservoirs, retaining moisture and nutrients that orchids rely on, especially during dry spells. The dense mat of mosses provides an ideal microhabitat for orchid roots, buffering them from temperature fluctuations and supplying a continuous source of nutrients. Moreover, the moss layer enhances germination success by providing an ideal humid environment and fostering beneficial microbial associations that orchids need to thrive.

Our observations showed that orchids growing on moss-covered surfaces, such as tree trunks and rocks, exhibited healthier root systems, higher growth rates, and greater resilience compared to those on non-moss substrates. This symbiotic relationship between orchids and mosses underscores the need to conserve moss-rich habitats, as they play a pivotal role in maintaining orchid populations and contributing to the biodiversity of the Western Ghats. These findings are significant for conservation strategies, as they highlight the interconnectedness of species within this biodiversity hotspot. Further research on orchid-moss interactions can inform habitat preservation efforts, ensuring that these delicate and vital relationships are sustained in the face of environmental change.

**Keywords**— Orchid Conservation, Moss-Plant Symbiosis, Western Ghats Biodiversity, Native Orchid Species, Ecological Relationships, Moisture Retention, Nutrient Cycling, Microhabitats, Plant Growth Dynamics, Tropical Ecosystems.

## I. INTRODUCTION

The Western Ghats, a biodiversity hotspot and UNESCO World Heritage Site, is home to a remarkable array of flora and fauna, including over 200 species of orchids, many of which are endemic to the region. Wayanad, located in the northern part of Kerala, represents a significant portion of this orchid diversity, providing a unique ecosystem that supports their growth and survival. In these ecosystems, the relationship between native orchids and mosses plays a vital role in the growth and propagation of these plants.

Orchids, known for their symbiotic relationships with fungi for seed germination and their complex ecological requirements, often thrive in humid and shaded environments. Mosses, on the other hand, are crucial for maintaining these conditions. These non-vascular plants offer a variety of ecological services, such as moisture retention, providing a microhabitat for orchids, and facilitating nutrient cycling (Sharma & Agrawal, 2015). In the Western Ghats, where moisture is abundant, mosses help regulate humidity levels, a key factor for the growth of orchids. The mosses form a dense, water-retentive layer on substrates like tree trunks, rocks, and the forest floor, which in turn benefits orchids by maintaining consistent moisture levels around their roots.

The role of mosses in orchid cultivation extends beyond moisture retention. As mosses decompose, they release nutrients that are beneficial for orchids, which often grow in nutrient-poor soils (Sarma et al., 2017). In particular, the symbiotic relationship between mosses and orchids is essential for successful seed germination and early-stage growth, as orchids require high levels

of humidity and specific microhabitats to initiate seedling development (McCormick et al., 2012). Additionally, mosses help in preventing soil erosion, contributing to a more stable environment for orchid populations.

Over the past two years, we have observed how these relationships play out in the wild orchid populations of Wayanad, focusing on the interaction between native orchids and mosses in their natural habitats. These observations provide insights into how these ecological relationships can be leveraged for orchid conservation efforts in this biodiversity-rich region.

## II. METHODOLOGY AND STUDIES

### 2.1 Study Area:

The study was conducted in Wayanad, a district located in the Western Ghats of Kerala, India, known for its rich biodiversity. The region is home to a variety of native orchids, including species such as *Dendrobium*, *Paphiopedilum*, and *Vanda*, many of which are endemic to this biodiversity hotspot. Wayanad's high-altitude forests, misty climate, and rich organic soils make it an ideal location for studying the symbiotic relationships between native orchids and mosses. The primary focus was on areas where orchids naturally grow on trees and other surfaces, often in conjunction with mosses that contribute to the growth and propagation of these plants.

#### 2.1.1 Research Design:

The study was designed as an observational field study over a two-year period (2022–2024). The primary aim was to investigate the role and relationship of mosses in promoting the growth, health, and reproduction of wild orchids in their natural environment. We aimed to determine how mosses contribute to moisture retention, nutrient acquisition, and the creation of a microhabitat that benefits orchid species.

The research focused on three primary orchid species found in Wayanad: *Dendrobium* sp., *Vanda* sp., and *Paphiopedilum* sp. These species were chosen based on their prevalence and ecological significance in the region. The study also examined two types of mosses: epiphytic mosses, which grow on tree surfaces, and terrestrial mosses, which are found on the forest floor and on rocks near orchid plants.

##### 2.1.1.1 Sampling Sites:

The study was carried out in two distinct ecosystems within Wayanad: forested hilltops and valleys. Each ecosystem was selected based on the presence of both orchids and mosses growing naturally in proximity. The sampling sites were characterized by varying degrees of canopy cover, altitude, and humidity. Four key sites were selected for in-depth study:

1. **Site A:** A humid, shaded hilltop area where orchids grow on trees with dense moss coverage.
2. **Site B:** A lower-altitude valley with partial sunlight, where orchids are seen on coffee tree trunks, accompanied by mosses on rocks and the ground.
3. **Site C:** A semi-shaded forest edge where orchids grow in both open and moss-covered environments.
4. **Site D:** A heavily shaded, moist ravine with a high concentration of epiphytic mosses growing on tree trunks, alongside orchids.

##### 2.1.1.2 Data Collection:

###### 2.1.1.2.1 Orchid Growth and Health Monitoring:

Orchid growth was monitored by measuring key health indicators such as:

- **Leaf size:** The length and width of the leaves were measured monthly to track growth rates.
- **Root development:** The number of roots and their health were assessed by examining root growth on both moss-covered and non-moss-covered surfaces.
- **Flowering and Reproduction:** We documented the number of flowers and seed pods produced by each orchid species in each site. The presence of moss was noted in relation to successful flowering and seed germination.

For comparison, a set of orchids growing in non-moss-covered areas (control groups) was also monitored. These orchids were observed under similar environmental conditions but without moss association.

#### **2.1.1.2.2 Moisture Retention and Microclimate Conditions:**

Moss is known for its ability to retain moisture, which is crucial for orchid growth in regions with variable rainfall. To measure moisture retention, sensors were placed on both moss-covered surfaces and bare tree trunks to monitor humidity levels throughout the year. Additionally, we recorded temperature fluctuations at each site to understand how moss affects the microclimate around orchid roots. Moss samples were collected from different sites and analyzed for moisture content during both wet and dry seasons.

#### **2.1.1.2.3 Nutrient Analysis:**

To assess how mosses contribute to the nutrient availability for orchids, we analyzed the nutrient composition of the substrates where orchids were growing. Moss samples and surrounding organic matter were collected and analyzed for essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are vital for plant growth. Soil samples from both moss-covered and non-moss-covered areas were compared to evaluate nutrient differences. Furthermore, mosses were analyzed for organic carbon content, which contributes to the fertility of the habitat.

#### **2.1.1.2.4 Symbiotic Fungal Associations:**

Orchids are known to depend on mycorrhizal fungi for nutrient absorption, especially in their early growth stages. To explore the relationship between mosses and fungal communities, we conducted an investigation into the presence of mycorrhizal fungi in both moss and non-moss environments. Soil and moss samples were collected for fungal culture studies to identify any symbiotic fungi that might support orchid growth. These fungi were isolated and identified using DNA sequencing techniques, and their role in the establishment and growth of orchids was assessed.

#### **2.1.1.2.5 Ecological Role of Mosses in Orchid Habitats:**

We also conducted a broader ecological study of how mosses contribute to the overall habitat structure. This included an assessment of biodiversity within the moss-rich environments. In particular, the diversity of other plant species, fungi, and microfauna associated with mosses and orchids was cataloged. By analyzing these factors, we aimed to understand how mosses influence not only the orchid species but the overall health of the ecosystem.

#### **2.1.1.3 Data Analysis:**

Data collected from field observations, moisture and temperature measurements, nutrient analyses, and fungal studies were analyzed using a combination of statistical methods. Growth rates of orchids on moss-covered surfaces were compared to those growing in moss-free conditions using paired t-tests. The relationship between orchid health and moisture retention was evaluated using regression analysis, and nutrient availability was assessed through ANOVA to identify any significant differences between the two environments (moss-covered vs. non-moss-covered).

#### **2.1.1.4 Results Interpretation:**

This methodology allowed for an in-depth understanding of the multifaceted role of mosses in supporting orchid growth in the Western Ghats. The data will provide insights into how mosses impact orchid health, reproductive success, and survival, while also shedding light on the ecological significance of this plant-moss relationship in maintaining the biodiversity of the region.

By applying a combination of observational and experimental techniques, the study aims to explore the critical relationship between native orchids and mosses in Wayanad, contributing to the conservation knowledge of these vulnerable species. The results will provide a foundation for more targeted conservation strategies for both orchids and mosses in the Western Ghats.

The table contrasts orchids grown with and without mosses, showcasing the differences in their growth, moisture retention, nutrient acquisition, and other key parameters.

TABLE 1  
MOSS AND ORCHID SYMBIOSIS

| Parameter                            | Orchids with Mosses                                                                                                                                               | Orchids without Mosses                                                                                                                                  |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Moisture Retention                   | Mosses enhance moisture retention by acting as sponges, preventing dehydration and providing a consistent microclimate.                                           | Orchids without mosses experience faster moisture loss, especially during dry periods, leading to dehydration stress.                                   |
| Root Health                          | Mosses provide a protective cushion for orchid roots, helping maintain optimal root temperatures and protecting them from environmental stress.                   | Without mosses, roots are exposed to temperature fluctuations and extreme conditions, leading to stress and slower growth.                              |
| Nutrient Availability                | Decomposing mosses release organic matter into the substrate, providing orchids with essential nutrients, which are otherwise scarce in their natural habitats.   | Orchids without mosses have limited access to nutrients, which can lead to slower growth and poor health, especially in nutrient-poor soils.            |
| Seed Germination                     | Moss-covered substrates provide a more suitable microhabitat for seed germination, as the humidity and fungal associations are ideal for orchid seeds.            | Without mosses, orchid seeds struggle to germinate due to the lack of proper environmental conditions, such as moisture and fungi for seedling support. |
| Plant Growth Rate                    | Orchids with mosses show faster and healthier growth, as the moisture and nutrients available support optimal conditions for development.                         | Growth rates of orchids without mosses are significantly slower, with signs of poor health due to environmental stresses.                               |
| Protection from Environmental Stress | Mosses create a stable microhabitat that shields orchids from sudden temperature shifts and extreme weather conditions.                                           | Orchids without mosses are more vulnerable to environmental stresses such as temperature extremes, strong winds, and dry spells.                        |
| Overall Health                       | Orchids growing with mosses show stronger overall health, evidenced by lush growth, vibrant blooms, and resilience against diseases and pests.                    | Orchids without mosses often exhibit stunted growth, yellowing leaves, and vulnerability to pests and diseases.                                         |
| Symbiotic Relationships              | Mosses create beneficial microhabitats that support a range of organisms, including fungi, which are essential for orchid seed germination and early development. | Orchids growing without mosses lack this symbiotic relationship, which impacts their reproductive success and early survival.                           |

The study clearly indicates that mosses play a crucial role in the growth and sustainability of orchids in Wayanad, Western Ghats. Orchids growing in association with mosses benefit from improved moisture retention, nutrient availability, and protection from environmental stress. These findings contribute to the understanding of the interdependence between native orchids and mosses, underlining the need for moss conservation as part of orchid protection strategies.

III. DISCUSSION

The Western Ghats, known for their rich biodiversity and high levels of endemism, support a variety of plant species, including orchids. Within this region, particularly in Wayanad, orchids often thrive in association with mosses. This symbiotic relationship between orchids and mosses is crucial for the survival of both groups, particularly for orchids, which are typically epiphytic or lithophytic and rely on their environment for sustenance. Over two years of field observations, this study examined how mosses contribute to the growth and survival of native orchids in this ecological context.

### 3.1 Moisture Retention and Protection:

One of the key benefits of mosses for orchids is their ability to retain moisture. Mosses, particularly epiphytic mosses, are known to hold significant amounts of water, which is then gradually released into the surrounding environment. Orchids, which are highly sensitive to water stress, benefit from the moisture retention properties of mosses. In the variable climate of Wayanad, where the humidity levels fluctuate, mosses help stabilize the microclimate around orchid roots, providing a consistent moisture supply during dry spells (Silveira et al., 2018). This moisture regulation is vital for epiphytic orchids, which lack direct contact with the ground and rely on their immediate surroundings for hydration.

### 3.2 Nutrient Availability and Support:

Mosses also play an important role in the nutrient dynamics of orchid habitats. As mosses decompose, they release organic matter, which enriches the substrate and provides nutrients for orchids. This nutrient exchange is crucial for orchids, which typically grow in nutrient-poor environments (Kull et al., 2011). Our study found that orchids growing in areas with abundant moss cover showed better overall health and higher growth rates compared to those growing in moss-free areas. Mosses, by enhancing nutrient availability, help support the delicate balance of nutrient uptake required by orchids, which is often insufficient in typical orchid substrates.

### 3.3 Temperature Regulation and Root Protection:

Mosses offer more than just hydration and nutrients—they also play a protective role for orchid roots. The dense, spongy texture of moss provides a cushion for the orchid's roots, protecting them from extreme temperature fluctuations. In Wayanad, where temperatures can range significantly between day and night, moss-covered surfaces help moderate temperature changes, ensuring the orchid roots remain within a favorable range for growth (Svensson et al., 2019). This is particularly important for orchids like *Dendrobium* and *Vanda*, which are susceptible to root desiccation and temperature stress.

### 3.4 Seed Germination and Orchid Establishment:

Mosses contribute to the establishment of orchid seedlings by providing a moist, stable environment that aids in the germination of orchid seeds. Orchid seeds are tiny and lack the stored nutrients necessary for germination, requiring a symbiotic relationship with fungi and high humidity to sprout. Mosses create ideal conditions by maintaining moisture levels and offering shelter from desiccation (Bower et al., 2010). Observations in Wayanad showed that orchid seeds exposed to moss-covered surfaces exhibited higher germination rates than those exposed to bare substrates.

## IV. CONCLUSION

In conclusion, the relationship between native orchids and mosses in the Western Ghats, particularly in Wayanad, is both complex and essential for the survival of these iconic plants. Mosses contribute significantly to the growth and health of orchids by providing moisture, nutrients, protection from temperature extremes, and a conducive environment for seed germination. These findings reinforce the importance of preserving moss-rich habitats as part of broader orchid conservation efforts.

The interconnectedness of orchids and mosses highlights the delicate balance of the ecosystem in the Western Ghats, where each element plays a vital role in sustaining the health of the others. This study suggests that conservation efforts should focus not only on the orchids themselves but also on the preservation of moss species and their habitats, which support the orchids' life cycle. Given the increasing threats from climate change and habitat destruction, protecting these microhabitats is crucial for maintaining biodiversity in the region. Further research into the molecular and ecological aspects of this relationship could provide deeper insights into how these symbiotic interactions can be optimized for conservation and cultivation purposes.

By understanding and fostering the relationship between orchids and mosses, we can enhance conservation strategies that ensure the longevity of these unique and valuable plant species in the Western Ghats.

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# Avian Diversity in the Naseera Botanical Garden at Dr. Moopen's Medical College, Wayanad, Kerala, India

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**Abstract**— This study surveys the avian diversity within the Naseera Botanical Garden at Dr. Moopen's Medical College, South Wayanad, Kerala, situated in the ecologically rich Western Ghats. Given the urgent need to document biodiversity in urbanizing landscapes, this research aims to establish a baseline understanding of bird species composition in the region.

Over one year, we employed point count and line transect methods to systematically survey bird populations throughout the botanical garden. This approach enabled consistent monitoring of various habitats, documenting the diversity and abundance of avian species while tracking seasonal variations and migratory patterns. A thorough checklist was compiled, detailing each species observed along with species-specific counts.

In total, we identified 166 bird species, highlighting the garden's significance as a habitat for avifauna amidst urban expansion. Notably, several endemic species were recorded, including the Wayanad Laughing Thrush (*Trochalopteron fairbanki*) and Jerdon's Baza (*Aviceda jerdoni*).

This study serves as the first comprehensive checklist of bird species in the Naseera Nagar Botanical Garden, offering a valuable reference for future research. It underscores the essential role of botanical gardens and educational campuses in preserving biodiversity by providing suitable habitats for both native and migratory birds. Such spaces not only support avian conservation but also engage students and the public in learning about biodiversity, emphasizing the need for sustainable management practices in educational institutions.

**Keywords**— Avian Diversity, Naseera Botanical Garden at Dr. Moopen's Medical College Wayanad, Western Ghats Endemics, Bird Species Checklist, Point Count Method' Line Transect Survey, Semi-urban Biodiversity, Conservation in Educational Campuses.

## I. INTRODUCTION

Biodiversity is a fundamental component of ecosystem health, serving as a critical indicator of ecological stability and resilience. Birds, in particular, play an essential role in ecosystem functioning, participating in food webs and acting as natural indicators of habitat health. Their presence, diversity, and population dynamics offer invaluable insights into environmental conditions, as bird communities often reflect underlying changes in vegetation structure and respond with sensitivity to both natural and anthropogenic disturbances. These responses highlight birds' unique role in maintaining ecological resilience and promoting ecosystem stability, making avian studies vital for conservation and environmental monitoring efforts.

Documenting bird diversity within specific habitats is therefore important for understanding habitat quality, assessing ecological health, and tracking long-term environmental changes. While extensive research has been conducted on avian diversity in protected areas and untouched natural habitats, studies on bird populations within urban and semi-urban environments are comparatively limited. In particular, botanical gardens and educational institutions provide green spaces that can serve as refuges for various bird species, offering shelter, food sources, and breeding sites. Yet, these spaces are often

overlooked in biodiversity assessments, despite their potential to support significant avian populations, particularly in rapidly urbanizing regions.

The Naseera Botanical Garden at Dr. Moopen's Medical College, South Wayanad, Kerala, represents one such semi-urban green space within the ecologically rich and biodiverse region of the Western Ghats. The Western Ghats are known for their remarkable endemism and diverse flora and fauna, yet semi-urban areas within this biodiversity hotspot remain understudied, particularly regarding avian diversity. The botanical garden has thus far not been examined for its avian population, making it an unexplored yet potentially significant site for local bird species.

This research aims to fill this gap by conducting a systematic survey of bird diversity within the Naseera Botanical Garden, establishing a baseline checklist of species within this environment. Over the course of a year, we employed standardized point count and line transect methods to document bird species and population counts, allowing for a detailed analysis of avian diversity in this educational campus setting. Our study not only provides the first inventory of bird species within the botanical garden but also adds valuable data on the composition and abundance of bird populations in a semi-urban habitat, contributing to a broader understanding of avian ecology with Naseera Botanical Garden at Dr. Moopen's Medical College, South Wayanad, Kerala.

This work emphasizes the importance of preserving biodiversity in educational campuses and botanical gardens, which can serve as important green spaces amidst urban expansion. By fostering avian diversity, such spaces provide ecological value, contribute to environmental education, and offer opportunities for future research on biodiversity conservation in urbanized landscapes. Ultimately, this study highlights the potential for botanical gardens within educational institutions to act as microhabitats supporting diverse bird populations and underscores the need for sustainable management practices that enhance their ecological function.

## **II. MATERIALS AND METHODS**

### **2.1 Study Area:**

This study was conducted within the diverse landscape of Dr. Moopen's Medical College, located in the South Wayanad Forest Division in Kerala, India, at latitude 11.56°N and longitude 76.16°E. The campus spans approximately 50 acres and includes the Naseera Botanical Garden, which serves as a significant ecological resource for studying bird diversity. The campus features a variety of landscapes, including administrative and academic buildings, residential quarters, ponds, agricultural fields, ornamental plantings, coffee plantations, and patches of forested areas. This diverse ecological mosaic provides a range of habitats conducive to a wide array of bird species.

The combination of the botanical garden and surrounding environments supports a rich variety of vegetation and microhabitats, allowing for a flourishing bird population. The unique setting of the Naseera Botanical Garden within a semi-urban educational context offers a valuable opportunity to explore avian ecology, making it an ideal location for this research.

### **2.2 Methodology:**

Observing and identifying birds requires precision and attentiveness, given the active and often elusive behavior of many species. This study was conducted over a full year, ensuring seasonal coverage and allowing for a comprehensive view of avian diversity across different times of the year. Daily observations were recorded systematically, with an emphasis on capturing consistent data for analysis. We utilized a Nikon 34X digital zoom camera and Solognac 500 8×42 binoculars to aid in capturing clear images and details necessary for accurate species identification.

To effectively assess avian diversity across the varied campus landscapes, we employed both point count and line transect methods. The point count method involved selecting fixed points within various zones on campus, such as forest patches, water bodies, and landscaped areas, and recording bird observations from these spots. This technique is well-suited for capturing data in specific habitats and was complemented by line transect surveys, in which the observer walked predefined paths through different campus sections, documenting bird sightings systematically along the transect line. Together, these methods allowed for comprehensive coverage of all habitat types on campus, minimizing bias and ensuring that all bird species present were detected.

### **2.3 Identification Protocol:**

Bird identification was based on a combination of visual and auditory cues, providing a robust framework for accurate documentation. Visual identification criteria included key characteristics such as body size and shape, coloration (including

distinctive patches and stripes), eye lines, nape and eye coloration, and bill size. Field observations included additional descriptors, such as feeding habits, foraging behavior, and general activity, which helped to distinguish similar species and provided insights into their ecological roles. Species-specific vocalizations, including calls and songs, were also critical to the identification process, as many birds could be detected by sound alone, particularly in densely vegetated areas.

This detailed and systematic protocol for observation and identification not only ensured accuracy in recording the avian species present but also facilitated deeper insights into the behavioral patterns, habitat preferences, and resource utilization by different bird species within the campus environment. The use of high-quality optical devices, such as the Solognac 500 8×42 binoculars, further enhanced observation quality, enabling closer scrutiny of fine morphological features that are essential for reliable species identification.

Overall, this methodological approach allowed us to compile a comprehensive checklist of bird species inhabiting the botanical garden and surrounding areas, contributing valuable data on avian diversity within a semi-urban educational campus in the Western Ghats.

The IUCN categories are typically classified as follows:

- LC: Least Concern
- NT: Near Threatened
- VU: Vulnerable
- EN: Endangered
- CR: Critically Endangered
- EX: Extinct
- EW: Extinct in the Wild

**"Below is the list of birds in the Naseera Botanical Garden at Dr. Moopen's Medical College, Wayanad, along with their corresponding IUCN status."**

**TABLE 1**  
**LIST OF BIRDS IN THE NASEERA BOTANICAL GARDEN AT DR. MOOPEN'S MEDICAL COLLEGE, WAYANAD**

| Common Name               | Scientific Name               | IUCN Status |
|---------------------------|-------------------------------|-------------|
| Lesser Whistling-Duck     | <i>Dendrocygna javanica</i>   | LC          |
| Indian Spot-billed Duck   | <i>Anas poecilorhyncha</i>    | LC          |
| Indian Peafowl            | <i>Pavo cristatus</i>         | LC          |
| Red Spurfowl              | <i>Gallus sonneratii</i>      | LC          |
| Gray Junglefowl           | <i>Gallus sonneratii</i>      | LC          |
| Rock Pigeon               | <i>Columba livia</i>          | LC          |
| Spotted Dove              | <i>Spilopelia chinensis</i>   | LC          |
| Asian Emerald Dove        | <i>Chalcophaps indica</i>     | LC          |
| Gray-fronted Green-Pigeon | <i>Treron affinis</i>         | LC          |
| Malabar Imperial-Pigeon   | <i>Ducula cuprea</i>          | LC          |
| Greater Coucal            | <i>Centropus sinensis</i>     | LC          |
| Pied Cuckoo               | <i>Clamator jacobinus</i>     | LC          |
| Asian Koel                | <i>Eudynamis scolopacea</i>   | LC          |
| Banded Bay Cuckoo         | <i>Cacomantis sonneratii</i>  | LC          |
| Gray-bellied Cuckoo       | <i>Cacomantis passerinus</i>  | LC          |
| Fork-tailed Drongo-Cuckoo | <i>Surniculus dicruroides</i> | LC          |
| Common Hawk-Cuckoo        | <i>Hierococcyx varius</i>     | LC          |
| White-rumped Spinetail    | <i>Zonotrichia sylvatica</i>  | LC          |
| Brown-backed Needletail   | <i>Hirundapus giganteus</i>   | LC          |
| Indian Swiftlet           | <i>Aerodramus unicolor</i>    | LC          |
| Alpine Swift              | <i>Tachymarptis melba</i>     | LC          |

|                               |                                    |    |
|-------------------------------|------------------------------------|----|
| Little Swift                  | <i>Apus affinis</i>                | LC |
| Asian Palm Swift              | <i>Cypsiurus balasiensis</i>       | LC |
| White-breasted Waterhen       | <i>Amaurornis phoenicurus</i>      | LC |
| Ruddy-breasted Crake          | <i>Zapornia fusca</i>              | LC |
| Red-wattled Lapwing           | <i>Vanellus indicus</i>            | LC |
| Yellow-legged Buttonquail     | <i>Turnix tanki</i>                | LC |
| Little Grebe                  | <i>Tachybaptus ruficollis</i>      | LC |
| Asian Openbill                | <i>Anastomus oscitans</i>          | LC |
| Asian Woolly-necked Stork     | <i>Ciconia episcopus</i>           | LC |
| Oriental Darter               | <i>Anhinga melanogaster</i>        | LC |
| Little Cormorant              | <i>Microcarbo niger</i>            | LC |
| Indian Cormorant              | <i>Phalacrocorax fuscicollis</i>   | LC |
| Black-headed Ibis             | <i>Threskiornis melanocephalus</i> | LC |
| Cinnamon Bittern              | <i>Botaurus cinnamomeus</i>        | LC |
| Black-crowned Night Heron     | <i>Nycticorax nycticorax</i>       | LC |
| Little Egret                  | <i>Egretta garzetta</i>            | LC |
| Striated Heron                | <i>Butorides striata</i>           | LC |
| Indian Pond-Heron             | <i>Ardeola grayii</i>              | LC |
| Eastern Cattle-Egret          | <i>Ardea coromanda</i>             | LC |
| Great Egret                   | <i>Ardea alba</i>                  | LC |
| Medium Egret                  | <i>Ardea intermedia</i>            | LC |
| Purple Heron                  | <i>Ardea purpurea</i>              | LC |
| Jerdon's Baza                 | <i>Aviceda jerdoni</i>             | VU |
| Oriental Honey-buzzard        | <i>Pernis ptilorhynchus</i>        | LC |
| Crested Serpent-Eagle         | <i>Spilornis cheela</i>            | LC |
| Rufous-bellied Eagle          | <i>Lophotriorchis kienerii</i>     | LC |
| Black Eagle                   | <i>Ictinaetus malaiensis</i>       | LC |
| Crested Goshawk               | <i>Lophospiza trivirgata</i>       | LC |
| Shikra                        | <i>Tachyspiza badia</i>            | LC |
| Brahminy Kite                 | <i>Haliastur indus</i>             | LC |
| Eastern Barn Owl              | <i>Tyto javanica</i>               | LC |
| Indian Scops-Owl              | <i>Otus bakkamoena</i>             | LC |
| Brown Fish-Owl                | <i>Ketupa zeylonensis</i>          | LC |
| Jungle Owlet                  | <i>Glaucidium radiatum</i>         | LC |
| Brown Boobook                 | <i>Ninox scutulata</i>             | LC |
| Eurasian Hoopoe               | <i>Upupa epops</i>                 | LC |
| Malabar Gray Hornbill         | <i>Ocyeros griseus</i>             | VU |
| Blue-bearded Bee-eater        | <i>Nyctornis athertoni</i>         | LC |
| Asian Green Bee-eater         | <i>Merops orientalis</i>           | LC |
| Chestnut-headed Bee-eater     | <i>Merops leschenaulti</i>         | LC |
| Common Kingfisher             | <i>Alcedo atthis</i>               | LC |
| Stork-billed Kingfisher       | <i>Pelargopsis capensis</i>        | LC |
| White-throated Kingfisher     | <i>Halcyon smyrnensis</i>          | LC |
| Indian Roller                 | <i>Coracias benghalensis</i>       | LC |
| Dollarbird                    | <i>Eurystomus orientalis</i>       | LC |
| Malabar Barbet                | <i>Psilopogon malabaricus</i>      | LC |
| White-cheeked Barbet          | <i>Psilopogon viridis</i>          | LC |
| Speckled Piculet              | <i>Picumnus innominatus</i>        | LC |
| Heart-spotted Woodpecker      | <i>Hemicircus canente</i>          | LC |
| Brown-capped Pygmy Woodpecker | <i>Yungipicus nanus</i>            | LC |
| Malabar Flameback             | <i>Chrysocolaptes socialis</i>     | LC |
| Rufous Woodpecker             | <i>Micropternus brachyurus</i>     | LC |

|                              |                           |    |
|------------------------------|---------------------------|----|
| Black-rumped Flameback       | Dinopium benghalense      | LC |
| Lesser Yellownappe           | Picus chlorolophus        | LC |
| Streak-throated Woodpecker   | Picus xanthopygaeus       | LC |
| White-bellied Woodpecker     | Dryocopus javensis        | LC |
| Peregrine Falcon             | Falco peregrinus          | LC |
| Rose-ringed Parakeet         | Psittacula krameri        | LC |
| Plum-headed Parakeet         | Psittacula cyanocephala   | LC |
| Malabar Parakeet             | Psittacula columboides    | NT |
| Vernal Hanging-Parrot        | Loriculus vernalis        | LC |
| Indian Pitta                 | Pitta brachyura           | LC |
| Small Minivet                | Pericrocotus cinnamomeus  | LC |
| Orange Minivet               | Pericrocotus flammeus     | LC |
| Black-headed Cuckooshrike    | Lalage melanoptera        | LC |
| Indian Golden Oriole         | Oriolus kundoo            | LC |
| Ashy Woodswallow             | Artamus fuscus            | LC |
| Malabar Woodshrike           | Tephrodornis sylvicola    | LC |
| Bar-winged Flycatcher-shrike | Hemipus picatus           | LC |
| Asian Fairy-bluebird         | Irena puella              | LC |
| Common Iora                  | Aegithina tiphia          | LC |
| Black Drongo                 | Dicrurus macrocercus      | LC |
| Ashy Drongo                  | Dicrurus leucophaeus      | LC |
| Bronzed Drongo               | Dicrurus aeneus           | LC |
| Greater Racket-tailed Drongo | Dicrurus paradiseus       | LC |
| Black-naped Monarch          | Hypothymis azurea         | LC |
| Indian Paradise-Flycatcher   | Terpsiphone paradisi      | LC |
| Common Rosefinch             | Carpodacus erythrinus     | LC |
| Brown Shrike                 | Lanius cristatus          | LC |
| Bay-backed Shrike            | Lanius vittatus           | LC |
| Long-tailed Shrike           | Lanius schach             | LC |
| House Crow                   | Corvus splendens          | LC |
| Large-billed Crow            | Corvus macrorhynchos      | LC |
| Asian Tit                    | Parus cinereus            | LC |
| Indian Yellow Tit            | Machlolophus aplonotus    | LC |
| Common Tailorbird            | Orthotomus sutorius       | LC |
| Gray-breasted Prinia         | Prinia hodgsonii          | LC |
| Ashy Prinia                  | Prinia socialis           | LC |
| Thick-billed Warbler         | Arundinax aedon           | LC |
| Blyth's Reed Warbler         | Acrocephalus dumetorum    | LC |
| Clamorous Reed Warbler       | Acrocephalus stentoreus   | LC |
| Dusky Crag-Martin            | Ptyonoprogne concolor     | LC |
| Hill Swallow                 | Hirundo domicola          | LC |
| Eastern Red-rumped Swallow   | Cecropis daurica          | LC |
| Yellow-browed Bulbul         | Acritillas indica         | LC |
| Red-whiskered Bulbul         | Pycnonotus jocosus        | LC |
| Red-vented Bulbul            | Pycnonotus cafer          | LC |
| Green Warbler                | Phylloscopus nitidus      | LC |
| Greenish Warbler             | Phylloscopus trochiloides | LC |
| Large-billed Leaf Warbler    | Phylloscopus magnirostris | LC |
| Lesser Whitethroat           | Curruca curruca           | LC |
| Indian White-eye             | Zosterops palpebrosus     | LC |
| Tawny-bellied Babbler        | Dumetia hypertyra         | LC |
| Dark-fronted Babbler         | Dumetia atriceps          | LC |

|                           |                                  |    |
|---------------------------|----------------------------------|----|
| Indian Scimitar-Babbler   | <i>Pomatorhinus horsfieldii</i>  | LC |
| Puff-throated Babbler     | <i>Pellorneum ruficeps</i>       | LC |
| Brown-cheeked Fulvetta    | <i>Alcippe poioicephala</i>      | LC |
| Rufous Babbler            | <i>Argya subrufa</i>             | LC |
| Jungle Babbler            | <i>Argya striata</i>             | LC |
| Wayanad Laughingthrush    | <i>Pterorhinus delesserti</i>    | NT |
| Velvet-fronted Nuthatch   | <i>Sitta frontalis</i>           | LC |
| Southern Hill Myna        | <i>Gracula indica</i>            | LC |
| Brahminy Starling         | <i>Sturnia pagodarum</i>         | LC |
| Chestnut-tailed Starling  | <i>Sturnia malabarica</i>        | LC |
| Malabar Starling          | <i>Sturnia blythii</i>           | VU |
| Common Myna               | <i>Acridotheres tristis</i>      | LC |
| Jungle Myna               | <i>Acridotheres fuscus</i>       | LC |
| Orange-headed Thrush      | <i>Geokichla citrina</i>         | LC |
| Indian Blackbird          | <i>Turdus simillimus</i>         | LC |
| Asian Brown Flycatcher    | <i>Muscicapa dauurica</i>        | LC |
| Brown-breasted Flycatcher | <i>Muscicapa muttui</i>          | LC |
| Oriental Magpie-Robin     | <i>Copsychus saularis</i>        | LC |
| Verditer Flycatcher       | <i>Eumyias thalassinus</i>       | LC |
| Tickell's Blue Flycatcher | <i>Cyornis tickelliae</i>        | LC |
| Indian Blue Robin         | <i>Larvivora brunnea</i>         | LC |
| Malabar Whistling-Thrush  | <i>Myophonus horsfieldii</i>     | LC |
| Rusty-tailed Flycatcher   | <i>Ficedula ruficauda</i>        | LC |
| Blue-capped Rock-Thrush   | <i>Monticola cinclorhyncha</i>   | LC |
| Pied Bushchat             | <i>Saxicola caprata</i>          | LC |
| Pale-billed Flowerpecker  | <i>Dicaeum erythrorhynchos</i>   | LC |
| Nilgiri Flowerpecker      | <i>Dicaeum concolor</i>          | LC |
| Purple-rumped Sunbird     | <i>Leptocoma zeylonica</i>       | LC |
| Crimson-backed Sunbird    | <i>Leptocoma minima</i>          | LC |
| Purple Sunbird            | <i>Cinnyris asiaticus</i>        | LC |
| Loten's Sunbird           | <i>Cinnyris lotenius</i>         | LC |
| Little Spiderhunter       | <i>Arachnothera longirostra</i>  | LC |
| Scaly-breasted Munia      | <i>Lonchura punctulata</i>       | LC |
| Black-throated Munia      | <i>Lonchura kelaarti</i>         | LC |
| White-rumped Munia        | <i>Lonchura striata</i>          | LC |
| House Sparrow             | <i>Passer domesticus</i>         | LC |
| Forest Wagtail            | <i>Dendronanthus indicus</i>     | LC |
| Gray Wagtail              | <i>Motacilla cinerea</i>         | LC |
| White-browed Wagtail      | <i>Motacilla maderaspatensis</i> | LC |
| Paddyfield Pipit          | <i>Anthus rufulus</i>            | LC |

## 2.4 Summary of IUCN Status:

- Least Concern (LC): Most species listed fall into this category.
- Near Threatened (NT): A few species, such as the Malabar Parakeet and Wayanad Laughingthrush.
- Vulnerable (VU): Jerdon's Baza, Malabar Gray Hornbill, and Malabar Starling.

## III. RESULTS AND DISCUSSION

During the study, a total of 166 species were documented. Key findings include several endemic species of the Western Ghats, such as the Wayanad Laughing Thrush and Jerdon's Baza, underscoring the ecological significance of the Naseera Botanical

Garden as a habitat for both resident and migratory species. The diversity of birds recorded reflects the rich habitats available within the campus, which supports a wide variety of avian species.

Bird species richness within the study area suggests a robust ecological environment, attributed to the variety of vegetation types and habitat patches present within the campus. The botanical garden serves as an important refuge for avifauna, providing food sources, nesting sites, and protection from urban disturbances. Observations align with previous studies that underscore the role of semi-urban green spaces in maintaining avian diversity.

This baseline checklist provides essential information for future conservation efforts and habitat management in the **Naseera Botanical Garden at Dr. Moopen's Medical College, Wayanad**. Additionally, it establishes a foundation for long-term avian studies within the educational campus setting, contributing to broader efforts to conserve Western Ghats biodiversity. This research highlights the importance of preserving and enhancing green spaces in semi-urban areas, offering insights into how academic institutions can support biodiversity conservation.

#### IV. CONCLUSION

The assessment of avian diversity within the **Naseera Botanical Garden at Dr. Moopen's Medical College** has revealed a rich tapestry of bird species, underscoring the ecological importance of this habitat in the Western Ghats. Our findings indicate that most species observed fall under the Least Concern (LC) category, suggesting a stable population status for the majority of birds within the garden. However, the presence of Near Threatened (NT) species such as the Malabar Parakeet and Wayanad Laughingthrush highlights the need for continued monitoring and conservation efforts in the region.

Additionally, the identification of Vulnerable (VU) species, including Jerdon's Baza, Malabar Gray Hornbill, and Malabar Starling, serves as a crucial indicator of the pressures these birds face in their natural habitats. This underscores the necessity for proactive conservation strategies to safeguard these species and their ecosystems.

Overall, this study emphasizes the significance of the **Naseera Botanical Garden at Dr. Moopen's Medical College** as a vital sanctuary for avian diversity. It is essential to maintain and enhance such green spaces, not only for the birds they support but also for the broader ecological health of the Western Ghats. Further research and targeted conservation actions will be imperative to protect vulnerable species and ensure the sustainability of bird populations in this biodiverse region.

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# Effect of Balanced Nutrient Approaches on Yield, Quality and Economics of Different Rice Varieties Under Direct Seeded Upland Condition in Eastern India

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**Abstract**— A field experiment was conducted at Central Rain-fed Upland Rice Research Station (CRURRS), Hazaribagh, research station in Jharkhand with the objective to determine better nutrient management practices for zero till upland rice and their effect on yield and nutrient use efficiency. The experiment was laid out in split-plot design with three replications having three rice cultivar Vandana, Anjali and CR Dhan 40 in main plot and four nutrient management practices [soil test fertilizer recommendation meter (STFR), integrated nutrient management (INM), soil test crop response equation (STCR) and recommended dose of fertilizers (RDF)] in sub-plot. Results indicated that CR Dhan 40 recorded higher leaf area index, dry matter accumulation and number of effective tillers at 90 DAS compared to Vandana and Anjali. However, Vandana was better in terms of plant height of rice. Among nutrient management practices, STFR recorded significantly higher plant height, LAI and tillers per plant compared to other practices. Whereas STFR and INM were equally good in terms of DMA of rice at 90 DAS. CR Dhan 40 recorded the highest grain (3.85 t/ha), straw yield (6.22 t/ha), net returns ( $47.59 \times 10^3$  ₹/ha) and B:C ratio (1.98) followed by Anjali and Vandana. STFR enhanced the grain yield by 47% compared to RDF. STFR based NPK recorded the highest net returns ( $38.20 \times 10^3$  ₹/ha) followed by other NM practices. CR Dhan 40 had higher milling (60.3%) and head rice recovery (51.5%) compared to Anjali and Vandana. Whereas STFR based NPK application was better in hulling, milling and head rice recovery. STFR and INM recorded higher values of protein yield followed by STCR. Therefore, based on research findings, it can be concluded that rice cultivar “CR Dhan 40” with STFR and INM based fertilization may enhance the productivity and profitability of upland rice in the Eastern regions of India.

**Keywords**— Zero Tillage, INM, Soil Test Crop Response equation, Varieties.

## I. INTRODUCTION

Rice (*Oryza sativa* L.) is the second most important grain crop in India and cultivated in 43.38 million hectares (mha), with an annual production of 104.32 million tons (mt)[1]. It is a staple food for the 60 percent population of India. To address the growing demand for the food, feed and industrial sectors, as well as to access the export markets, rice production would still need to increase by additional 143 mt to cope with 40% world population and to raise average food consumption to 3130 kcal/person/day by 2050 [1]. In Asia, rice is commonly grown with wet tillage land preparation (puddled soil) by transplanting seedlings which adversely affects soil physical properties by destroying soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths [2]. Alongside, it is considered one of the major sources of methane (CH<sub>4</sub>) emissions and accounts for 10-20% (50-100 Tg/year) of total global annual CH<sub>4</sub> emissions [3]. Puddling and transplanting require large amount of water and labour, both of which are becoming increasingly scarce and expensive. Upland rice grown in rain-fed, naturally well-drained soils, without surface water accumulation could be a better under direct seeded rice method.

Dry-seeding of rice with subsequent aerobic soil conditions eliminates the need of puddling and subsequent submerged soil conditions, thus reducing the overall water demand and providing opportunities for water and labour savings[2]. Direct seeding enables the sowing of rice without any heavy tillage operation under conservation agriculture. Conservation agriculture (CA) has been widely promoted in rice-wheat cropping system to sustain the productivity and soil health in a long run[4]. CA is a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (*i.e.* zero tillage), and diversification of plant species. ZT rice has several advantages such as it involves low fuel consumption in land preparation, reduced labour costs, improved soil health and quality and conserves soil moisture with higher water use efficiency (WUE) and NUE of about 15-20% along with higher yield.

Rice grown under upland condition is generally low in nutrient availability. In addition, the imbalance and indiscriminate use of fertilizer is one of the most important factors for low productivity and nutrient use efficiency in rice crop [5]. The development of early maturing varieties and improved nutrient management techniques along with integrated weed management methods have encouraged many farmers in the Philippines, Thailand and India to switch from Transplanted Rice (TPR) to Direct Seeded Rice (DSR) [6]. Conjunctive use of organic manure along with fertilizer has been proved to be an efficient source of nutrient supply. Organic residue recycling is becoming an increasingly important aspect of environmentally sound sustainable agriculture. Returning residues like green manure to the soil is necessary for maintaining soil organic matter, which is important for favorable soil structure, soil water retention and soil microflora and fauna activities. To enhance farm profitability under different soil-climate conditions, it is necessary to determine the optimum fertilizer doses and appropriate method of fertilizer application on the basis of soil test and crop response studies [7]. In order to achieve the higher and sustained yield over long period by maintaining the soil fertility level and preventing the environmental contamination, it is very much necessary to maintain balance between nutrient requirement of crops and nutrient reserves in soil. Managing the location specific variability in nutrient supply is a key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand in upland rice environments. The soil test crop response (STCR) approach is a novel approach wherein fertilizer recommendations are made by considering nutrient use efficiency (NUE) of the crop and nutrient contribution of soil. STCR approach could be a strategy to enhance rice productivity (15-35%) and NUE in rice-wheat cropping system [7]. Besides this, soil test fertilizer recommendation (STFR) meter can give nutrient-specific fertilizer requirement to crop. It addresses the site-specific nutrient management (SSNM) principles and utilizes information of the growing environment to provide balanced fertilizer recommendations for rice which are tailored for a particular location, cropping system, rice ecology, season, and farmer resource availability [8]. Despite the huge vast scope of growing rice under zero-till upland conditions in Jharkhand, with fertilizer recommendations by STFR meter and STCR approach, very limited research has been done for evaluating these management practices. Therefore, it need to be tested in various ecologies for sustainable production in Jharkhand region. With respect to it, the current study is planned on the topic entitled "Developing nutrient management options for different rice cultivars under zero-till upland conditions.

## II. MATERIAL AND METHODS

A field experiment was conducted during *kharif* season, 2018 at Mashipirhi farm, Central Rainfed Upland Rice Research Institute, Hazaribagh, Jharkhand is characterized by humid and sub-humid tropical climate. The average temperature of Hazaribagh was 23.7 °C and 1274 mm respectively during crop duration. The average rainfall of the district is 783 mm of which 700 mm of rainfall is precipitated during the months of June to September (Figure1). The experimental field was under rice-fallow cropping system during the last five years. The initial soil physical characteristics reveals the mechanical composition (Hydrometer method Bouyocos 1962 [9]) as red with textural class as Sandy clay loam. Moisture at 1/3 and 15 bar tension is 28.72 and 14.87 % respectively (Pressure plate apparatus, Richards and Weaver, 1943 [10]). Bulk density (0–15 cm layer) is 1.5 (Mg/m<sup>3</sup>). Soil chemical characteristics were as pH 5.2 (Piper, 1966 [11]), EC is 0.29 (m mhos cm<sup>-1</sup>) organic carbon 0.39 % (Walkley and Black, 1934 [12]), available-N 220 kg/ha (Subbiah & Asija, 1956 [13]), available-P 15.6 kg/ha (Bray's No.1 Method [14]) and available-K 420 kg/ha (Hanway and Heidel, 1952 [15]) were recorded as per the procedures mentioned.

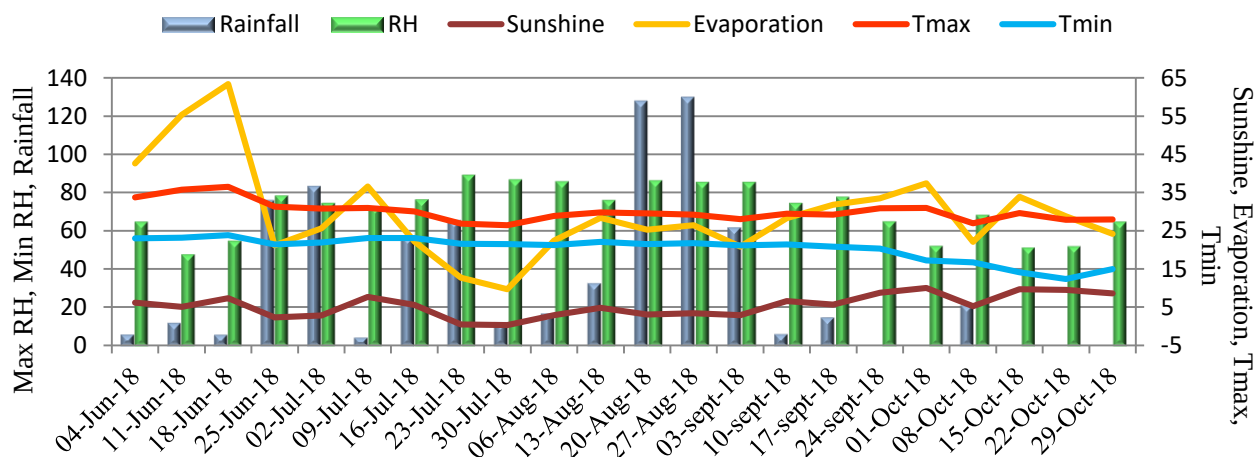


FIGURE 1: Agro-meteorological parameters recorded during *kharif* 2018

### 2.1 Description of imposed treatments:

The experiment was laid out in split-plot design with three replications having three rice cultivars Vandana, Anjali and CR Dhan 40 in main plots and four nutrient management practices soil test fertilizer recommendation meter (STFR), integrated nutrient management (INM), soil-test crop response equation (STCR) and recommended dose of fertilizers (RDF) in sub-plots. Treatments were allocated randomly on the experimental units. The experimental field was kept under zero-till conditions. The sowing was done with the help of seed drill at row spacing of 22.5 cm using seed 50 kg/ ha.

### 2.2 Soil test crop response (STCR):

Soil test crop response (STCR) equations for soil test-based fertilizer were as

- $FN = 6.14T - 0.55SN$  (FN= Fertilizer N), (T=Targeted yield), (SN= Soil available N)
- $FP_2O_5 = 2.83T - 2.16SP_2O_5$  ( $FP_2O_5$  = Fertilizer P), ( $SP_2O_5$  = Soil available  $P_2O_5$ )
- $FK_2O = 3.73T - 0.70SK_2O$  ( $FK_2O$ = Fertilizer K), ( $SK_2O$ = Soil available  $K_2O$ ) for N, P and K respectively. Based on above equations Fertilizer dose required calculated and analyzed further.

TABLE 1  
SOIL TEST-BASED ANALYSIS FOR SOIL TEST CROP RESPONSE (STCR) EQUATION

| STCR general equation for Jharkhand | Variety    | Targeted yield (t/ha) | Soil test value of nutrient (kg/ha) | Recommended dose (kg/ha) |
|-------------------------------------|------------|-----------------------|-------------------------------------|--------------------------|
| $FN = 6.14T - 0.55SN$               | Vandana    | 3.5                   | 220                                 | 87                       |
|                                     | Anjali     | 3.5                   |                                     |                          |
|                                     | CR Dhan 40 | 3.5                   |                                     |                          |
| $FK_2O = 3.73T - 0.70SK_2O$         | Vandana    | 3.5                   | 420                                 | Not required             |
|                                     | Anjali     | 3.5                   |                                     |                          |
|                                     | CR Dhan 40 | 3.5                   |                                     |                          |
| $FP_2O_5 = 2.83T - 2.16SP_2O_5$     | Vandana    | 3.5                   | 15.6                                | 44                       |
|                                     | Anjali     | 3.5                   |                                     |                          |
|                                     | CR Dhan 40 | 3.5                   |                                     |                          |

### 2.3 Soil test-based fertilizer recommendation (STFR) meter:

Plot-wise soil samples were collected before sowing of crop from 0–15 cm and 0-30 depth of soil and evaluated. Based on analysis, the STFR meter recommended the amount of fertilizers DAP, MOP, urea as 98, 15 and 217 kg/ha along with manure (6.5 t/ha) and lime (6 t/ha) according to soil pH, soil organic carbon and available NPK of the site.

One third of nitrogen (i.e. 29, 34, 27, 23 kg/ha from STCR, STFR, 50% RDF + 50% Organics, and RDF respectively are applied through urea, full dose of phosphorus through diammonium phosphate (DAP) and potassium through muriate of potash

(MOP) were applied as basal at the time of sowing in all the treatments. Further nitrogen was top dressed in splits at one third dose at 30 & 60 DAS respectively. Lime application was done 15 days before sowing of the crop.

## 2.4 Recording growth parameters and grain yield:

Five plants randomly selected were tagged permanently in each plot for recording plant height, total number of tillers and effective tillers. The number of effective tillers were counted over meter square area at crop harvest stage. Plants from one square meter length from second row onwards were uprooted and sun dried for 2-3 days followed by drying in oven at  $60-65 \pm 2^\circ\text{C}$  for 24 hours to get dry matter accumulation in grams/m<sup>2</sup>. Leaf area meter (LI-COR Model LI-3100) was used to record leaf area (cm<sup>2</sup>) then leaf area index of selected plants was calculated by using the leaf area Index formula. Grain yield was calculated from the area by leaving 2 border rows on each side and reported at 12.5% moisture content. Straw yield was obtained by subtracting grain yield from respective total biomass yield (grain + straw). Crude protein content in rice grain was calculated by multiplying N concentration of grain with a coefficient factor 5.95 and multiplied with grain yield to get protein yield. Sun dried paddy samples weighing 100 g were hulled in a mini “Satake Rice Mill”, weight of brown rice was recorded and hulling percentage was calculated. The hulled brown grains of rice were passed through Satake Rice Whitening and Caking Machine for 2 minutes. Weight of polished rice was obtained and milling percentage was computed. The milled rice was sieved to separate whole kernels from broken grains to record head rice recovery in percentage.

## III. RESULT AND DISCUSSION

### 3.1 Growth parameters:

#### 3.1.1 Plant height, LAI, Dry-matter accumulation and Tiller production:

The growth parameters viz. plant height, LAI, dry-matter accumulation and tiller production were significantly influenced by different varieties at 90 DAS (Table 2). Vandana recorded higher plant height as compared to Anjali and CR Dhan 40 at 90 DAS. However, variety CR Dhan 40 recorded the highest number of tillers (344) followed by Anjali (308) and Vandana (282). Similarly CR Dhan 40 have highest DMA (1125 g/m<sup>2</sup>) and LAI (3.87) among all the varieties whereas among Anjali and Vandana were found to be at par. The plant varieties show a difference in plant height due to genetic makeup. The plant height and grain yield of different cultivars were inversely related due to more erectness, which lead to more height in Vandana [16].

Among nutrient management (NM) practices, STFR recorded the highest plant height (105 cm) LAI (3.92) and tillers/m<sup>2</sup> (331) followed by STCR and INM dose. RDF performed significantly poor in these growth parameters. However, STFR (1074 g/m<sup>2</sup>) and INM (1062 g/m<sup>2</sup>) were equally good in respect to the DMA followed by STCR and RDF. While, STCR (1046 g/m<sup>2</sup>) was also at par with INM (1039 g/m<sup>2</sup>). NPK application was balanced and as per the demand in STFR treatment which might have enhanced nutrient uptake from the soil by cultivars which lead to higher growth of rice plants[17].

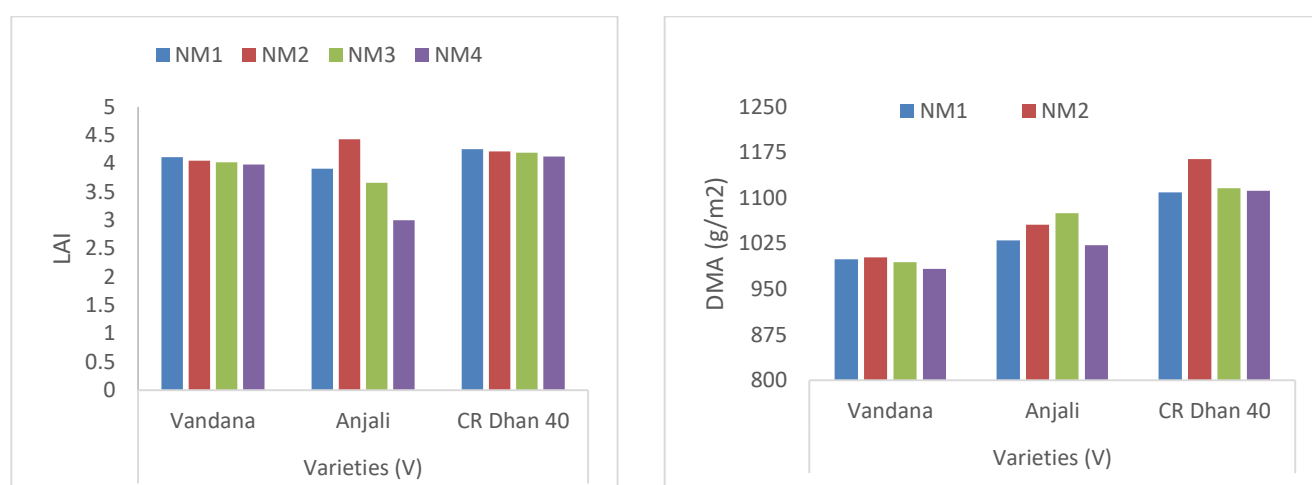


**FIGURE 2: Interaction effect of rice varieties and nutrient management on DMA and LAI of direct-seeded upland rice**  
(NM 1: STCR), (NM 2: STFR), (NM 3: INM), (NM 4: RDF)

Interaction results for Table 2 and Figure 2 shows that fertilizer application based on NM3 in the varieties Vandana and CR Dhan 40 decreased the dry matter accumulation by 4.1% and 3.2% respectively than NM2, whereas the fertilizer application based on NM3 in variety Anjali increased the dry mater accumulation by 9 %. Similarly, NM4 in the variety Vandana decreased the DMA by 6.6% than NM3, whereas it was decreased by 13.2% in the CR Dhan 40. In terms of LAI adoption of NM2 in the variety Vandana and CR Dhan 40 decreased the leaf area index by 1.46 % and 0.94% respectively than adoption of NM1, whereas the adoption of NM1 in variety Anjali increased the leaf area index by 13.2% than NM2. Similarly, the adoption of NM4 in the variety Vandana decreased the LAI by 0.99 % than NM3, whereas it was decreased by 1.67 % in the CR Dhan 40. It might have happened due to uniform rainfall solubilized lime in soil which increased the availability of nutrients according to the plant requirement [17].

**TABLE 2**  
**EFFECT OF RICE VARIETIES AND NUTRIENT MANAGEMENT ON GROWTH AND QUALITY PARAMETERS OF DIRECT-SEEDED UPLAND RICE**

| Treatment                | Hulling (%) | Milling (%) | Head rice recovery (%) | Crude protein (%) | At 90 DAS    |                     |     |                             |
|--------------------------|-------------|-------------|------------------------|-------------------|--------------|---------------------|-----|-----------------------------|
|                          |             |             |                        |                   | Plant height | DMA                 | LAI | Plant tiller/m <sup>2</sup> |
|                          |             |             |                        |                   | (cm)         | (g/m <sup>2</sup> ) |     |                             |
| Varieties (V)            |             |             |                        |                   |              |                     |     |                             |
| Vandana                  | 62.5        | 53.5        | 48.9                   | 7.2               | 104          | 994                 | 3.6 | 282                         |
| Anjali                   | 64.3        | 54.8        | 47.9                   | 7.3               | 97.2         | 1046                | 3.4 | 308                         |
| CR Dhan 40               | 69.5        | 60.3        | 51.5                   | 7.7               | 96.3         | 1125                | 3.9 | 344                         |
| SEm±                     | 1.84        | 1.04        | 1.27                   | 0.07              | 1.4          | 15.8                | 0.1 | 1.88                        |
| CD (P=0.05)              | 7.21        | 4.07        | 4.97                   | 0.27              | 5.56         | 62.2                | 0.2 | 7.36                        |
| Nutrient management (NM) |             |             |                        |                   |              |                     |     |                             |
| STCR                     | 64.8        | 55.7        | 48.3                   | 7.43              | 99.3         | 1046                | 3.8 | 311                         |
| STFR                     | 69.7        | 59.4        | 50.8                   | 7.73              | 105          | 1074                | 3.9 | 331                         |
| INM                      | 68.8        | 56.6        | 49.2                   | 7.69              | 96.2         | 1062                | 3.6 | 320                         |
| RDF                      | 59          | 52.8        | 45.3                   | 6.84              | 93.3         | 1039                | 3.2 | 284                         |
| SEm±                     | 0.89        | 0.72        | 0.31                   | 0.1               | 0.9          | 7.58                | 0.1 | 1.28                        |
| CD (P=0.05)              | 2.64        | 2.13        | 0.92                   | 0.3               | 2.7          | 22.5                | 0.2 | 3.8                         |
| V×NM                     | NS          | NS          | NS                     | NS                | NS           | S                   | S   | S                           |

### 3.1.2 Yield:

Grain and straw yield were significantly influenced by different rice varieties (Table 3). CR Dhan 40 recorded the highest grain (3.85 t/ha) and straw (6.22 t/ha) following Anjali and Vandana which remained at par. The variation in yield of CR Dhan 40 might be due to more number of effective tillers and dry matter production. Further, higher weed competitiveness and higher yield potential of CR Dhan 40 contributed towards higher yield.

### 3.1.3 Harvest index:

The harvest index was not influenced with different rice varieties (Table 3). In different nutrient management practices, STFR based NPK dose, INM and STCR remained at par with each other in terms of harvest index i.e. (40.5 %, 39.5 % and 38.9 %) respectively. RDF practice recorded the lowest harvest index values (34.6%).

**TABLE 3**  
**EFFECT OF RICE VARIETIES AND NUTRIENT MANAGEMENT ON YIELD AND ECONOMICS OF DIRECT-SEEDED UPLAND RICE**

| Treatment                | Yield (t/ha) |       |                       |        | Cost of Cultivation (×10 <sup>3</sup> ₹/ha) | Net Return (×10 <sup>3</sup> ₹/ha) | Net B:C |
|--------------------------|--------------|-------|-----------------------|--------|---------------------------------------------|------------------------------------|---------|
|                          | Grain        | Straw | Protein yield (kg/ha) | HI (%) |                                             |                                    |         |
| Varieties(V)             |              |       |                       |        |                                             |                                    |         |
| Vandana                  | 3.20         | 5.61  | 230                   | 38.2   | 23.67                                       | 29.25                              | 1.24    |
| Anjali                   | 3.40         | 5.56  | 248                   | 37.8   | 23.67                                       | 29.83                              | 1.26    |
| CR Dhan 40               | 3.85         | 6.22  | 309                   | 38.8   | 24.07                                       | 47.59                              | 1.98    |
| SEm±                     | 0.10         | 0.11  | 4.54                  | 0.65   | -                                           | 0.08                               | 0.04    |
| CD (P=0.05)              | 0.41         | 0.46  | 17.79                 | NS     | -                                           | 0.31                               | 0.15    |
| Nutrient management (NM) |              |       |                       |        |                                             |                                    |         |
| STCR                     | 3.50         | 5.80  | 274                   | 38.9   | 24.00                                       | 36.56                              | 1.52    |
| STFR                     | 4.02         | 6.06  | 309                   | 40.5   | 26.07                                       | 38.20                              | 1.46    |
| INM                      | 3.68         | 6.05  | 301                   | 39.5   | 24.13                                       | 36.75                              | 1.52    |
| RDF                      | 2.73         | 5.30  | 205                   | 34.6   | 21.00                                       | 30.72                              | 1.46    |
| SEm±                     | 0.13         | 0.13  | 1.35                  | 1.32   | -                                           | 0.10                               | 0.68    |
| CD (P=0.05)              | 0.38         | 0.38  | 4.00                  | 3.9    | -                                           | 0.29                               | NS      |
| Interactions (C×NM)      | NS           | NS    | NS                    | NS     |                                             |                                    |         |

#### 3.1.4 Quality parameters:

Rice varieties had non-significant impact on hulling percentage. However milling and head rice recovery was significantly affected by different rice varieties. CR Dhan 40 had higher milling (60.3%) and head rice recovery (51.5%) compared to Anjali and Vandana. Whereas Anjali and Vandana remained on par in both all quality parameters. The main reason could be the genetic characteristics and genetic yield potential of the different varieties. Further, a higher strength of aleurone layer in rice grain in CR Dhan 40 might be the reason for higher head rice recovery [20,21].

Nutrient management (NM) practices shown significant influence on the hulling, milling and head rice recovery percentage (Table 2). In different nutrient management practices, STFR and INM based NPK dose remained at par with respect to hulling followed by STCR and RDF. In terms of milling percentage, STFR based fertilization recorded the highest values (59.4%) followed by INM (56.6%), STCR based fertilization (55.7%) and RDF practice (52.8%). STFR based NPK dose had highest head rice recovery. Moreover, INM and STCR were on par and INM was found to have lowest percent head rice recovery values. The optimum and balanced dose of NPK fertilization and application of fertilizers based on soil nutrient status with various nutrient management options in site specific manner might be the reason for increased quality parameters [22]. Furthermore, mobilization of nutrients might be the reason for higher protein yield [23].

#### 3.1.5 Protein concentration and yield:

The protein concentration and yield were significantly influenced with different rice varieties (Table 2). The rice variety CR Dhan 40 recorded the highest protein concentration and yield followed by Anjali and Vandana. In different nutrient management practices, STFR based NPK dose, INM based NPK dose, STCR based fertilization and RDF practices remained at par with protein concentration. However, STFR based fertilization and INM recorded higher values of protein yield followed by STCR and RDF.

#### 3.1.6 Economics:

Cost of cultivation variation is not large in different rice varieties (Table 3). The rice variety CR Dhan 40 costs the highest cultivation charges ( $24.07 \times 10^3$  ₹/ha) followed by Vandana and Anjali. Among nutrient management (NM) practices, STFR based NPK dose recorded the highest cost of cultivation ( $26.07 \times 10^3$  ₹/ha), while lowest in RDF practice. The net return and benefit: cost (B:C) were significantly varied with different rice varieties (Table 3). The rice variety CR Dhan 40 recorded the

highest net returns ( $47.59 \times 10^3$  ₹/ha) and Net B:C ratio (1.98) followed by Vandana and Anjali. The higher grain and straw yield of CR Dhan 40 might have contributed to higher gross and net return. Nutrient management (NM) practices shown non-significant impact on the B:C ratio results. However net return was significantly influenced by different nutrient management practices. STFR based NPK dose recorded the highest net returns ( $38.20 \times 10^3$  ₹/ha) followed by other NM practices. INM based NPK dose remained at par with STCR based fertilization in terms of net returns followed by RDF practice.

#### IV. CONCLUSION

The different rice cultivars and various nutrient management practices significantly influenced the growth parameters, yield attributes and yield of upland rice under rain-fed conditions in Jharkhand. The rice cultivar CR Dhan 40 recorded vigorous growth, yield attributes and yield followed by Anjali and Vandana. STFR based NPK fertilization recorded the highest growth parameters, yield attributes and yield which remained at par with INM (50 % RDF+ 50% Organics) and STCR (87 kg N, 44 kg  $P_2O_5$ , 0 K + 1.5 t/ha lime) followed by RDF application (70 kg N, 40 kg  $P_2O_5$ , 20 kg  $K_2O$ ).

Based on the research findings, it can be concluded that rice cultivar CR Dhan 40 was the best cultivar in terms of yield and economics. STFR based NPK dose (100 kg N, 44 kg  $P_2O_5$ , 20 kg  $K_2O$  + 5 t/ha lime) and INM (50% RDF+50% organics) NPK dose [40 kg N, 28 kg  $P_2O_5$ , 10 kg  $K_2O$  (50%) + 6 t/ha FYM (50%) + lime 1 t/ha] were found optimum in terms of yield, economics and use efficiency of applied NPK. Therefore, based on research findings, it can be concluded that rice cultivar “CR Dhan 40” with STFR and INM based fertilization may enhance the productivity and profitability of upland rice in the Eastern regions of India.

#### AUTHOR CONTRIBUTIONS

Conceptualization, S.S. , R. B. and N.K.P., methodology, B.S.P and K.A.; software, B.S.P.,; Validation B.P., and K.A.; formal analysis, B.P. and S.S; investigation, B.P. and R.B.; resources, S.S.; data curation, B.S.P and K.A.; writing-B.S.P.; writing-review and editing, S.S.; and N.K.P. visualization. S.S.; supervision, S.S. and N.K.P.; project administration, S.S.; funding acquisition S.S.; All authors have read and agreed to the published version of the manuscript.

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Not applicable

#### DATA AVAILABILITY STATEMENT

All the data are included within the manuscript and supplementary table.

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#### CONFLICT OF INTEREST

The author declares no conflict of interest.

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RETRACTED

This article has been retracted

# Varietal Screening of Rice Genotypes for Stem Rot (*Sclerotium oryzae*) under Artificial Inoculation Method

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**Abstract**— Rice (*Oryza sativa* L.) is a staple food in many countries and food security to millions of population in the world and is one of the major food crops of India. Stem rot is the one among major diseases of paddy infect the crop from moderate to severe form and also result in commercial yield losses. Looking to the disease severity, the present investigation was carried out to study the sources of resistance of pathogen in order to minimize the crop losses of rice. Screening of forty four genotypes along with two susceptible checks against stem rot pathogen under artificial inoculation condition during kharif 2019 revealed that, 18 genotypes were found moderately resistant viz., NVSR-317, NVSR-348, NVSR-355, NVSR-2147, NVSR-2566, NVSR-330, NVSR-360, NVSR-365, NVSR-370, NVSR-374, NVSR-405, NVSR-407, NVSR-2102, NVSR-2117, NVSR-2130, NVSR-2140, NVSR-2153 and IET-24336. Whereas, 12 genotypes viz., NVSR-2101, NVSR-328, NVSR-2528, NVSR-331, NVSR-335, NVSR-364, NVSR-384, NVSR-2435, NVSR-368, IET-25470, GR-11 and TN-1 were found susceptible to *Sclerotium oryzae*.

**Keywords**— Rice, *Sclerotium oryzae*, Genotypes, Pathogen.

## I. INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal crop in the developing world and is a staple food of over half the world's population and food security to millions of population in the world. The total area of the world under harvested rice is 167.24 million hectares producing 500 million tonnes of grains in 2017 (Anonymous, 2020). In India, rice is cultivated on 43.19 million hectares with an annual production of 117.47 million tonnes and annual yield 2550 kg/ha (Anonymous, 2019). In Gujarat, Rice is cultivated on 0.84 million hectares with an annual production of 1.93 million tonnes and annual yield 2306 kg/ha in 2016-2017 (Anonymous, 2017). Stem rot is a fungal disease caused by *Sclerotium oryzae* was first described from Italy by Cattaneo in the sclerotial form in 1876 and he was given name *Sclerotium oryzae* Catt. Cavara in 1889 later reported *Helminthosporium sigmoideum* Cav. on rice (Gopika *et al.*, 2016<sup>b</sup>). Stem rot (*Sclerotium oryzae* Catt.) perfect state *Magnaporthe salvinii* Catt., is a destructive disease under favourable weather conditions in rice growing areas of the world which eventually causes substantial spectrum of diseases (Venkateswarlu *et al.*, 2013). Stem rot was considered as a minor disease in earlier, is now one of the major constraint in rice cultivation in East Godavari, Warangal and Khammam districts of Andhra Pradesh in recent years (Gopika *et al.*, 2016<sup>a</sup>). The pathogen has been reported to cause substantial losses in grain yield ranging from 5-80 per cent (Kumar *et al.*, 2003).

## II. MATERIALS AND METHODS

Use of high yielding and identification of resistant or tolerant genotypes or entries is the most viable, environmentally safe and economically sound technique for the management of the disease. Hence, the present investigation was undertaken to find out resistant sources against stem rot disease of rice under artificial condition. Forty four genotypes + two checks were screened under field with 15 cm x 20 cm spacing, fertilizer 150:30:00 (N: P: K) kg/hectare. The screening trial was conducted during *kharif* 2019 at Main Rice Research Centre, N.A.U., Navsari. Two rows of two meter length for each genotypes were taken and international susceptible check TN-1 and local susceptible check GR-11 were planted after 10<sup>th</sup> test entry. The local susceptible check GR-11 was planted around the screening nursery. The artificial inoculation of stem rot pathogen was done by standard sclerotium inoculation technique after 30 days of transplanting by placing the inoculum between the tillers just above the water line with the help of sterilized forceps and observations were recorded by using 0-9 SES scale as per SES of rice (IRRI, 2013).

**Formula for calculating per cent disease intensity is**

$$PDI = \frac{\text{Sum of score}}{\text{No. of observation} \times \text{Highest number of rating scale}} \times 100 \quad (1)$$

Ten hills from each genotype was randomly selected and considered for grading the severity of disease on standing plants. The severity of stem rot disease was recorded by following the standard evaluation system of rice.

**Disease severity scale for stem rot of rice (IRRI, 2013).**

|   |                                |
|---|--------------------------------|
| 0 | No incidence (Immune)          |
| 1 | Less than 1% (Resistant)       |
| 3 | 1-5% (Moderately Resistant)    |
| 5 | 6-25% (Moderately Susceptible) |
| 7 | 26-50% (Susceptible)           |
| 9 | 51-100% (Highly Susceptible)   |

## III. RESULTS AND DISCUSSION

Forty four rice genotypes along with two susceptible check GR-11 and TN-1 were screened against the *S. oryzae* under field condition by artificial inoculation method. The results presented in [Table-1 and Table-2] revealed that among all the tested genotypes none were found immune, resistant as well as highly susceptible. Out of them, 18 genotypes were found moderately resistant viz., NVSR-317, NVSR-348, NVSR-355, NVSR-2147, NVSR-2566, NVSR-330, NVSR-360, NVSR-365, NVSR-370, NVSR-374, NVSR-405, NVSR-407, NVSR-2102, NVSR-2117, NVSR-2130, NVSR-2140, NVSR-2153 and IET-24336. Whereas, 16 genotypes viz., NVSR-350, NVSR-411, NVSR-2103, NVSR-401, NVSR-329, NVSR-2526, NVSR-2565, NVSR-338, NVSR-367, NVSR-389, NVSR-406, NVSR-2115, NVSR-2116, NVSR-2155, IET-25453 and IET-24783 were found moderately susceptible. 12 genotypes viz., NVSR-2101, NVSR-328, NVSR-2528, NVSR-331, NVSR-335, NVSR-364, NVSR-384, NVSR-2435, NVSR-368, IET-25470, GR-11 and TN-1 were found susceptible to *S. oryzae*.

Among forty four screened genotypes, highest disease severity (45.6 %) was recorded in international susceptible check TN-1, which was followed by; genotype NVSR-331 (43.3 %) and susceptible state check GR-11 (42.2 %). Whereas, lowest disease severity (1.1 %) was recorded in genotype NVSR-370 and NVSR-2153.

From the study, it was revealed that out of 44 genotypes tested along with 2 susceptible checks, 18 genotypes were found moderately resistant. Whereas, 16 genotypes were showed moderately susceptible reaction and 12 genotypes were found susceptible to *S. oryzae* under artificial inoculation method [Table-2].

**TABLE 1**  
**SCREENING OF PADDY GENOTYPES FOR STEM ROT UNDER ARTIFICIAL INOCULATION METHOD**

| Sr. No. | Genotypes | Disease severity (%) | Disease Index scale (0-9 Scale) | Disease reaction | Sr. No. | Genotypes     | Disease severity (%) | Disease Index scale (0-9 Scale) | Disease reaction |
|---------|-----------|----------------------|---------------------------------|------------------|---------|---------------|----------------------|---------------------------------|------------------|
| 1       | NVSR-317  | 4.4                  | 3                               | MR               | 24      | NVSR-370      | 1.1                  | 3                               | MR               |
| 2       | NVSR-348  | 3.3                  | 3                               | MR               | 25      | NVSR-374      | 3.3                  | 3                               | MR               |
| 3       | NVSR-350  | 15.6                 | 5                               | MS               | 26      | NVSR-384      | 34.4                 | 7                               | S                |
| 4       | NVSR-355  | 2.2                  | 3                               | MR               | 27      | NVSR-389      | 13.3                 | 5                               | MS               |
| 5       | NVSR-411  | 13.3                 | 5                               | MS               | 28      | NVSR-405      | 4.4                  | 3                               | MR               |
| 6       | NVSR-2101 | 28.9                 | 7                               | S                | 29      | NVSR-2435     | 40.0                 | 7                               | S                |
| 7       | NVSR-2103 | 16.7                 | 5                               | MS               | 30      | NVSR-406      | 21.1                 | 5                               | MS               |
| 8       | NVSR-401  | 6.7                  | 5                               | MS               | 31      | NVSR-407      | 3.3                  | 3                               | MR               |
| 9       | NVSR-2147 | 2.2                  | 3                               | MR               | 32      | NVSR-368      | 38.8                 | 7                               | S                |
| 10      | NVSR-328  | 27.3                 | 7                               | S                | 33      | NVSR-2102     | 4.4                  | 3                               | MR               |
| 11      | NVSR-329  | 11.1                 | 5                               | MS               | 34      | NVSR-2115     | 13.3                 | 5                               | MS               |
| 12      | NVSR-2526 | 20.0                 | 5                               | MS               | 35      | NVSR-2116     | 23.3                 | 5                               | MS               |
| 13      | NVSR-2528 | 35.6                 | 7                               | S                | 36      | NVSR-2117     | 3.3                  | 3                               | MR               |
| 14      | NVSR-2565 | 23.3                 | 5                               | MS               | 37      | NVSR-2130     | 4.4                  | 3                               | MR               |
| 15      | NVSR-2566 | 4.4                  | 3                               | MR               | 38      | NVSR-2140     | 3.3                  | 3                               | MR               |
| 16      | NVSR-330  | 3.3                  | 3                               | MR               | 39      | NVSR-2153     | 1.1                  | 3                               | MR               |
| 17      | NVSR-331  | 43.3                 | 7                               | S                | 40      | NVSR-2155     | 7.8                  | 5                               | MS               |
| 18      | NVSR-335  | 40.1                 | 7                               | S                | 41      | IET-25453     | 13.3                 | 5                               | MS               |
| 19      | NVSR-338  | 7.8                  | 5                               | MS               | 42      | IET-25470     | 27.8                 | 7                               | S                |
| 20      | NVSR-360  | 2.2                  | 3                               | MR               | 43      | IET-24783     | 14.4                 | 5                               | MS               |
| 21      | NVSR-364  | 35.6                 | 7                               | S                | 44      | IET-24336     | 2.2                  | 3                               | MR               |
| 22      | NVSR-365  | 3.3                  | 3                               | MR               | 45      | Check - GR-11 | 42.2                 | 7                               | S                |
| 23      | NVSR-367  | 22.2                 | 5                               | MS               | 46      | Check -TN-1   | 45.6                 | 7                               | S                |

**MR-Moderately Resistant, MS-Moderately Susceptible, S-Susceptible, HS- Highly Susceptible**

**TABLE 2**  
**GROUPING OF PADDY GENOTYPES BASED ON THEIR REACTIONS AGAINST STEM ROT UNDER FIELD CONDITION**

| Scale | Disease Severity (%) | Disease Reaction       | Genotypes                                                                                                                                                                                  | No. of genotypes perceived |
|-------|----------------------|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| 0     | 0                    | Immune                 | Nil                                                                                                                                                                                        | 0                          |
| 1     | < 1                  | Resistant              | Nil                                                                                                                                                                                        | 0                          |
| 3     | 1 -5                 | Moderately Resistant   | NVSR-317, NVSR-348, NVSR-355, NVSR-2147, NVSR-2566, NVSR-330, NVSR-360, NVSR-365, NVSR-370, NVSR-374, NVSR-405, NVSR-407, NVSR-2102, NVSR-2117, NVSR-2130, NVSR-2140, NVSR-2153, IET-24336 | 18                         |
| 5     | 6 – 25               | Moderately Susceptible | NVSR-350, NVSR-411, NVSR-2103, NVSR-401, NVSR-329, NVSR-2526, NVSR-2565, NVSR-338, NVSR-367, NVSR-389, NVSR-406, NVSR-2115, NVSR-2116, NVSR-2155, IET-25453, IET-24783                     | 16                         |
| 7     | 26 – 50              | Susceptible            | NVSR-2101, NVSR-328, NVSR-2528, NVSR-331, NVSR-335, NVSR-364, NVSR-384, NVSR-2435, NVSR-368, IET-25470, GR-11, TN-1                                                                        | 12                         |
| 9     | 51 – 100             | Highly Susceptible     | Nil                                                                                                                                                                                        | 0                          |

Screening of paddy genotypes against stem rot was carried out on different varieties by earlier workers. Konthoujam and Chhetry (2007) screened 34 varieties among them, Chakhao amuba, Ching Chakhao and Huikap were found moderately resistant. While 17 varieties were found susceptible to the *S. oryzae* under field condition. Kumar *et al.* (2003) screened 234 varieties among them, 38 varieties were found moderately resistant. While 103 varieties were found moderately susceptible and 88 varieties were found highly susceptible reaction to the *S. oryzae*. Panwar *et al.* (1988) screened 61 genotypes. Among them, no genotype was found resistant and six genotypes viz., PR 4141, HKR 120, HKR 122, IR 54, HAU 83-222 and RP 2151-21-1 were found moderately resistant against stem rot. The new genotypes screened in the present study, so no specific information was available related to screening with respect to stem rot of paddy.

#### IV. CONCLUSION

Forty-four genotypes were screened against stem rot pathogen under artificial inoculation condition, highest per cent disease severity (45.6%) was recorded in international susceptible check TN-1 followed by genotype NVSR-331 (43.3%) and susceptible state check GR-11 (42.2%). Whereas, lowest per cent disease severity (1.1%) was recorded in genotype NVSR-370 and NVSR-2153. Out of 44 genotypes tested along with 2 susceptible check, 18 genotypes were found moderately resistant. Whereas, 16 genotypes were moderately susceptible and 12 genotypes were found susceptible reaction to *S. oryzae* under artificial inoculation condition.

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# Efficacy of Novel Fungicides for the Management of Sheath Blight of Rice Caused by *Rhizoctonia solani* (Kuhn)

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Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

**Abstract**— In the present studies eight fungicides were evaluated against the sheath blight disease of rice during Kharif-2021-23. Among the different fungicides evaluated, two sprays of azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC) at 0.03 per cent (10 ml/10 l. water) or trifloxystrobin 25 + tebuconazole 50 (75 WG), 0.03 per cent (04g/10 l.water) for effective management of sheath blight. First spray should be applied at appearance of disease and second spray at booting stage. PHI 31 days for azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC) or 21 days for trifloxystrobin 25 + tebuconazole 50 (75 WG). The other effective fungicides were viz., flusilazole 12.5 + carbendazim 25 (37.5 SE), Kresoxim methyl 44.3 SC, Zineb 68 + hexaconazole 4 (72 WP) and Propiconazole 25 EC.

**Keywords**— Rice, Sheath blight, Fungicides, *Rhizoctonia solani*.

## I. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the popular cereal crop as well as staple food for more than two-thirds of the Indian population and playing a vital role in the people's food, feed and livelihood security. Sheath blight disease is potentially an emerging fungal disease and major biotic constraint of rice in almost all rice growing areas of India. Sheath blight of paddy caused by *Rhizoctonia solani* Kuhn [Thanatephorus cucumeris (Frank) Donk]. The potential losses occur due to sheath blight singly in India up to 51.3 per cent (Rajan, 1987). Sheath blight is currently ranked second position, it is a widely distributed soil-borne plant parasitic-saprophytic fungus (Mirmajlessi *et al.*, 2012). Sheath blight, also known as "oriental sheath and leaf blight" of rice was first reported in Japan by Miyake (1910) Subsequently, its occurrence was recorded throughout the temperate and tropical rice growing areas including Africa, Bangladesh, Brazil, Burma, Colombia, China, Cuba, Germany, Fiji, Formosa, India, Indonesia, Iran, Korea, Liberia, Madagascar, Malaya, Malaysia, Netherland, Nigeria, Papua New Guinea, Philippines, Russia, Senegal, Sri Lanka, Surinam, Taiwan, Thailand, Trinidad, Tobago, UK, USA, Venezuela and Vietnam (Singh *et al.*, 2016).

## II. MATERIALS AND METHODS

A field experiment was conducted at Main Rice Research Centre, NAU, Navsari, Gujarat during kharif, 2021-23 to find out most effective fungicides for the management of sheath blight disease. Experiment was carried out in Randomised Block Design (RBD) with nine treatments with three replications. Cultivar used during experiment was GR-11 and the gross plot size was 5.4 m x 3.6 m. square and the recommended agronomical packages of practices were followed for conducting the experiment. Two sprays of fungicides were given for each treatment. First spray was given at the appearance of disease and second spray at booting stage. For recording the intensity of sheath blight, 30 hills/plot were randomly selected and labelled, these labelled plants were observed for disease intensity using methods described in Standard Evaluation System (SES) for

Rice (IRRI 2013). The grain and straw yield were recorded from net plot area recorded at the time of harvest of crop. Residue analysis was also carried out and then data was statistically analyzed.

**Formula for calculating per cent disease intensity is**

$$PDI = \frac{\text{Sum of score}}{\text{No.of observation} \times \text{Highest number of rating scale}} \times 100 \quad (1)$$

### III. RESULTS AND DISCUSSIONS

The results of the experiments indicated that the different treatments had significantly reduced the per cent sheath blight disease intensity over control during all the years as well as in pooled results. The results on per cent disease intensity are given in (Table.1) The treatment azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l was found significantly superior and recorded minimum disease severity (16.87 %) which was at par with trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l with disease severity (19.03 %). The next best treatment in order of merit was fluxapyroxad 62.5g/l FS + epoxiconazole 62.5 g/L EC @ 1.25 ml/l during 1<sup>st</sup> year. The treatment azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l was found significantly superior and recorded minimum disease severity (18.32%) which was statistically at par with trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l with disease severity (20.72 %). The next best treatment in order of merit was tebuconazole 25.9 EC @ 1.0 ml/l during 2<sup>nd</sup> year. While, in 3<sup>rd</sup> year the treatment azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l was observed significantly superior and recorded minimum disease intensity (15.70 %) which was statistically at par with trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l with disease severity (18.23 %). The next best treatment in order of merit was treatment tebuconazole 25.9 EC @ 1.0 ml/l. In case of pooled results, the treatment azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l was found significantly superior and recorded minimum disease intensity (24.30%) which was at par with trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l (26.02%). The next best treatment in order of merit was tebuconazole 25.9 EC @ 1.0 ml/l (29.13%). The year effect in polled analysis was found non significant.

The results on grain and straw yield of rice affected by different treatments are given in (Table 2) result indicated that the effects of different treatments were found to be significant during all the individual years as well in pooled result. All the treatments were found superior over control. The significantly highest grain yield (6291 kg/ha) and straw yield (7659 kg/ha) was recorded in treatment (T<sub>3</sub>) azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l which was statistically at par with the treatment (T<sub>7</sub>) trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l grain yield (5882 kg/ha) and straw yield (7292 kg/ha) and fluxapyroxad 62.5g/l FS + epoxiconazole 62.5 g/L EC @ 1.25 ml/l. with grain yield (5515 kg/ha) in the 1<sup>st</sup> year. During 2<sup>nd</sup> year significantly higher grain yield (6025kg/ha) and straw yield (7302kg/ha) was recorded in treatment (T<sub>3</sub>) azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l which was at par with the treatment (T<sub>7</sub>) trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l grain yield (5739 kg/ha), straw yield (6883kg/ha) and treatment (T<sub>2</sub>) tebuconazole 25.9 EC @ 1.0 ml/l. with grain yield (5331 kg/ha) straw yield (6413kg/ha). While, in 3<sup>rd</sup> year also the treatment T<sub>3</sub> was recorded significantly higher grain (6250 kg/ha) and straw yield (7455 kg/ha) which remained statistically at par with treatment T<sub>7</sub> for yield of grain 5903 and straw 7149 kg/ha. In case of pooled results, the treatments T<sub>3</sub> i.e. azoxystrobin 18.2 + difenoconazole 11.4 @ 1.0 ml/l was recorded significantly higher grain yield (6189 kg/ha) and straw yield (7472 kg/ha) which was at statistically par with T<sub>7</sub> i.e. trifloxystrobin 25 + tebuconazole 50 WG @ 0.4 g/l for grain (5842 kg/ha) and straw yield (7108 kg/ha). More or less similar results were reported by earlier workers for efficacy of different fungicides under field condition that is tebuconazole + trifloxystrobin, (Raji *et al.* 2016), azoxystrobin+ difenoconazole (Bhuvaneswari and Raju, 2012), tebuconazole + trifloxystrobin and hexaconazole (Bag, 2009), propiconazole and fluxapyroxad (Uppala and Zhou 2018), Lore *et al.* (2007) found that propiconazole was most effective fungicides followed by carbendazim. Efficacy of propiconazole + difenconazole followed by hexaconazole was found effective by other workers in reducing the disease (Surulirajan and Khandari, 2003; Suryadai and Kadir, 1989).

**TABLE 1**  
**EFFECT OF DIFFERENT TREATMENTS ON PER CENT DISEASE INTENSITY OF SHEATH BLIGHT OF RICE**

| Sr. No.        | Treatments                                          | Per cent Disease Intensity      |                                 |                                 |                                |
|----------------|-----------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|--------------------------------|
|                |                                                     | 2021                            | 2022                            | 2023                            | Pooled                         |
| T <sub>1</sub> | Fluxapyroxad 62.5g/l FS + Epoxiconazole 62.5 g/L EC | 22.10<br>(27.96) <sup>cba</sup> | 25.10<br>(30.04) <sup>cba</sup> | 27.03<br>(31.31) <sup>cb</sup>  | 24.74<br>(29.77) <sup>c</sup>  |
| T <sub>2</sub> | Tebuconazole 25.9 EC                                | 22.57<br>(28.36) <sup>cb</sup>  | 24.85<br>(29.85) <sup>cba</sup> | 23.77<br>(29.17) <sup>ba</sup>  | 23.73<br>(29.13) <sup>cb</sup> |
| T <sub>3</sub> | Azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC )  | 16.87<br>(24.23) <sup>a</sup>   | 18.32<br>(25.32) <sup>a</sup>   | 15.70<br>(23.34) <sup>a</sup>   | 16.96<br>(24.30) <sup>a</sup>  |
| T <sub>4</sub> | Flusilazole 12.5 + carbendazim 25 (37.5 SE)         | 24.10<br>(29.38) <sup>c</sup>   | 25.57<br>(30.36) <sup>cba</sup> | 27.90<br>(31.87) <sup>cb</sup>  | 25.86<br>(30.54) <sup>c</sup>  |
| T <sub>5</sub> | Kresoxim methyl 44.3 SC                             | 26.37<br>(30.89) <sup>c</sup>   | 27.63<br>(31.67) <sup>cb</sup>  | 30.23<br>(33.33) <sup>c</sup>   | 28.08<br>(31.96) <sup>c</sup>  |
| T <sub>6</sub> | Zineb 68 + hexaconazole 4 (72 WP)                   | 27.23<br>(31.43) <sup>c</sup>   | 28.65<br>(32.34) <sup>c</sup>   | 31.80<br>(34.32) <sup>c</sup>   | 29.23<br>(32.70) <sup>c</sup>  |
| T <sub>7</sub> | Trifloxystrobin 25 + tebuconazole 50 (75 WG)        | 19.03<br>(25.84) <sup>ba</sup>  | 20.72<br>(27.01) <sup>ba</sup>  | 18.23<br>(25.22) <sup>ba</sup>  | 19.33<br>(26.02) <sup>ba</sup> |
| T <sub>8</sub> | Propiconazole 25 EC                                 | 26.07<br>(30.70) <sup>c</sup>   | 27.48<br>(31.59) <sup>cb</sup>  | 24.97<br>(29.96) <sup>cba</sup> | 26.17<br>(30.75) <sup>c</sup>  |
| T <sub>9</sub> | Control                                             | 40.10<br>(39.27) <sup>d</sup>   | 42.23<br>(40.51) <sup>d</sup>   | 45.80<br>(42.59) <sup>d</sup>   | 42.71<br>(40.79) <sup>d</sup>  |
|                | S.Em $\pm$                                          | 1.01                            | 1.37                            | 1.09                            | 0.69                           |
|                | C.D. at 5%                                          | 3.01                            | 4.09                            | 3.27                            | 1.95                           |
|                | C.V. %                                              | 5.84                            | 7.64                            | 6.04                            | 6.70                           |
|                | Y x T                                               | -                               |                                 |                                 | N.S                            |

*Treatment means with the letter(s) in common by DNMRT at 5% level of significance*

**TABLE 2**  
**THE EFFECT OF FUNGICIDAL TREATMENTS ON YIELD PARAMETERS.**

| Sr. No.        | Treatments                                          | Grain Yield (kg/ha) |      |      |        | Straw Yield (kg/ha) |      |      |        |
|----------------|-----------------------------------------------------|---------------------|------|------|--------|---------------------|------|------|--------|
|                |                                                     | 2021                | 2022 | 2023 | Pooled | 2021                | 2022 | 2023 | Pooled |
| T <sub>1</sub> | Fluxapyroxad 62.5g/l FS + Epoxiconazole 62.5 g/L EC | 5515                | 5157 | 5249 | 5307   | 6556                | 6219 | 6516 | 6430   |
| T <sub>2</sub> | Tebuconazole 25.9 EC                                | 5372                | 5331 | 5494 | 5399   | 6475                | 6413 | 6618 | 6502   |
| T <sub>3</sub> | Azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC )  | 6291                | 6025 | 6250 | 6189   | 7659                | 7302 | 7455 | 7472   |
| T <sub>4</sub> | Flusilazole 12.5 + carbendazim 25 (37.5 SE)         | 5198                | 4963 | 4841 | 5001   | 6434                | 6036 | 5984 | 6151   |
| T <sub>5</sub> | Kresoxim methyl 44.3 SC                             | 4984                | 4698 | 4677 | 4786   | 6199                | 5964 | 6189 | 6117   |
| T <sub>6</sub> | Zineb 68 + hexaconazole 4 (72 WP)                   | 4973                | 4657 | 4616 | 4749   | 6127                | 5739 | 5923 | 5930   |
| T <sub>7</sub> | Trifloxystrobin 25 + tebuconazole 50 (75 WG)        | 5882                | 5739 | 5903 | 5842   | 7292                | 6883 | 7149 | 7108   |
| T <sub>8</sub> | Propiconazole 25 EC                                 | 5065                | 4882 | 5433 | 5127   | 6332                | 5944 | 6536 | 6270   |
| T <sub>9</sub> | Control                                             | 4044                | 3891 | 4013 | 3983   | 5494                | 4882 | 5045 | 5140   |
|                | S.Em ±                                              | 285                 | 233  | 246  | 148    | 350                 | 318  | 274  | 182    |
|                | C.D. at 5%                                          | 856                 | 698  | 738  | 421    | 1050                | 954  | 822  | 519    |
|                | C.V. %                                              | 9.42                | 8.01 | 8.30 | 8.6    | 9.32                | 8.96 | 7.79 | 8.62   |
|                | Y x T                                               | N.S                 |      |      |        | N.S                 |      |      |        |

#### IV. CONCLUSION

Field experiment with eight fungicides with two sprays carried out in Randomised Block Design (RBD) with three replications conducted to find out most effective fungicides for the management of sheath blight disease. Among the tested fungicides, azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC) at 0.03 per cent (10 ml/10 L. water) or trifloxystrobin 25 + tebuconazole 50 (75 WG), 0.03 per cent (04g/10 L. water) were found effective for management of sheath blight. The first spray should be given at appearance of disease and second spray at booting stage. PHI 31 days for azoxystrobin 18.2 + difenoconazole 11.4 (29.6 SC) or 21 days for trifloxystrobin 25 + tebuconazole 50 (75 WG).

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# Effects of Nitrogen Aerosols on Biochemical Traits of Some Kharif Rice (*Oryza sativa* L.) Genotypes

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**Abstract**— Nitrogen (N) is a vital plant nutrient for crop growth and development. In tropics and subtropics, nitrogen is lost by leaching, runoff and volatilization. Foliar nutrition in crops has increased in importance alternative to soil application. In nature, the input of nitrogen is possible through dry and wet deposition of nitrogen or as aerosols on foliage. The responses of rice crops to aerosols of nitrogen linked to its productivity deserve strong attention in the present climate change scenarios globally. Therefore, a field experiment (2020) was conducted in ICR Farm, Assam Agriculture University to investigate into effects of N-aerosols on biochemical traits in 10 (ten) kharif rice genotypes. The aerosols viz.,  $\text{KNO}_3$ ,  $\text{NH}_4\text{NO}_3$  and  $\text{Ca}(\text{NO}_3)_2$  @60 kg ha<sup>-1</sup> (~600ppm), 1000 cm<sup>3</sup> each were sprayed at maximum tillering and heading stages of the rice crop. In the experiment, the nitrogen aerosols increased biochemical traits viz., contents of chlorophyll 'a' (40.91-91.66%) & (10.52-47.22%), chlorophyll 'b' (4.91-19.67%) & (6.89-10.34%), total chlorophyll (21.51-53.96%) & (23.42-39.03%), NR activity (64.21-95.92%) & (50.66-72.39%) at maximum and heading stages respectively, nitrogen in grains (13.04-22.61%), and protein in grains (13.49-20.72%). Moreover, there were increments in lipid peroxidation (4.71-107.14%) and Cell membrane stability (CMS) (5.72-29.85.92%), intercellular  $[\text{K}^+]$  (20.23-70%), exchangeable  $[\text{K}^+]$  (68.46-77.02%), intercellular  $[\text{Ca}^{2+}]$  (6.77-17.80%) and exchangeable  $[\text{Ca}^{2+}]$  (3.29-33.80%), which varied significantly depending on the types of the N-aerosols. In the experiment, the variety Gitesh showed the highest response to the N-aerosols irrespective of the crop growth stages. Further, among the N-aerosols,  $\text{KNO}_3$  was found to be the best followed by  $\text{Ca}(\text{NO}_3)_2$  &  $\text{NH}_4\text{NO}_3$ , control distilled water in terms of the traits.

**Keywords**— Aerosols, Chlorophyll, CMS, Nitrogen, NR, Protein.

## I. INTRODUCTION

Nitrogen is indispensable for plant growth, as it makes up 1 to 4% of the dry matter of the plants. In proteins and nucleic acids, it is a major component. It acts as an essential constituent of chlorophyll and many other enzymes (Leghari *et al.*, 2016). Therefore, the availability of nitrogen in sufficient quantity throughout the growing season is essential for optimum growth and production of crop plant. There is also importance of nitrogen to maintain its correct ratio (12:1 to 15:1) with sulphur in improving yield and quality of crops (Klikocka and Marks, 2018). In order to increase crop production, approximately 107.55 million metric tons of N fertilizers were applied globally in 2019 (Statista, 2022). Approx. 80 million tones of the total N fertilizer is utilized for cereals globally (FAO, 2014). Generally, only 40–50% of the applied N fertilizer is utilized by the crop (Sylvester-Bradley and Kindred, 2009). Leaching, runoff, volatilization, and denitrification are major causes of nitrogen losses in the environment. Nitrogen which is lost from the plant–soil system can result in environmental problems, including water and air pollution (Sainju, 2017). Dissolved N in ground water mostly in the form of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  are leached out or lost through gaseous emissions of nitrous oxide and ammonia (Neill *et al.*, 2005). Janzen and Ellert (1998) observed that nitrogen is lost by the denitrification mechanism from agricultural soils. Neill *et al.* (2005) reported a loss of 20–40% of the N applied in the soil. In general, Urea or Diammonium phosphate (DAP) is used at basal and maximum tillering stages of rice crop, which is prone to the environmental losses. Apart from these forms of synthetic N, knowledge on fertilizing crops with N-aerosols is lacking. Because, N may be received from the atmosphere as a consequence of lightening or dry and wet deposition of N on

foliage at physiological pH. In this context, the responses of *kharif* rice genotypes to nitrate and ammonium forms of nitrogen aerosols are poorly understood.

A stable suspension of solid and liquid particles in a gas is known as aerosols. Aerosol particle size varies in between 0.001 to 100µm (Colbeck and Lazaridis, 2010). Nitrogen oxides (NO<sub>x</sub>) viz., NO and NO<sub>2</sub>, and N<sub>2</sub>O are major atmospheric pollutants in rapidly growing urban and its surrounding areas of Assam (Bharali *et al.*, 2012). The NO<sub>x</sub> emitted in the form of nitric oxide (NO), reacts rapidly in the atmosphere and in a complex cycle with light, ozone, hydrocarbons, and produces nitric acid. These materials interact with plants and soil locally or transported from the site to react with atmospheric particulates to form aerosols. These aerosols come back to fertilize terrestrial and aquatic systems in the form of wet and dry deposition. It was estimated that about 5% of the total anthropogenic greenhouse effect is credited to N<sub>2</sub>O form, which is 70% of annual global anthropogenic emissions come from animals and crop production (Arvind, 2001). There is the possibility of nitrogen nutrition in rice by foliar feeding with N-aerosols (salts of nitrogen) instead of soil application (Bharali *et al.*, 2017). Therefore, an investigation into effects of N-aerosols on biochemical traits of rice crop especially NUE in rice crop was undertaken.

## II. MATERIALS AND METHODS

A field experiment following factorial randomised design with two replications was conducted to study the biochemical variations of ten *kharif* rice genotypes (viz., Aghonibora, Gitesh, Aki Sali, Prafulla, Solpana, Bahadur, Ranjit, Swarna sub-I, Chahou, Shruboni) upon application of nitrogen aerosols (KNO<sub>3</sub>, NH<sub>4</sub>NO<sub>3</sub> & Ca(NO<sub>3</sub>)<sub>2</sub> each @ 60 kg ha<sup>-1</sup> against a control i.e. distilled water) during *kharif* season (July -December) of 2020 at ICR Farm (GPS at 26°45'N latitude and 94°12'E longitude) under Assam Agricultural University, Jorhat. The climatic condition during the experimental period was characterised by Temperature (10.5-33.6°C), Relative Humidity (61-99%), total bright sunshine (28hours) and total rainfall: 1110.2mm (Source: Meteorological observatory, AAU, Jorhat). There were variations in canopy temperature (measured by Infrared Thermometer at an angle of 45° and at a distance of 10 cm from the leaf) among the varieties at maximum tillering (19.95-22.79°C) and heading (20.06-23.13°C) stages of the crop irrespective of treatments.

The aerosols @ 600 ppm (≈60 kg N ha<sup>-1</sup>), solution was prepared by dissolving 600mg each of KNO<sub>3</sub>, Ca(NO<sub>3</sub>)<sub>2</sub> and NH<sub>4</sub>NO<sub>3</sub> in small amount of distilled water separately, and then volume was made upto 1000ml by distilled water. These nitrogen aerosols were applied in three splits on sunny days in the afternoon (after 2–3 p.m) when air temperature was low. Spraying of nitrogen aerosols was finished in such a way that each variety obtained 1000cm<sup>3</sup> of the respective nitrogen aerosols solutions. Treatments were applied at 30 days after transplanting at maximum tillering stage of the crop as foliar misting using knapsack sprayer. The pHs of the respective solutions measured using a digital pH meter (Eutech pH 510) were as for distilled water: 7.00; KNO<sub>3</sub>: 5.66; Ca(NO<sub>3</sub>)<sub>2</sub>: 5.49 and NH<sub>4</sub>(NO<sub>3</sub>): 5.89. The estimation of biochemical indices were done as per the standard methods as mentioned below:

| Sl.No. | Methodologies                                                                                                               | References                                                       |
|--------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| 1.     | Chlorophyll (a, b & total) contents (mgg <sup>-1</sup> fresh weight of leaf)                                                | Colorimetric method (Arnon, 1949)                                |
| 2.     | Nitrate Reductase (NR) activity (µmoles NO <sub>2</sub> formed g <sup>-1</sup> fresh tissue wt hr <sup>-1</sup> ) in plants | Keeper <i>et al.</i> (1971)                                      |
| 3.     | Lipid peroxidation (n mol MDA g <sup>-1</sup> fw)                                                                           | Heath and Packer (1968)                                          |
| 4.     | Cell membrane stability (CMS)                                                                                               | Sullivan (1979), Bharali <i>et al.</i> (2015)                    |
| 5.     | Estimation of cellular K <sup>+</sup>                                                                                       | Jackson (1973)                                                   |
| 6.     | Estimation of cellular Ca <sup>2+</sup>                                                                                     | Ca <sup>2+</sup> (Richards, 1954; Bharali <i>et al.</i> , 2015b) |
| 7.     | Nitrogen and protein contents in grains (%)                                                                                 | Jackson (1973)                                                   |

Data for each character was analysed by Fisher's method of analysis of variance (Panse and Sukhatme, 1978). Significant differences between two mean values due to treatments or varieties and their interaction at a crop growth stage were computed by comparing their significant levels at P<0.05.

## III. RESULTS AND DISCUSSION

In the study, simulated N-aerosols viz., KNO<sub>3</sub>, CaNO<sub>3</sub> and NH<sub>4</sub>NO<sub>3</sub> @ 600 ppm each (≈60 kg N ha<sup>-1</sup>) along with a control, applied at different growth stages of winter rice crop, brought about significant biochemical changes in the crop. It was aimed to find out the most responsive variety corresponding to the type of N-aerosol judged by the biochemical traits at different growth stages of the crop, as explored in the discussion.

In the experiment, during maximum tillering stage (Table 1a), the highest increment in chlorophyll 'a' content was found in treatment  $\text{Ca}(\text{NO}_3)_2$  (91.66%) >  $\text{KNO}_3$  (83.33%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (40.91%) as compared to the control. During heading stage (Table 1b), the highest per cent increase in chlorophyll 'a' content was found in treatment  $\text{KNO}_3$  (47.22%) >  $\text{Ca}(\text{NO}_3)_2$  (42.11%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (10.52%) as compared to the control.

Plant pigments viz., chlorophylls are vital molecules that are formed by plants and plays an important role in photosynthesis process which is accountable for plant growth (Brotosudarmo *et al.*, 2018). Qeyami *et al.* (2020) reported that application of calcium nitrate enhanced the nitrogen content in leaves and greater absorption of  $\text{Mg}^{2+}$  from soil, and thus attributed to raised chlorophyll 'a' content in leaves of apple plant. Zhao *et al.* (2016) stated that in maize both Chl a and Chl b got reduced under  $\text{KNO}_3$  deficiency conditions because potassium deficiency directly influence the photosynthetic apparatus through biosynthesis and functioning of key photosynthetic components whereas nitrogen deficiency reduces the photosynthetic enzymes and chlorophyll components.

In the experiment, during maximum tillering stage (Table 2a), the highest increment in chlorophyll 'b' content was found in treatment  $\text{Ca}(\text{NO}_3)_2$  (19.67%) >  $\text{KNO}_3$  (18.03%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (4.91%) as compared to the control. During heading stage (Table 2b), the highest increment in chlorophyll 'b' content was recorded in treatment  $\text{KNO}_3$  (10.34%) >  $\text{Ca}(\text{NO}_3)_2$  (8.78%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (6.89%) as compared to the control. Chlorophyll b is different from Chlorophyll a in only one of the functional groups bonded to the porphyrin ring (Xu *et al.*, 2001). Chlorophyll b is an accessory pigment and acts indirectly in photosynthesis by transferring light energy to Chl a (Eggink *et al.*, 2001). El- Mogy *et al.* (2019) proposed that potassium nitrate application in long pepper plant improved the stability of protein complex and chloroplast structure and thus maintained the Chl a and Chl b contents. Norozi *et al.* (2019) illustrated that potassium nitrate application caused significant improvement in Chl a and Chl b because of potassium regulates various enzymes related to photosynthesis, and further it assist in detoxification of ROS which prevent the degradation of chlorophyll contents.

In case of total chlorophyll contents, at maximum tillering stage (Table 3a), the highest per cent increase in total chlorophyll content was found in treatment  $\text{KNO}_3$  (53.96%) >  $\text{Ca}(\text{NO}_3)_2$  (43.79%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (21.51%) as compared to the control. During heading stage (Table 3b), the highest per cent increase in total chlorophyll content was found in treatment  $\text{KNO}_3$  (39.03%) >  $\text{Ca}(\text{NO}_3)_2$  (36.66%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (23.42%) as compared to the control. In rice, nitrogen is an indispensable nutrient out of which 75% of leaf N is coupled with chloroplasts, and thus it is physiologically significant in production of dry matter by photosynthesis process (Dalling, 1985). Foliar application of nitrogen improved chlorophyll production in the leaves (Suwanarit and Sestapukdee, 1989). Peng *et al.* (2021) found that with rising nitrogen treatment rates, chlorophyll content is improved in leaves at the booting, heading, and maturity phase of rice. It suggested that nitrogen shortage might resulted in drop of chlorophyll content. Nitrogen foliar spray at later crop growth stages retarded the formation of abscisic acid, accelerated the cytokinin activity and resulted in higher chlorophyll retention. Thus, photosynthetic activity increased in leaves with the supply of photosynthates toward the grain and consequently resulted in higher yield of crops (Sarkar *et al.*, 2007). Avila *et al.* (2021) revealed that potassium nitrate foliar application enhanced chlorophyll content, rate of photosynthesis, conductance of stomata, transpiration and carboxylation efficiency in sorghum plants. Oosterhuis and Bednarz (1997) concluded that potassium deficiency lowered the chlorophyll a and total chlorophyll concentration in cotton plants.

In the experiment, during maximum tillering stage (Table 4a), the highest per cent increase in nitrate reductase (NR) activity was found in treatment  $\text{KNO}_3$  (95.92%) >  $\text{Ca}(\text{NO}_3)_2$  (75.89%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (64.21%) as compared to the control. During heading stage (Table 4b), the highest percent increase in total chlorophyll content was found in treatment  $\text{KNO}_3$  (72.39%) >  $\text{Ca}(\text{NO}_3)_2$  (59.42%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (50.66%) as compared to the control (distilled water). Nitrate reductase is key regulator enzyme involved in nitrogen assimilation within the plants (Latifa and Anggarwulan, 2009). Nitrate reductase activity reflects the condition of nitrogen uptake and utilization within the plant (Liu *et al.*, 2018). It was found that decline in NR activity may be due to low availability of substrate i.e.  $\text{NO}_3^-$  (Pal *et al.*, 2005). NR activity can be promoted by application of nitrogenous compound. A direct relation was observed between nitrate reductase activity and nitrogen content of leaf during water logging situation (Gomathi and Chandran, 2012). Chen and Huang *et al.* (2020) reported that in maize the NR activity was greater in nitrogen treated maize. Ahanger *et al.* (2015) stated that NR activity got enhanced by application of potassium nitrate in oats. Because, addition of potassium improves nitrogen utilization by depleting nitrogen contents from the medium and accompany of nitrate anion is necessary for the activity of NR activity.

**TABLE 1**  
**EFFECT OF NITROGEN AEROSOLS ON CHLOROPHYLL ‘A’ CONTENT IN LEAF AT DIFFERENT GROWTH STAGES OF RICE CROP**

| <div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Treatments</div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Varieties</div> </div> | (a) Chlorophyll ‘a’ content (mg g <sup>-1</sup> fw of leaf) at maximum tillering stage |                  |                                 |                                   |      | (b) Chlorophyll ‘a’ content (mg g <sup>-1</sup> fw of leaf) at heading stage |                  |                                 |                                   |      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|
|                                                                                                                                                                                                                                                          | N-aerosols (60 Kg ha <sup>-1</sup> )                                                   |                  |                                 |                                   |      | N-aerosols (60 Kg ha <sup>-1</sup> )                                         |                  |                                 |                                   |      |
|                                                                                                                                                                                                                                                          | Control                                                                                | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean | Control                                                                      | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean |
| Aghonibora                                                                                                                                                                                                                                               | 0.61                                                                                   | 0.64             | 0.62                            | 0.68                              | 0.64 | 0.72                                                                         | 0.91             | 0.74                            | 0.77                              | 0.78 |
| Gitesh                                                                                                                                                                                                                                                   | 0.58                                                                                   | 0.66             | 0.63                            | 0.68                              | 0.64 | 0.82                                                                         | 0.89             | 0.84                            | 0.86                              | 0.85 |
| Aki Sali                                                                                                                                                                                                                                                 | 0.48                                                                                   | 0.6              | 0.51                            | 0.58                              | 0.54 | 0.67                                                                         | 0.77             | 0.72                            | 0.75                              | 0.72 |
| Prafulla                                                                                                                                                                                                                                                 | 0.56                                                                                   | 0.64             | 0.62                            | 0.65                              | 0.62 | 0.73                                                                         | 0.82             | 0.76                            | 0.79                              | 0.78 |
| Solpana                                                                                                                                                                                                                                                  | 0.48                                                                                   | 0.55             | 0.51                            | 0.56                              | 0.52 | 0.62                                                                         | 0.76             | 0.66                            | 0.71                              | 0.68 |
| Bahadur                                                                                                                                                                                                                                                  | 0.56                                                                                   | 0.61             | 0.59                            | 0.62                              | 0.59 | 0.72                                                                         | 0.81             | 0.74                            | 0.77                              | 0.76 |
| Ranjit                                                                                                                                                                                                                                                   | 0.62                                                                                   | 0.68             | 0.66                            | 0.72                              | 0.66 | 0.76                                                                         | 0.86             | 0.81                            | 0.83                              | 0.82 |
| Swarna sub1                                                                                                                                                                                                                                              | 0.46                                                                                   | 0.52             | 0.5                             | 0.54                              | 0.5  | 0.48                                                                         | 0.59             | 0.52                            | 0.58                              | 0.54 |
| Chahou                                                                                                                                                                                                                                                   | 0.28                                                                                   | 0.36             | 0.31                            | 0.38                              | 0.33 | 0.36                                                                         | 0.53             | 0.39                            | 0.51                              | 0.44 |
| Shruboni                                                                                                                                                                                                                                                 | 0.22                                                                                   | 0.44             | 0.28                            | 0.46                              | 0.34 | 0.38                                                                         | 0.55             | 0.42                            | 0.54                              | 0.47 |
| Mean                                                                                                                                                                                                                                                     | 0.48                                                                                   | 0.56             | 0.52                            | 0.58                              |      | 0.62                                                                         | 0.74             | 0.66                            | 0.71                              |      |
|                                                                                                                                                                                                                                                          | Factor                                                                                 | S.Ed(±)          | CD (0.05)                       |                                   |      | Factor                                                                       | S.Ed(±)          | CD (0.05)                       |                                   |      |
|                                                                                                                                                                                                                                                          | Varieties (A)                                                                          | 0.02             | 0.04                            |                                   |      | Varieties (A)                                                                | 0.02             | 0.03                            |                                   |      |
|                                                                                                                                                                                                                                                          | Aerosols (B)                                                                           | 0.01             | 0.02                            |                                   |      | Aerosols (B)                                                                 | 0.01             | 0.02                            |                                   |      |
|                                                                                                                                                                                                                                                          | A×B                                                                                    | 0.04             | NS                              |                                   |      | A×B                                                                          | 0.03             | NS                              |                                   |      |

**TABLE 2**  
**EFFECT OF NITROGEN AEROSOLS ON CHLOROPHYLL ‘B’ CONTENT IN LEAF AT DIFFERENT STAGES OF RICE CROP**

| <div> <div>Treatments</div> <div>Varieties</div> </div> | (a) Chlorophyll ‘b’ content (mg g <sup>-1</sup> fw of leaf) at maximum tillering stage |                  |                                 |                                   |      | (b) Chlorophyll ‘b’ content (mg g <sup>-1</sup> fw of leaf) at heading stage |                  |                                 |                                   |      |
|---------------------------------------------------------|----------------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|
|                                                         | N-aerosols (60 Kg ha <sup>-1</sup> )                                                   |                  |                                 |                                   |      | N-aerosols (60 Kg ha <sup>-1</sup> )                                         |                  |                                 |                                   |      |
|                                                         | Control                                                                                | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean | Control                                                                      | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean |
| Aghonibora                                              | 1.66                                                                                   | 1.76             | 1.71                            | 1.72                              | 1.71 | 1.74                                                                         | 1.94             | 1.84                            | 1.82                              | 1.8  |
| Gitesh                                                  | 1.69                                                                                   | 1.78             | 1.72                            | 1.76                              | 1.74 | 1.76                                                                         | 1.92             | 1.86                            | 1.88                              | 1.84 |
| Aki Sali                                                | 1.57                                                                                   | 1.66             | 1.61                            | 1.64                              | 1.62 | 1.68                                                                         | 1.8              | 1.71                            | 1.775                             | 1.74 |
| Prafulla                                                | 1.61                                                                                   | 1.72             | 1.64                            | 1.67                              | 1.66 | 1.75                                                                         | 1.84             | 1.78                            | 1.82                              | 1.79 |
| Solpana                                                 | 1.54                                                                                   | 1.63             | 1.56                            | 1.61                              | 1.58 | 1.64                                                                         | 1.78             | 1.68                            | 1.73                              | 1.71 |
| Bahadur                                                 | 1.61                                                                                   | 1.69             | 1.63                            | 1.66                              | 1.64 | 1.74                                                                         | 1.84             | 1.76                            | 1.79                              | 1.78 |
| Ranjit                                                  | 1.64                                                                                   | 1.74             | 1.67                            | 1.71                              | 1.69 | 1.78                                                                         | 1.86             | 1.82                            | 1.84                              | 1.82 |
| Swarna sub1                                             | 1.46                                                                                   | 1.6              | 1.52                            | 1.54                              | 1.53 | 1.48                                                                         | 1.61             | 1.52                            | 1.61                              | 1.54 |
| Chahou                                                  | 1.28                                                                                   | 1.37             | 1.31                            | 1.39                              | 1.34 | 1.46                                                                         | 1.55             | 1.48                            | 1.52                              | 1.5  |
| Shruboni                                                | 1.22                                                                                   | 1.44             | 1.28                            | 1.46                              | 1.34 | 1.48                                                                         | 1.57             | 1.51                            | 1.56                              | 1.52 |
| Mean                                                    | 1.52                                                                                   | 1.64             | 1.56                            | 1.61                              |      | 1.66                                                                         | 1.77             | 1.68                            | 1.74                              |      |
|                                                         | Factor                                                                                 | S.Ed(±)          |                                 | CD (0.05)                         |      | Factor                                                                       | S.Ed(±)          |                                 | CD (0.05)                         |      |
|                                                         | Varieties (A)                                                                          | 0.02             |                                 | 0.04                              |      | Varieties (A)                                                                | 0.009            |                                 | 0.02                              |      |
|                                                         | Aerosols (B)                                                                           | 0.01             |                                 | 0.02                              |      | Aerosols (B)                                                                 | 0.006            |                                 | 0.01                              |      |
|                                                         | A×B                                                                                    | 0.03             |                                 | NS                                |      | A×B                                                                          | 0.017            |                                 | 0.04                              |      |

**TABLE 3**  
**EFFECT OF NITROGEN AEROSOLS ON TOTAL CHLOROPHYLL CONTENT IN LEAF AT DIFFERENT STAGES OF RICE CROP**

| <div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Treatments</div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Varieties</div> </div> | (a) Total chlorophyll content (mg g <sup>-1</sup> fw of leaf) at maximum tillering stage |                  |                                 |                                   |           | (b) Total chlorophyll content (mg g <sup>-1</sup> fw of leaf) at heading stage |                  |                                 |                                   |           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|-----------|--------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|-----------|
|                                                                                                                                                                                                                                                          | N-aerosols (60 Kg ha <sup>-1</sup> )                                                     |                  |                                 |                                   |           | N-aerosols (60 Kg ha <sup>-1</sup> )                                           |                  |                                 |                                   |           |
|                                                                                                                                                                                                                                                          | Control                                                                                  | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean      | Control                                                                        | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean      |
| Aghonibora                                                                                                                                                                                                                                               | 1.83                                                                                     | 2.62             | 2.01                            | 2.55                              | 2.25      | 2.02                                                                           | 2.74             | 2.31                            | 2.39                              | 2.41      |
| Gitesh                                                                                                                                                                                                                                                   | 1.79                                                                                     | 2.48             | 1.82                            | 2.45                              | 2.13      | 2.41                                                                           | 3.05             | 2.52                            | 2.43                              | 2.72      |
| Aki Sali                                                                                                                                                                                                                                                 | 1.52                                                                                     | 1.9              | 1.6                             | 1.88                              | 1.72      | 1.73                                                                           | 1.98             | 1.79                            | 2.11                              | 1.93      |
| Prafulla                                                                                                                                                                                                                                                 | 1.72                                                                                     | 2.59             | 2.09                            | 2.36                              | 2.19      | 1.87                                                                           | 2.6              | 2.02                            | 2.25                              | 2.23      |
| Solpana                                                                                                                                                                                                                                                  | 1.49                                                                                     | 1.78             | 1.56                            | 1.74                              | 1.64      | 1.72                                                                           | 1.95             | 1.78                            | 2.07                              | 1.93      |
| Bahadur                                                                                                                                                                                                                                                  | 1.53                                                                                     | 2.4              | 1.7                             | 2.2                               | 1.95      | 1.75                                                                           | 2.25             | 2.16                            | 2.2                               | 2.14      |
| Ranjit                                                                                                                                                                                                                                                   | 1.89                                                                                     | 2.91             | 2.09                            | 2.54                              | 2.35      | 1.99                                                                           | 2.67             | 2.17                            | 2.35                              | 2.33      |
| Swarna sub1                                                                                                                                                                                                                                              | 1.48                                                                                     | 1.65             | 1.49                            | 1.5                               | 1.53      | 1.66                                                                           | 1.88             | 1.74                            | 2.1                               | 1.87      |
| Chahou                                                                                                                                                                                                                                                   | 1.36                                                                                     | 1.51             | 1.4                             | 1.44                              | 1.43      | 1.5                                                                            | 1.75             | 1.6                             | 2.05                              | 1.72      |
| Shruboni                                                                                                                                                                                                                                                 | 1.43                                                                                     | 1.56             | 1.46                            | 1.45                              | 1.47      | 1.66                                                                           | 1.88             | 1.74                            | 2.08                              | 1.87      |
| Mean                                                                                                                                                                                                                                                     | 1.61                                                                                     | 2.14             | 1.71                            | 2.01                              |           | 1.83                                                                           | 2.27             | 1.98                            | 2.2                               |           |
|                                                                                                                                                                                                                                                          | Factor                                                                                   |                  | S.Ed(±)                         |                                   | CD (0.05) | Factor                                                                         |                  | S.Ed(±)                         |                                   | CD (0.05) |
|                                                                                                                                                                                                                                                          | Varieties (A)                                                                            |                  | 0.02                            |                                   | 0.05      | Varieties (A)                                                                  |                  | 0.04                            |                                   | 0.09      |
|                                                                                                                                                                                                                                                          | Aerosols (B)                                                                             |                  | 0.02                            |                                   | 0.03      | Aerosols (B)                                                                   |                  | 0.03                            |                                   | 0.06      |
|                                                                                                                                                                                                                                                          | A×B                                                                                      |                  | 0.05                            |                                   | 0.11      | A×B                                                                            |                  | 0.09                            |                                   | 0.19      |

**TABLE 4**  
**EFFECT OF NITROGEN AEROSOLS ON NITRATE REDUCTASE (NR) ACTIVITY IN LEAF AT DIFFERENT STAGES OF RICE CROP**

| <div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Treatments</div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Varieties</div> </div> | (a) NR activity (nmol NO <sub>2</sub> <sup>-</sup> g <sup>-1</sup> fw of leaf h <sup>-1</sup> ) at maximum tillering stage |                  |                                 |                                   |       | (b) NR activity (nmol NO <sub>2</sub> <sup>-</sup> g <sup>-1</sup> fw of leaf h <sup>-1</sup> ) at heading stage |                  |                                 |                                   |       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|-------|------------------------------------------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|-------|
|                                                                                                                                                                                                                                                          | N-aerosols (60 Kg ha <sup>-1</sup> )                                                                                       |                  |                                 |                                   |       | N-aerosols (60 Kg ha <sup>-1</sup> )                                                                             |                  |                                 |                                   |       |
|                                                                                                                                                                                                                                                          | Control                                                                                                                    | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean  | Control                                                                                                          | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean  |
| Aghonibora                                                                                                                                                                                                                                               | 15.95                                                                                                                      | 22.31            | 18.84                           | 18.18                             | 18.82 | 19.26                                                                                                            | 28.31            | 25.2                            | 28.07                             | 25.21 |
| Gitesh                                                                                                                                                                                                                                                   | 13.15                                                                                                                      | 22.56            | 19.52                           | 18.81                             | 18.51 | 12.07                                                                                                            | 22.33            | 19.82                           | 21.23                             | 18.86 |
| Aki Sali                                                                                                                                                                                                                                                 | 12.1                                                                                                                       | 20.86            | 18.23                           | 19.29                             | 17.62 | 12.02                                                                                                            | 20.62            | 17.69                           | 19.05                             | 17.34 |
| Prafulla                                                                                                                                                                                                                                                 | 14.12                                                                                                                      | 22.62            | 19.64                           | 19.53                             | 18.97 | 13.19                                                                                                            | 23.08            | 20.92                           | 20.74                             | 19.48 |
| Solpana                                                                                                                                                                                                                                                  | 11.19                                                                                                                      | 19.08            | 15.59                           | 17.55                             | 15.85 | 10.95                                                                                                            | 19.12            | 15.18                           | 17.08                             | 15.58 |
| Bahadur                                                                                                                                                                                                                                                  | 16.94                                                                                                                      | 26.02            | 20.58                           | 23                                | 21.63 | 17.42                                                                                                            | 27.68            | 24.7                            | 28.19                             | 24.5  |
| Ranjit                                                                                                                                                                                                                                                   | 14.27                                                                                                                      | 21.08            | 17.72                           | 18.79                             | 17.96 | 15.12                                                                                                            | 25.69            | 22.01                           | 23.32                             | 21.53 |
| Swarna sub1                                                                                                                                                                                                                                              | 12.17                                                                                                                      | 18.31            | 13.16                           | 15.65                             | 14.82 | 11.71                                                                                                            | 18.23            | 12.86                           | 15.58                             | 14.59 |
| Chahou                                                                                                                                                                                                                                                   | 11.47                                                                                                                      | 17.13            | 12.29                           | 13.42                             | 12.58 | 8.83                                                                                                             | 17.3             | 11.51                           | 14.08                             | 12.93 |
| Shruboni                                                                                                                                                                                                                                                 | 11.81                                                                                                                      | 17.09            | 12.98                           | 15.35                             | 13.81 | 10.68                                                                                                            | 16.82            | 12.84                           | 14.77                             | 13.77 |
| Mean                                                                                                                                                                                                                                                     | 12.72                                                                                                                      | 20.71            | 16.85                           | 17.95                             |       | 13.12                                                                                                            | 21.92            | 18.28                           | 20.21                             |       |
|                                                                                                                                                                                                                                                          | Factor                                                                                                                     | S.Ed(±)          | CD (0.05)                       |                                   |       | Factor                                                                                                           | S.Ed(±)          | CD (0.05)                       |                                   |       |
|                                                                                                                                                                                                                                                          | Varieties (A)                                                                                                              | 0.45             | 0.92                            |                                   |       | Varieties (A)                                                                                                    | 0.32             | 0.66                            |                                   |       |
|                                                                                                                                                                                                                                                          | Aerosols (B)                                                                                                               | 0.28             | 0.58                            |                                   |       | Aerosols (B)                                                                                                     | 0.21             | 0.42                            |                                   |       |
|                                                                                                                                                                                                                                                          | A×B                                                                                                                        | 0.91             | 1.84                            |                                   |       | A×B                                                                                                              | 0.65             | 1.32                            |                                   |       |

**TABLE 5**  
**EFFECT OF NITROGEN AEROSOLS ON LIPID PEROXIDATION IN LEAF AT DIFFERENT GROWTH STAGES OF RICE CROP**

| <div style="display: flex; align-items: center; justify-content: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Treatments</div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">Varieties</div> </div> | (a) Lipid peroxidation (nmol MDA g <sup>-1</sup> fw) at maximum tillering stage |                  |                                 |                                   |      | (b) Lipid peroxidation (nmol MDA g <sup>-1</sup> fw )at heading stage |                  |                                 |                                   |      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|-----------------------------------------------------------------------|------------------|---------------------------------|-----------------------------------|------|
|                                                                                                                                                                                                                                                          | N-aerosols (60 Kg ha <sup>-1</sup> )                                            |                  |                                 |                                   |      | N-aerosols (60 Kg ha <sup>-1</sup> )                                  |                  |                                 |                                   |      |
|                                                                                                                                                                                                                                                          | Control                                                                         | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean | Control                                                               | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean |
| Agnibora                                                                                                                                                                                                                                                 | 0.57                                                                            | 0.68             | 1.18                            | 0.61                              | 0.76 | 1.02                                                                  | 1.06             | 1.11                            | 1.04                              | 1.06 |
| Gitesh                                                                                                                                                                                                                                                   | 0.56                                                                            | 0.57             | 1.16                            | 0.59                              | 0.72 | 1.02                                                                  | 1.06             | 1.08                            | 1.04                              | 1.05 |
| Aki Sali                                                                                                                                                                                                                                                 | 0.62                                                                            | 0.74             | 1.23                            | 0.68                              | 0.81 | 1.09                                                                  | 1.12             | 1.13                            | 1.11                              | 1.11 |
| Prafulla                                                                                                                                                                                                                                                 | 0.6                                                                             | 0.7              | 1.21                            | 0.66                              | 0.79 | 1.04                                                                  | 1.11             | 1.13                            | 1.06                              | 1.08 |
| Solpana                                                                                                                                                                                                                                                  | 0.63                                                                            | 0.68             | 1.24                            | 0.66                              | 0.8  | 1.13                                                                  | 1.2              | 1.23                            | 1.16                              | 1.18 |
| Bahadur                                                                                                                                                                                                                                                  | 0.61                                                                            | 0.62             | 1.18                            | 0.66                              | 0.76 | 1.05                                                                  | 1.12             | 1.17                            | 1.07                              | 1.1  |
| Ranjit                                                                                                                                                                                                                                                   | 0.59                                                                            | 0.68             | 1.19                            | 0.64                              | 0.77 | 1.04                                                                  | 1.08             | 1.13                            | 1.06                              | 1.08 |
| Swarna sub1                                                                                                                                                                                                                                              | 0.66                                                                            | 0.81             | 1.31                            | 0.75                              | 0.88 | 1.11                                                                  | 1.15             | 1.21                            | 1.12                              | 1.14 |
| Chahou                                                                                                                                                                                                                                                   | 0.64                                                                            | 0.72             | 1.21                            | 0.61                              | 0.79 | 1.06                                                                  | 1.15             | 1.18                            | 1.11                              | 1.12 |
| Shruboni                                                                                                                                                                                                                                                 | 0.66                                                                            | 0.79             | 1.23                            | 0.68                              | 0.84 | 1.12                                                                  | 1.14             | 1.22                            | 1.14                              | 1.15 |
| Mean                                                                                                                                                                                                                                                     | 0.61                                                                            | 0.69             | 1.21                            | 0.65                              |      | 1.07                                                                  | 1.12             | 1.16                            | 1.09                              |      |
|                                                                                                                                                                                                                                                          | Factor                                                                          | S.Ed(±)          | CD (0.05)                       |                                   |      | Factor                                                                | S.Ed(±)          | CD (0.05)                       |                                   |      |
|                                                                                                                                                                                                                                                          | Varieties (A)                                                                   | 0.02             | 0.04                            |                                   |      | Varieties (A)                                                         | 0.005            | 0.011                           |                                   |      |
|                                                                                                                                                                                                                                                          | erosols (B)                                                                     | 0.02             | 0.03                            |                                   |      | Aerosols (B)                                                          | 0.003            | 0.007                           |                                   |      |
|                                                                                                                                                                                                                                                          | A×B                                                                             | 0.04             | NS                              |                                   |      | A×B                                                                   | 0.011            | 0.022                           |                                   |      |

**TABLE 6**  
**EFFECT OF NITROGEN AEROSOLS ON CELL MEMBRANE STABILITY (CMS) IN LEAF AT MAXIMUM AT DIFFERENT STAGES OF RICE CROP**

| <div> <div>Treatments</div> <div>Varieties</div> </div> | (a) CMS at maximum tillering stage   |                  |                                 |                                   |      | (b) CMS at heading stage             |                  |                                 |                                   |      |
|---------------------------------------------------------|--------------------------------------|------------------|---------------------------------|-----------------------------------|------|--------------------------------------|------------------|---------------------------------|-----------------------------------|------|
|                                                         | N-aerosols (60 Kg ha <sup>-1</sup> ) |                  |                                 |                                   |      | N-aerosols (60 Kg ha <sup>-1</sup> ) |                  |                                 |                                   |      |
|                                                         | Control                              | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean | Control                              | KNO <sub>3</sub> | NH <sub>4</sub> NO <sub>3</sub> | Ca(NO <sub>3</sub> ) <sub>2</sub> | Mean |
| Aghonibora                                              | 4.45                                 | 4.99             | 4.71                            | 5.12                              | 4.82 | 5.16                                 | 5.98             | 5.57                            | 6.3                               | 5.75 |
| Gitesh                                                  | 4.64                                 | 5.01             | 4.86                            | 5.15                              | 4.91 | 7.23                                 | 7.58             | 7.37                            | 7.39                              | 7.39 |
| Aki Sali                                                | 4.03                                 | 4.15             | 4.07                            | 4.25                              | 4.12 | 6.23                                 | 7.78             | 6.62                            | 7.72                              | 7.09 |
| Prafulla                                                | 4.61                                 | 4.89             | 4.71                            | 5.03                              | 4.81 | 7.39                                 | 8.42             | 7.67                            | 9.18                              | 8.16 |
| Solpana                                                 | 3.96                                 | 4.25             | 4.11                            | 4.32                              | 4.16 | 6.31                                 | 7.2              | 6.58                            | 7.25                              | 6.83 |
| Bahadur                                                 | 6.23                                 | 6.64             | 6.43                            | 7.25                              | 6.63 | 6.27                                 | 6.76             | 6.24                            | 7.17                              | 6.61 |
| Ranjit                                                  | 4.66                                 | 4.91             | 4.81                            | 5.02                              | 4.85 | 6.54                                 | 7.55             | 7.24                            | 7.68                              | 7.25 |
| Swarna sub1                                             | 4.12                                 | 4.16             | 4.14                            | 4.55                              | 4.24 | 5.51                                 | 6.65             | 5.67                            | 5.79                              | 5.91 |
| Chahou                                                  | 3.71                                 | 3.91             | 3.89                            | 4.16                              | 3.92 | 5.36                                 | 6.22             | 5.55                            | 6.13                              | 5.82 |
| Shruboni                                                | 3.71                                 | 3.92             | 3.75                            | 4.09                              | 3.86 | 4.84                                 | 5.7              | 5.23                            | 6.28                              | 5.51 |
| Mean                                                    | 4.41                                 | 4.68             | 4.54                            | 4.89                              |      | 5.88                                 | 6.78             | 6.17                            | 6.99                              |      |
|                                                         | Factor                               | S.Ed(±)          | CD (0.05)                       |                                   |      | Factor                               | S.Ed(±)          | CD (0.05)                       |                                   |      |
|                                                         | Varieties (A)                        | 0.22             | 0.45                            |                                   |      | Varieties (A)                        | 0.005            | 0.011                           |                                   |      |
|                                                         | Aerosols (B)                         | 0.14             | 0.28                            |                                   |      | Aerosols (B)                         | 0.003            | 0.007                           |                                   |      |
|                                                         | A×B                                  | 0.45             | NS                              |                                   |      | A×B                                  | 0.011            | 0.022                           |                                   |      |

**TABLE 7**  
**EFFECT OF NITROGEN AEROSOLS ON NITROGEN AND PROTEIN CONTENTS IN GRAIN AT HARVEST STAGE OF RICE CROP**

| <div style="text-align: center;"> <b>Treatments</b><br/> <b>Varieties</b> </div> | <b>(a) Total nitrogen contents (%) in grain</b> |                        |                                     |                                       |             | <b>(b) Crude Protein content (%) in grains</b> |                        |                                     |                                       |             |
|----------------------------------------------------------------------------------|-------------------------------------------------|------------------------|-------------------------------------|---------------------------------------|-------------|------------------------------------------------|------------------------|-------------------------------------|---------------------------------------|-------------|
|                                                                                  | <b>N-aerosols (60 Kg ha<sup>-1</sup>)</b>       |                        |                                     |                                       |             | <b>N-aerosols (60 Kg ha<sup>-1</sup>)</b>      |                        |                                     |                                       |             |
|                                                                                  | <b>Control</b>                                  | <b>KNO<sub>3</sub></b> | <b>NH<sub>4</sub>NO<sub>3</sub></b> | <b>Ca(NO<sub>3</sub>)<sub>2</sub></b> | <b>Mean</b> | <b>Control</b>                                 | <b>KNO<sub>3</sub></b> | <b>NH<sub>4</sub>NO<sub>3</sub></b> | <b>Ca(NO<sub>3</sub>)<sub>2</sub></b> | <b>Mean</b> |
| Aghonibora                                                                       | 1.43                                            | 1.51                   | 1.45                                | 1.55                                  | 1.48        | 9.28                                           | 9.66                   | 9.52                                | 9.81                                  | 9.55        |
| Gitesh                                                                           | 1.56                                            | 1.62                   | 1.59                                | 1.58                                  | 1.59        | 10.03                                          | 10.59                  | 10.19                               | 10.88                                 | 10.42       |
| Aki Sali                                                                         | 1.34                                            | 1.42                   | 1.36                                | 1.52                                  | 1.41        | 8.36                                           | 8.81                   | 8.59                                | 9.36                                  | 8.78        |
| Prafulla                                                                         | 1.4                                             | 1.45                   | 1.49                                | 1.56                                  | 1.48        | 8.98                                           | 9.25                   | 9.2                                 | 9.55                                  | 9.24        |
| Solpana                                                                          | 1.25                                            | 1.34                   | 1.28                                | 1.44                                  | 1.32        | 7.94                                           | 8.61                   | 8.43                                | 9.42                                  | 8.6         |
| Bahadur                                                                          | 1.38                                            | 1.44                   | 1.41                                | 1.54                                  | 1.44        | 8.69                                           | 9.06                   | 8.85                                | 9.58                                  | 9.04        |
| Ranjit                                                                           | 1.38                                            | 1.45                   | 1.46                                | 1.55                                  | 1.46        | 8.94                                           | 9.25                   | 9.25                                | 9.7                                   | 9.28        |
| Swarna sub1                                                                      | 1.28                                            | 1.38                   | 1.34                                | 1.46                                  | 1.36        | 8.01                                           | 8.58                   | 8.32                                | 9.11                                  | 8.5         |
| Chahou                                                                           | 1.15                                            | 1.34                   | 1.3                                 | 1.41                                  | 1.3         | 7.19                                           | 8.36                   | 8.16                                | 8.68                                  | 8.1         |
| Shruboni                                                                         | 1.24                                            | 1.36                   | 1.29                                | 1.39                                  | 1.32        | 7.6                                            | 8.44                   | 8.22                                | 8.8                                   | 8.27        |
| Mean                                                                             | 1.34                                            | 1.43                   | 1.39                                | 1.5                                   |             | 8.5                                            | 9.06                   | 8.87                                | 9.48                                  |             |
|                                                                                  | Factor                                          | S.Ed(±)                | CD (0.05)                           |                                       |             | Factor                                         | S.Ed(±)                | CD (0.05)                           |                                       |             |
|                                                                                  | Varieties (A)                                   | 0.02                   | 0.04                                |                                       |             | Varieties (A)                                  | 0.15                   | 0.32                                |                                       |             |
|                                                                                  | Aerosols (B)                                    | 0.01                   | 0.02                                |                                       |             | Aerosols (B)                                   | 0.10                   | 0.21                                |                                       |             |
|                                                                                  | A×B                                             | 0.04                   | NS                                  |                                       |             | A×B                                            | 0.32                   | NS                                  |                                       |             |

In the experiment, during maximum tillering stage (Table 5a), the highest per cent increase in lipid peroxidation was brought about by  $\text{NH}_4\text{NO}_3$  (107.14%) followed by  $\text{KNO}_3$  (22.72%), and the lowest was in case of  $\text{Ca}(\text{NO}_3)_2$  (13.63%) as compared to the control. During heading stage (Table 5b), the highest per cent increase in lipid peroxidation was found in treatment  $\text{NH}_4\text{NO}_3$  (11.42%) followed by  $\text{KNO}_3$  (8.49%), and the lowest was in  $\text{Ca}(\text{NO}_3)_2$  (4.71%) as compared to the control (distilled water). Plant's stress condition can be monitored by a marker process known as lipid peroxidation (Bojtor *et al.*, 2019). Lipid peroxidation causes cell death and oxidative damage to cell structures by creating toxicity inside the cell (Bharali *et al.*, 2015a). Because, lipid peroxidation occurs due to formation of reactive nitrogen species (ROS). Kong *et al.* (2017) reported that excessive nitrogen application caused oxidative stress in plants because of inactivation of antioxidant enzymes and reduction in metabolites which plays role in scavenging ROS. Additionally, nitrogen and lipid metabolism also got disrupted. As a consequence, rate of grain filling is interrupted, leaf senescence is accelerated and eventually it reduces the grain yield. Campos *et al.* (2016) stated that ammonium ion in ammonium nitrate enhanced the production of reactive oxygen species in cucumber plant which resulted in decreased growth, chlorosis and necrosis of cucumber roots and leaves. Jan *et al.* (2019) proposed that potassium nitrate-maintained turgidity and lowered the deleterious effects of reactive oxygen species. Plant responses to environmental stresses were found to be regulated by calcium which has important role in cell wall and cell membrane stabilization (Ranty *et al.*, 2006). In *Oryza sativa* L. and *Hordum vulgare* L., it has been reported that potassium nitrate augmentation caused reduction of MDA content (Yu-Chuan *et al.*, 2008; Hafsi *et al.*, 2010).

In the experiment, during maximum tillering stage (Table 6a), the highest per cent increase in CMS was found in treatment  $\text{Ca}(\text{NO}_3)_2$  (14.92%) >  $\text{KNO}_3$  (12.01%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (5.72%) as compared to the control. During heading stage (Table 6b), the highest per cent increase in lipid peroxidation was found in treatment  $\text{Ca}(\text{NO}_3)_2$  (29.85%) >  $\text{KNO}_3$  (24.95%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (10.69%) as compared to the control (distilled water). Cell membrane stability determines the amount of leakage of electrolytes from the segment of leaf (Beltrano and Ronco, 2008). The membrane stability maintenance during the period of stress was found to be important for usual physiological metabolism to persist during reduced water potential (Tripathy *et al.*, 2000). In a study, the cation leakage was found to be greater by the influence of ammonium ions due to which cation's quantity was larger in the both intercellular and exchangeable locations and thus caused in reduction in the stability of the membrane in rice (Bharali *et al.*, 2015b). There is also possibility that lipid peroxidation got accelerated in ammonium treated tissues which is mainly due to more ROS production by ammonium ions (Zhu *et al.*, 2000; Hachiya *et al.*, 2010; Patterson *et al.*, 2010).

In the experiment, the highest per cent increase in intercellular  $[\text{K}^+]$  concentration in cell at maximum tillering (Fig 1a) stage was found in treatment  $\text{KNO}_3$  (59.04%) followed by  $\text{Ca}(\text{NO}_3)_2$  (44.76%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (31.42%) as compared to the control while in the highest per cent increase in exchangeable  $[\text{K}^+]$  concentration in cell at maximum tillering stage (Fig 1b) was found in treatment  $\text{KNO}_3$  (68.86%) followed by  $\text{Ca}(\text{NO}_3)_2$  (74.76%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (71.02%) as compared to the control (distilled water).

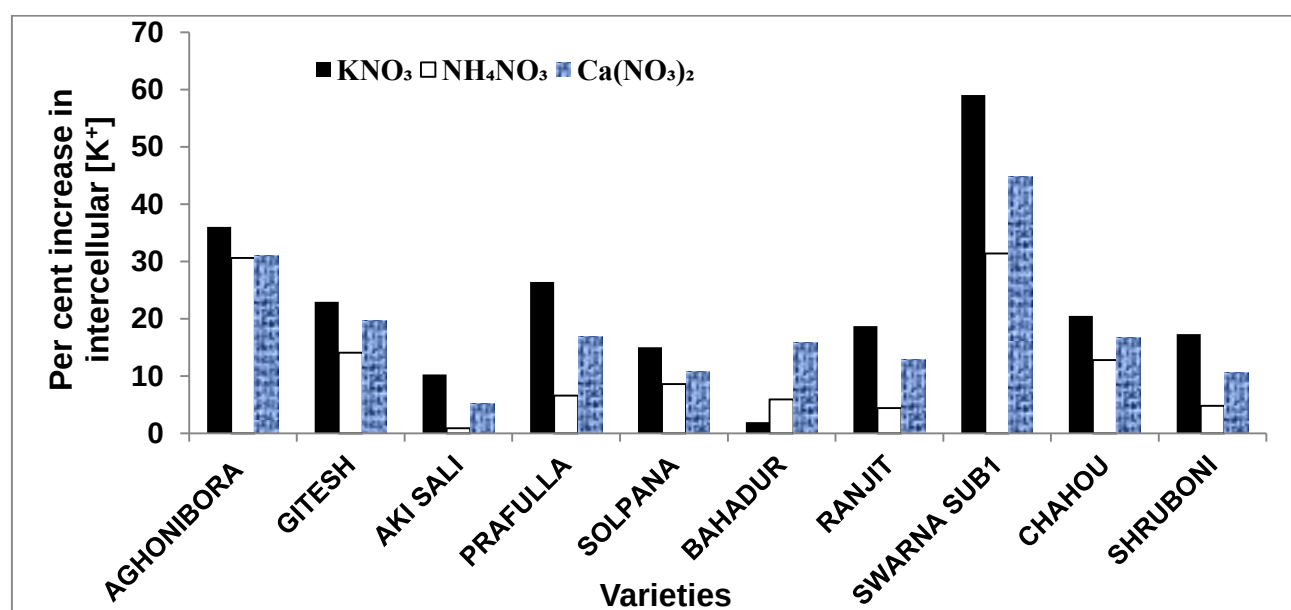


FIGURE 1 (a): Change in intercellular  $[\text{K}^+]$  of rice leaf at maximum tillering stage as affected by nitrogen aerosols as compared to control

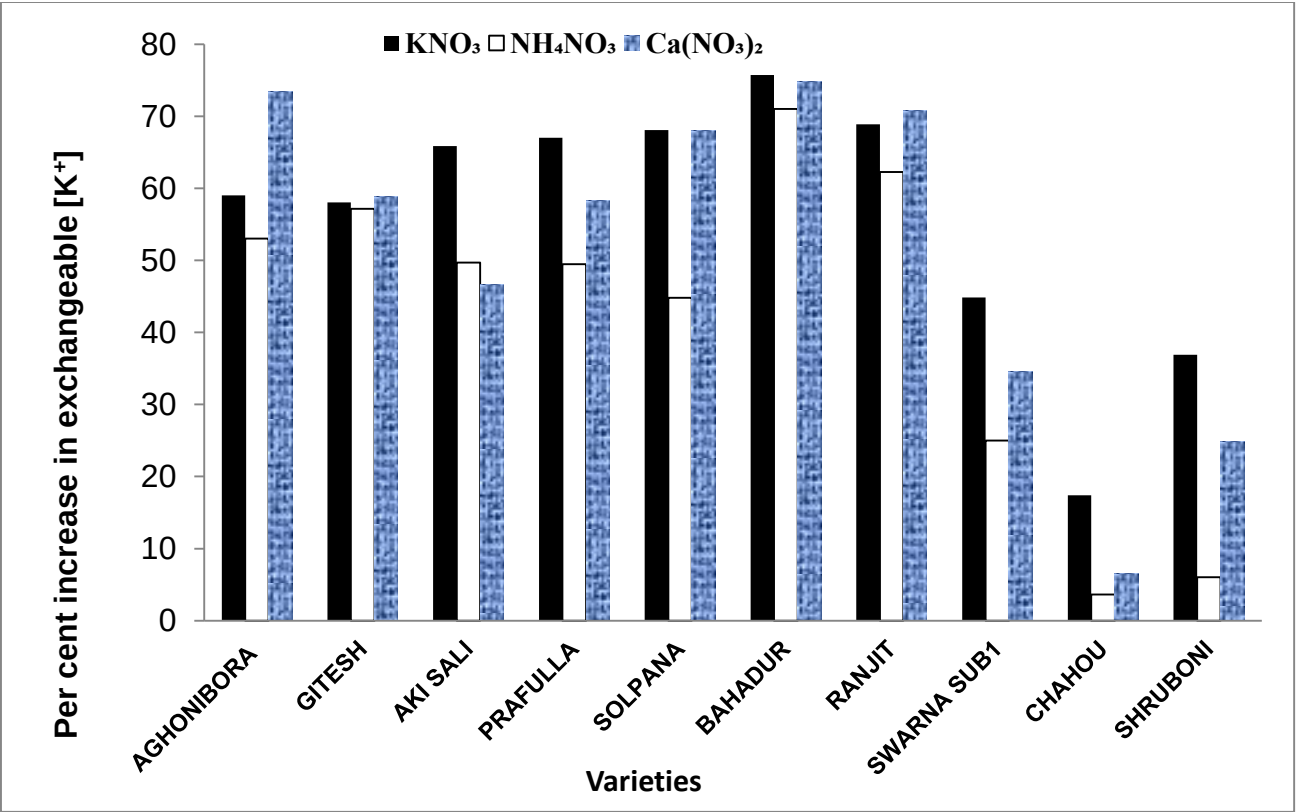


FIGURE 1 (b): Changes in exchangeable [ $K^+$ ] in rice at maximum tillering stage as affected by aerosols treatments as compared to control

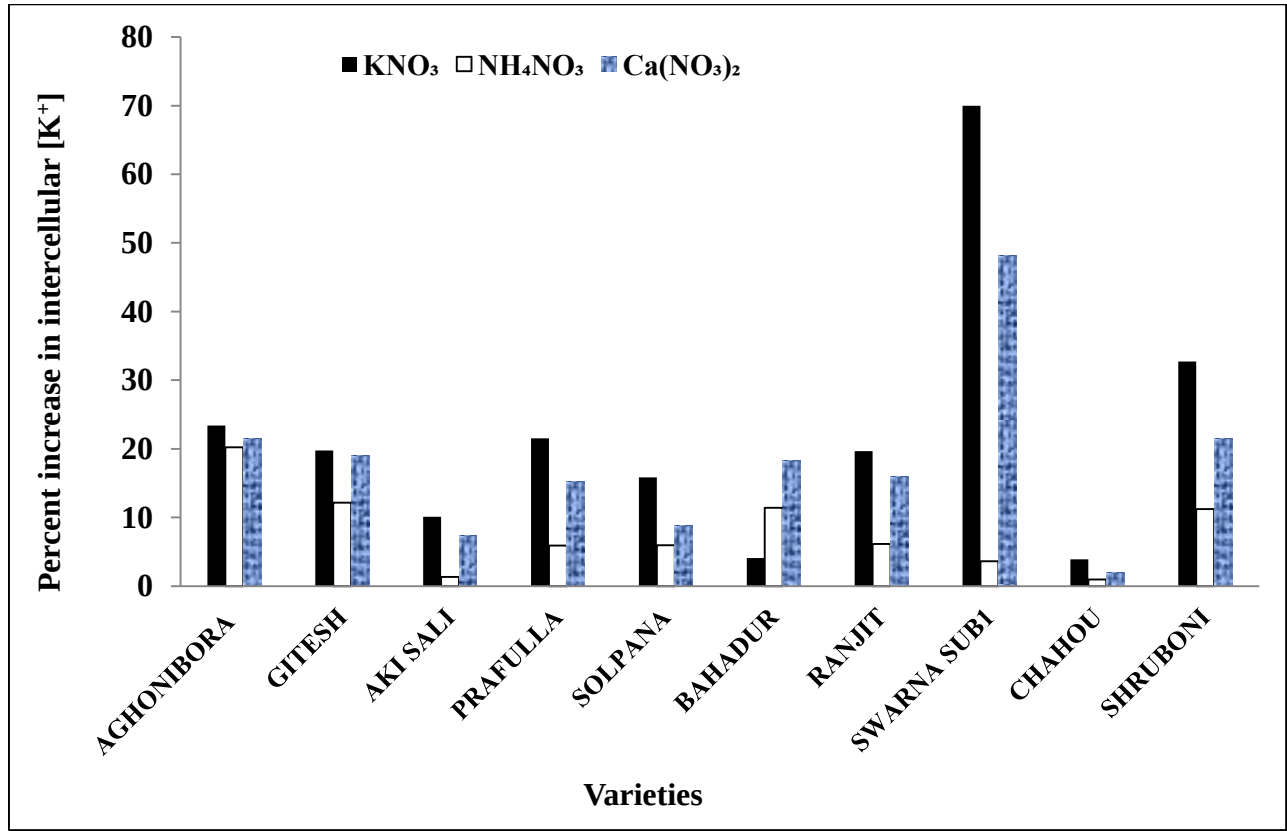


FIGURE 2 (a): Change in intercellular [ $K^+$ ] in leaf of rice at heading stage as affected by nitrogen aerosols as compared to control

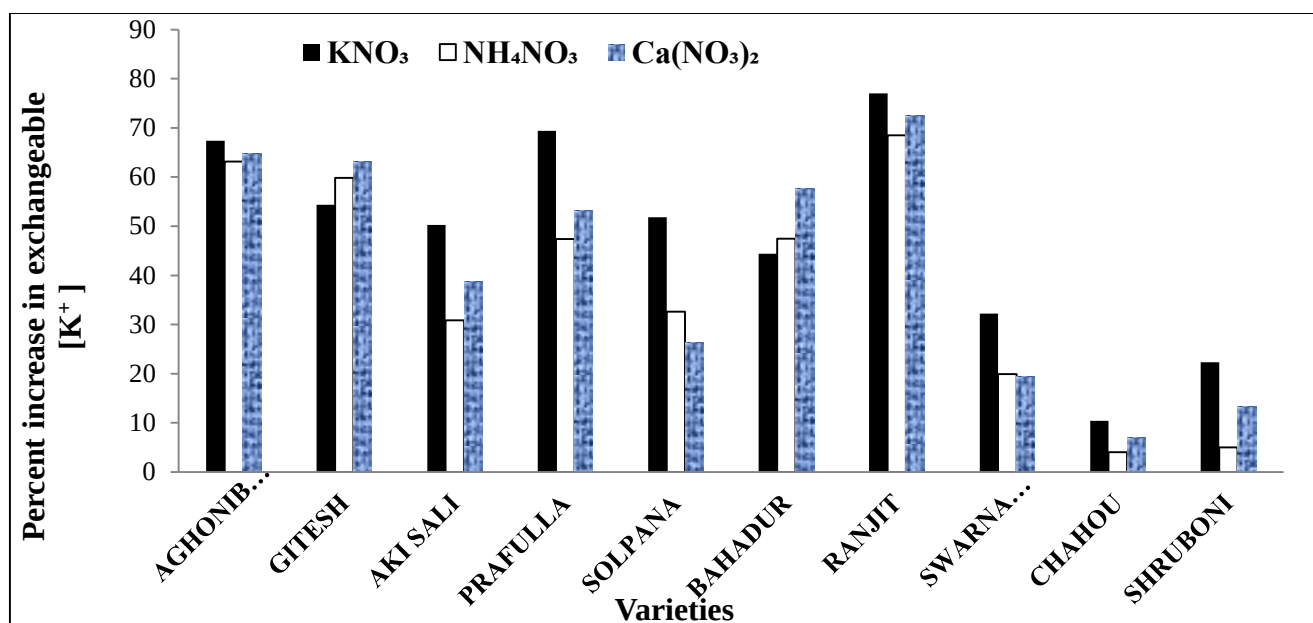


FIGURE 2 (b): Change in exchangeable [K<sup>+</sup>] in leaf of rice at heading stage as affected by aerosols in comparison to control

In the experiment (Fig.2a), the highest percent increase in intercellular [K<sup>+</sup>] concentration in cell at heading stage was found in treatment KNO<sub>3</sub> (23.41%) followed by Ca(NO<sub>3</sub>)<sub>2</sub> (48.18%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub> (20.23%) as compared to the control while the highest per cent increase in exchangeable [K<sup>+</sup>] concentration in cell at heading stage (Fig 2b) were found in treatment KNO<sub>3</sub> (77.02%) followed by Ca(NO<sub>3</sub>)<sub>2</sub> (72.52%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub> (68.46%) as compared to the control (distilled water). Ammonium and nitrite aerosols caused damaged to membrane which made membrane leaky for the cations and thus concentrations of cations became higher in intercellular and extracellular locations irrespective of plant varieties (Bharali *et al.*, 2015b). Potassium nitrate plays a key role in activation of various enzymes, supporting of electrical potential gradients across cell membranes. It is also indispensable for photosynthesis process, protein synthesis, and regulation of stomatal movement, and is the major cation in the maintenance of cation-anion balance (Marschner, 1995). Potassium has impact on enzymes required for conversion of atmospheric nitrogen to ammonia in rhizobium. Potassium nitrate was found to enhance carbohydrate supply for reduction of nitrogen inside the nodules for amino acid synthesis (Havilan *et al.*, 2005).

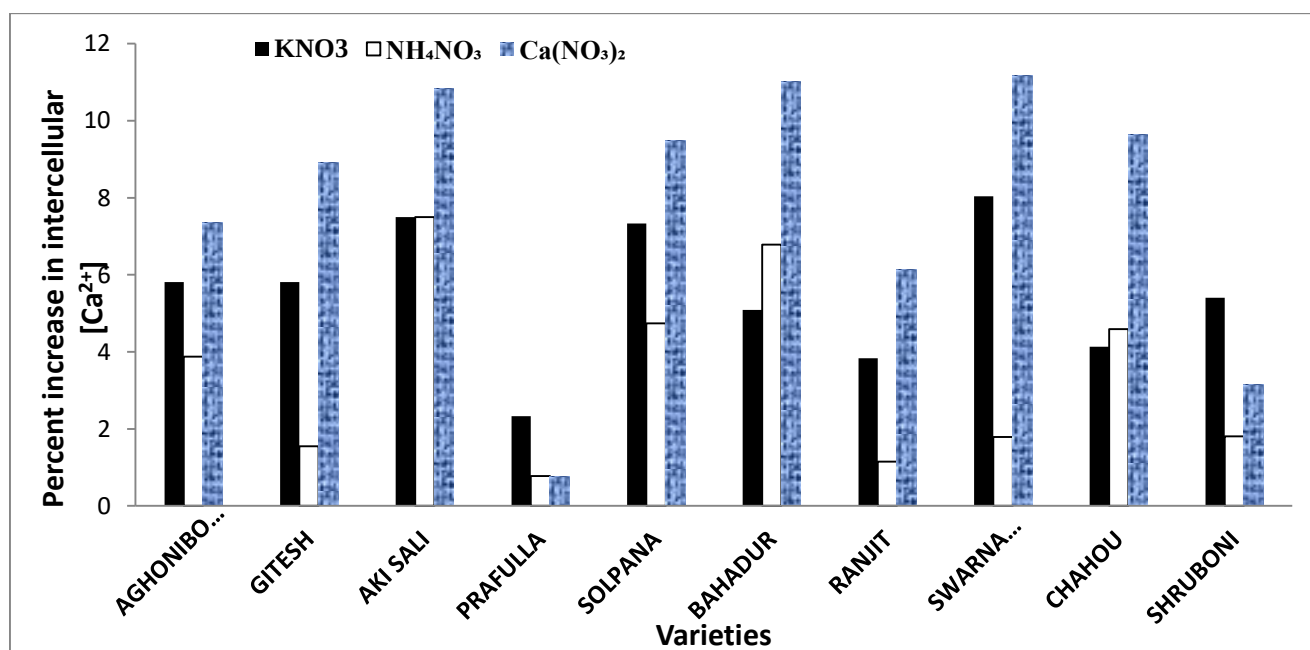


FIGURE 3 (a): Changes in intercellular [Ca<sup>2+</sup>] in leaf of rice at maximum tillering stage as affected by N-aerosols in comparison to control

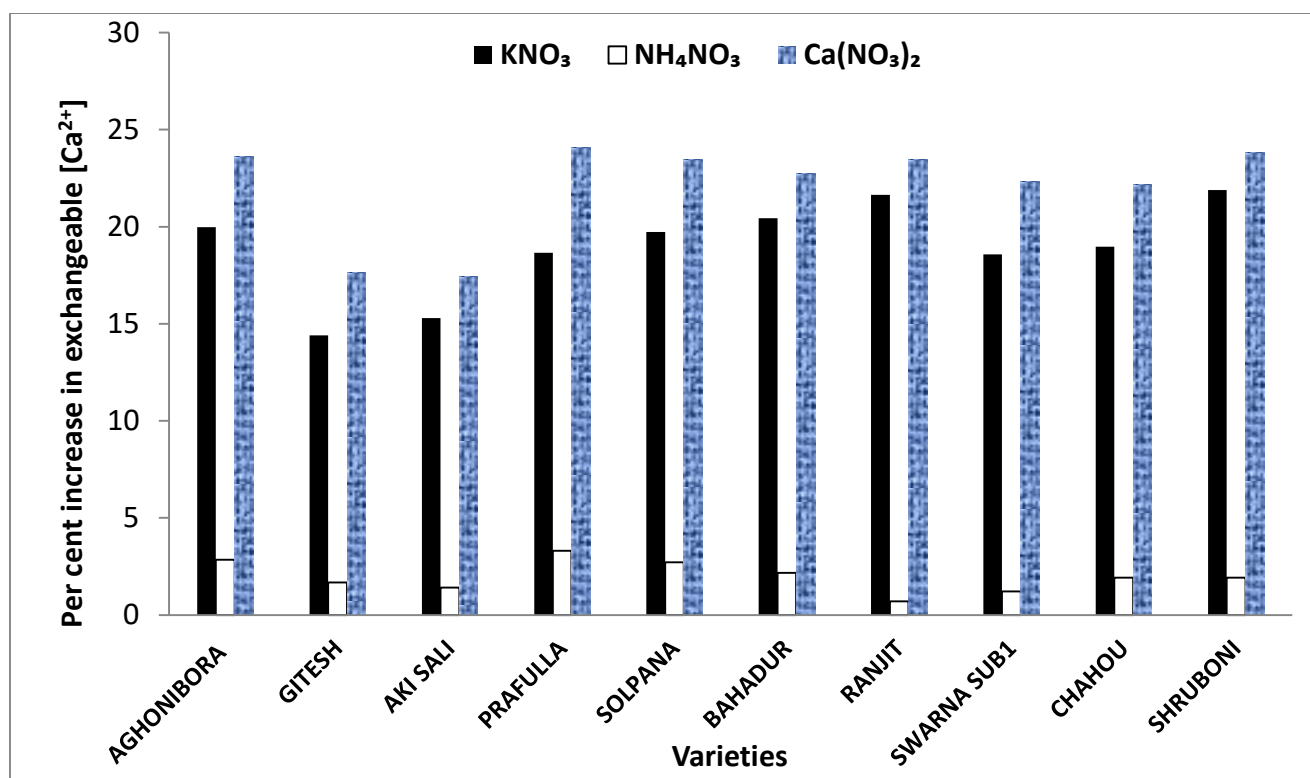


FIGURE 3 (b): Change in exchangeable  $[Ca^{2+}]$  in leaf of rice at maximum tillering stage as affected by aerosol in comparison to control

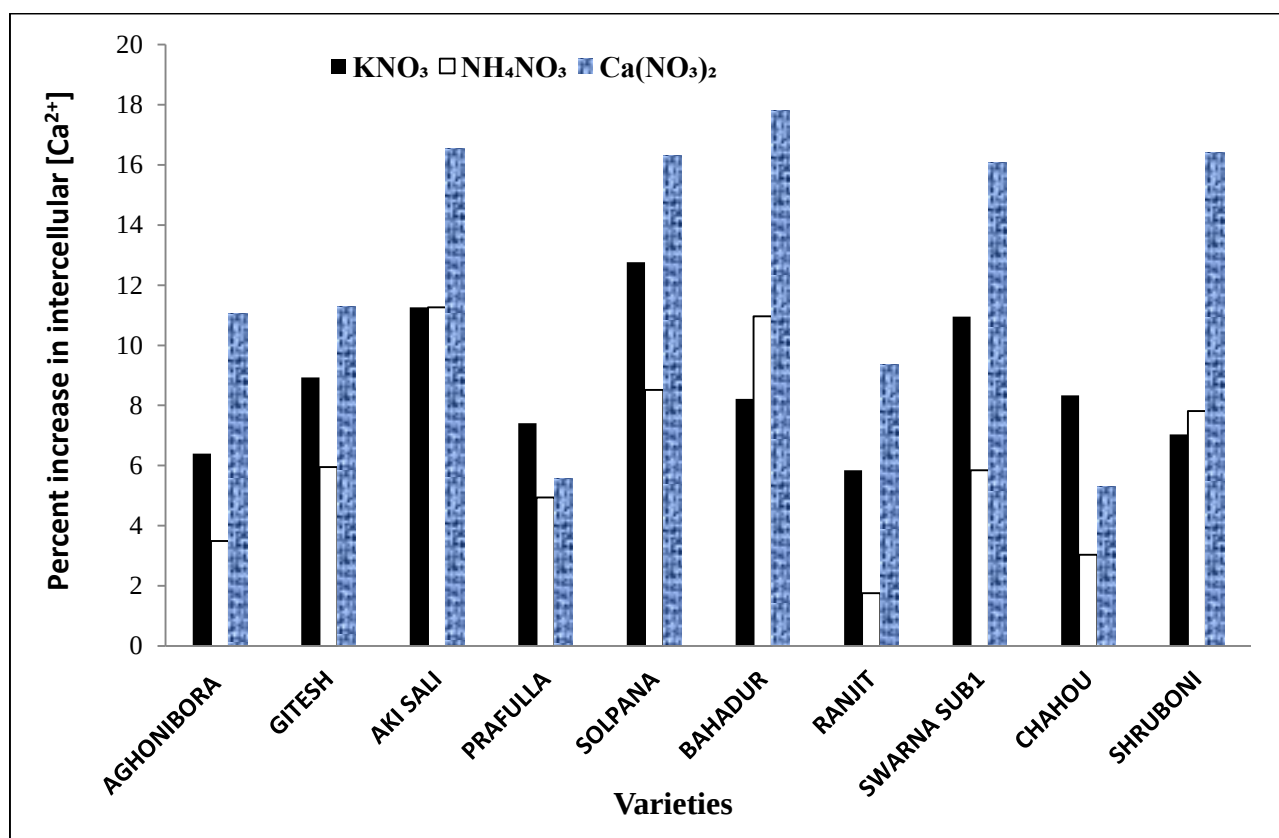


FIGURE 4 (a): Changes in intercellular  $[Ca^{2+}]$  in leaf of rice at heading stage as affected by N-aerosol in comparison to control

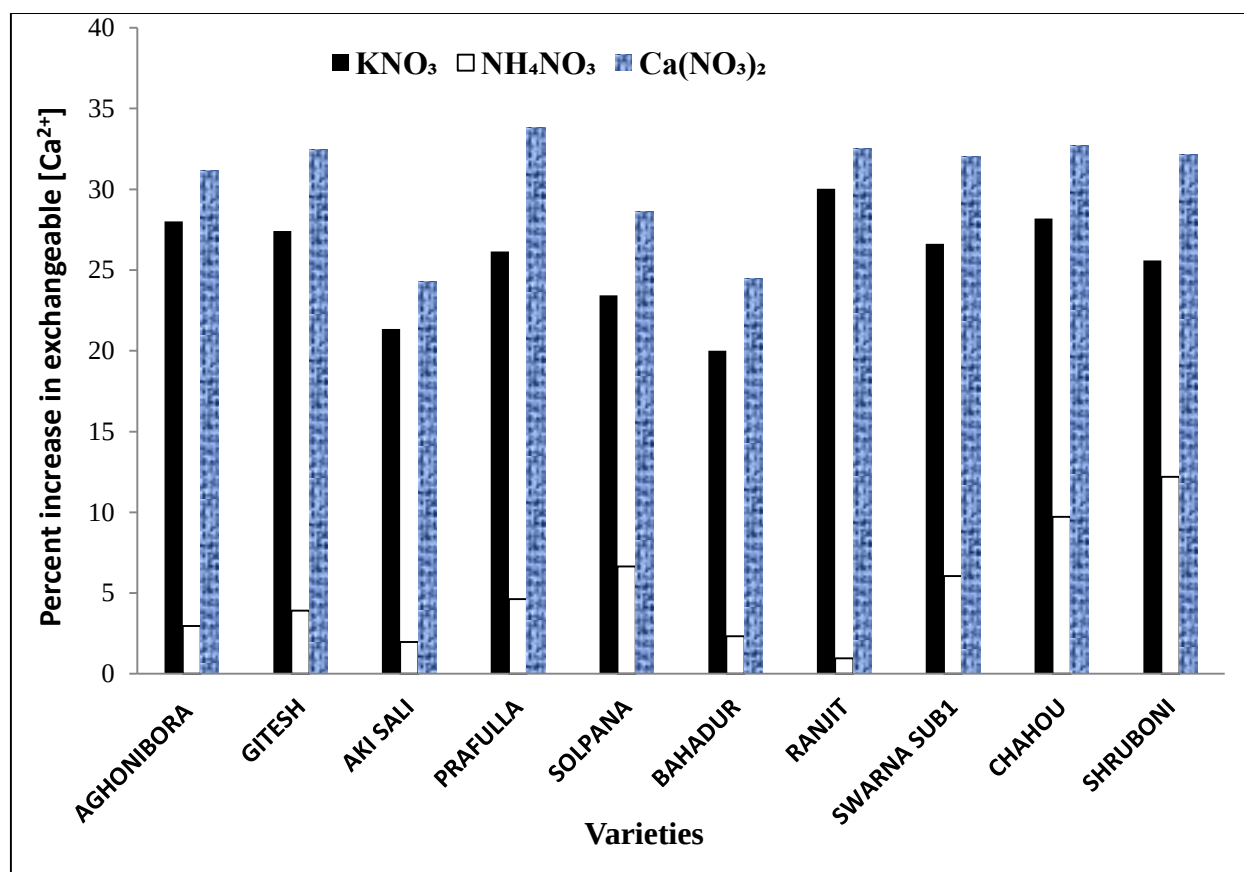


**FIGURE 4(b): Changes in exchangeable [Ca<sup>2+</sup>] in leaf of rice at heading stage as affected by N-aerosol in comparison to control**

In the experiment, during maximum tillering stage (Fig 3a) the highest per cent increase in intercellular [Ca<sup>2+</sup>] concentration in cell was found in treatment Ca(NO<sub>3</sub>)<sub>2</sub> (11.16%) > KNO<sub>3</sub> (8.03%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub> (6.77%) as compared to the control while the highest per cent increase in exchangeable [Ca<sup>2+</sup>] concentration (Fig 3b) in cell was found in treatment Ca (NO<sub>3</sub>)<sub>2</sub> (23.80%) > KNO<sub>3</sub> (21.88%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub> (3.29%) as compared to the control(distilled water).

In the experiment, heading stage the highest per cent increase in intercellular [Ca<sup>2+</sup>] concentration (Fig 4a) in cell was found in treatment Ca(NO<sub>3</sub>)<sub>2</sub> (17.80%) > KNO<sub>3</sub> (12.76%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub>(11.25%) as compared to the control while, the highest per cent increase in exchangeable [Ca<sup>2+</sup>] concentration (Fig 4b) in cell was found in treatment Ca (NO<sub>3</sub>)<sub>2</sub> (33.80%) > KNO<sub>3</sub> (30.03%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub>(12.21%) as compared to the control(distilled water). Calcium is essential for maintaining the strength of cell walls, growth and division of cell, assimilation of nitrogen and working as enzyme cofactors (Sajid *et al.*, 2020). Calcium nitrate aerosol supply calcium ions to plants which play important role in protecting the membrane from damage caused due to peroxidation of membranes and solute leakage and enhance the CMS within the plant cells (Borgohain *et al.*, 2019). Marschner (1995) reported that nitrogen foliar nutrition resulted in reduction in membrane permeability but adding up of Mg<sup>2+</sup> and Ca<sup>2+</sup> ions along with nitrogen application to plants and improved the integrity of membrane because of calcium which maintains the structural and functional integrity of plant membrane, stabilize cell wall structure, regulate ion transport and selectivity and control ion exchange behavior as well as enzyme activities.

In the experiment, during harvesting stage (Table 7a), the highest per cent increase in total nitrogen content in grains was found in treatment Ca(NO<sub>3</sub>)<sub>2</sub> (22.61%) > KNO<sub>3</sub> (16.52%), and the lowest was in NH<sub>4</sub>NO<sub>3</sub>(13.04%) as compared to the control (distilled water). The capacity of plant to translocate nitrogen into grains is considered as sink while the supply of N that is available for translocation into the grain is considered as source, and also these factors are thought to be governing the nitrogen content of grains (Kato, 2012). Lyu *et al.* (2022) stated that nitrogen foliar application fosters N remobilization and N uptake following anthesis by increasing the activity of grain N metabolism enzymes like NR, Glutamine synthetase (GS) and glutamate pyruvate transaminase (GPT) and protein accumulation particularly during the period of middle and late grain-filling stages. These in turn caused the grain N demand and remobilization of nitrogen, directing to greater grain protein content and grain quality. Application of nitrogen during the fruiting stage could boostup wheat's protein content from 10.8 to 21.0% (Woolfolk

*et al.*, 2002). Kaya *et al.* (2003) reported that  $\text{Ca}(\text{NO}_3)_2$  foliar spray improved the content of calcium and nitrogen in cucumber and melon plants. Calcium nitrate is highly soluble in nature and its high solubility makes it popular for immediate supply of available source of nitrate and calcium directly to soil through irrigation water or with foliar applications. Tripathy *et al.* (2018) suggested that  $\text{Ca}^{2+}$  presence along with nitrate improves the utilization of nitrogen and greater assimilation of nitrate in roots and leaves.

In the experiment, during harvesting stage (Table 7b), the highest percent increase in crude protein content in grains was found in treatment  $\text{Ca}(\text{NO}_3)_2$  (20.72%) >  $\text{KNO}_3$  (16.27%), and the lowest was in  $\text{NH}_4\text{NO}_3$  (13.49%) as compared to the control (distilled water). Tripathy *et al.* (2018) showed the significant effect of treatment of  $\text{NO}_3^-$  with the pair of counter ions ( $\text{K}^+$  and  $\text{Ca}^{2+}$ ) by increasing grain protein content and chlorophyll synthesis in hybrid rice. Yathish *et al.* (2021) stated that foliar treatment of calcium nitrate enhanced nitrogen and protein content in grains due to greater uptake of calcium cation which played a crucial role in utilization of nitrogen present in soil and assimilation of nitrate in leaves and roots of pigeonpea. Vijayakumar *et al.* (2022) reported that potassium nitrate foliar application promotes the amino acid translocation from vegetative parts to grains as well as conversion of amino acids to grain proteins.

#### IV. CONCLUSIONS

- Among the nitrogen aerosols,  $\text{KNO}_3$  was observed to be more effective than  $\text{CaNO}_3$  and  $\text{NH}_4\text{NO}_3$  as compared to the control (distilled water). Because,  $\text{KNO}_3$  was found to support K and N-nutrition as well as maintained the cell membrane stability with higher retention of intercellular and exchangeable ions and greater enzymatic (NR) activity in rice.
- All the N-aerosols @60 Kg ha<sup>-1</sup> impacted majority of the biochemical traits of rice crop positively.
- Among the 10 rice varieties, Gitesh was found to be the best as it possessed the desirable characteristics under the influence of foliar nitrogen aerosols application.
- In the present investigation, variety Gitesh can be considered prominent one in terms of foliar K-nutrition. This variety may be explored in rice improvement programme in the current climate change scenarios globally.

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# MILLET: The Environment Sustainable and Future Grain

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**Abstract**— Traditionally referred to as "poor man's cereals," millets are now gaining prominence on prestigious platforms, such as being served to national guests at the G20 summit in India. Despite their rising popularity, millet production has not kept pace. Rich in both macro and micro-nutrients, millets offer numerous health benefits, including aiding digestion and addressing heart-related issues. The average person requires 109.5 kg of millet annually. With India's population at 1.4 billion and an annual millet production of 120 lakh tons (2022), the country faces a deficit of 33.3 lakh tons from its required 153.3 lakh tons. This highlights the urgent need for increased awareness and production of millets.

**Keywords**— Millets, Sustainability, Nutrient Benefits, Future Grain.

## I. INTRODUCTION

Millets have been cultivated for thousands of years, holding significant cultural and nutritional value across Asia and Africa. Despite their rich history, they have been overshadowed by rice and wheat in modern agriculture. However, a renewed interest in millets is emerging, driven by their potential to address food security, climate resilience, and malnutrition challenges.



FIGURE 1: Millets

These nutrient-rich grains are abundant in protein, fiber, vitamins, and minerals. Their resilience to drought, low water requirements, and adaptability to poor soils make them an ideal crop for climate-affected regions. Additionally, millets contribute to biodiversity and promote sustainable farming practices by reducing dependency on monoculture.

Millets are versatile in the kitchen, suitable for a variety of dishes beyond traditional preparations, including soups, salads, gluten-free baked goods, and desserts. They empower smallholder farmers, especially in marginalized areas, by creating economic opportunities and enhancing food system resilience. However, challenges such as limited research, consumer awareness, and investment in millet production must be addressed.

This paper explores the multifaceted benefits of millets, emphasizing their role in sustainable agriculture, nutrition, and climate adaptation while calling for a unified effort to promote their cultivation and consumption.

## II. MATERIALS AND METHODS

### 2.1 Nutritional Value of Millets:

Millets are often called "powerhouses of nutrients." They are rich in macro-nutrients like protein, carbohydrates, and dietary fiber and provide essential micronutrients. On average, millets contain:

- **Protein:** 7–12%
- **Fat:** 2–5%
- **Carbohydrates:** 65–75%
- **Dietary Fiber:** 15–20%

Millets also provide high levels of phosphorus, iron, and essential amino acids, making them a superior choice compared to traditional cereals like maize. They are particularly beneficial in improving digestion and metabolic health due to their high antioxidant activity from phytates, polyphenols, and tannins.

### 2.2 Health Benefits:

1. **Diabetes Management:** Low glycemic index helps regulate blood sugar levels.
2. **Heart Health:** Rich in magnesium, fiber, and antioxidants that support healthy cholesterol levels and reduce inflammation.
3. **Digestive Health:** High fiber content aids in maintaining gut health and preventing constipation.
4. **Weight Management:** Millets provide a satiating, low-calorie food option that supports metabolism.

### 2.3 Environmental Benefits:

Millets are environmentally friendly, requiring minimal water, chemical fertilizers, and pesticides. They protect soil fertility through their deep root systems and organic farming practices, which reduce soil degradation and enhance biodiversity.

### 2.4 Suitability for Dry Lands:

Millets thrive in dry and arid conditions where other crops fail. Their exceptional drought tolerance and ability to grow in nutrient-poor soils make them a viable option for dry land agriculture. By cultivating millets, farmers can ensure food security while improving land management practices.

## III. RESULTS AND DISCUSSION

### 3.1 Current Millet Awareness in India:

Despite initiatives like the International Year of Millets (2023), the gap between production and demand persists. Increased consumer demand is evident in urban areas, but rural regions still prefer traditional staples like rice and wheat. Bridging this awareness gap is essential for sustained millet production.

### 3.2 Recommendations:

1. **Educational Campaigns:** Promote millet benefits and recipes to encourage consumption in rural and urban areas.
2. **Farmer Training:** Introduce improved cultivation techniques and drought-resistant millet varieties.
3. **Collaborative Efforts:** Governments, NGOs, chefs, and food companies should work together to highlight millet's environmental and nutritional advantages.
4. **Market Incentives:** Stabilize prices and provide financial support to farmers cultivating millets.

## IV. CONCLUSION

Millets hold immense potential as a sustainable and nutritious crop for India and the world. Addressing production deficits requires a concerted effort to raise awareness, invest in market infrastructure, and promote millet-based products. Collaborative

actions between governments, NGOs, and private sectors can ensure millets become a staple for future generations. Embracing millets will not only improve public health but also contribute to environmental sustainability and economic resilience in the agricultural sector.

By prioritizing millets, we can secure a healthier and more sustainable future, ensuring that these ancient grains reclaim their rightful place as a cornerstone of global agriculture.

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# Efficacy of Biorational Spray Schedules for Sustainable Management of Citrus Thrips (*Scirtothrips dorsalis* Hood) in Acid Lime

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**Abstract**— Citrus thrips (*Scirtothrips dorsalis* Hood) is a major constraint in acid lime production, causing leaf distortion, flower drop and severe fruit scarring. Excessive reliance on synthetic insecticides has led to resistance development, residue concerns and disruption of natural enemies. Field experiments were conducted during 2022–23 and 2023–24 at Citrus Research Station, Petlur, Tirupati (Dt), Andhra Pradesh, India to evaluate the efficacy of different biorational insecticide spray schedules against citrus thrips. Eight treatments comprising neem-based botanicals, horticultural mineral oil (HMO), entomopathogenic fungi and Spinosad were evaluated in a randomized block design with three replications. Two sequential sprays were applied at petal fall and pea-size fruit stages. Treatments involving HMO @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit and Azadirachtin 1% EC (2 ml/lit) followed by Spinosad 48 SC @ 0.25 ml/lit recorded the lowest thrips population, minimum fruit infestation (3.6–4.1%) and highest yield (20.9–22.4 t/ha) across both seasons. Entomopathogenic fungi provided moderate but significant control, whereas mineral oil alone was less effective under higher pest pressure. The study clearly demonstrates that rotation of biorational insecticides with different modes of action ensures effective suppression of citrus thrips, reduces fruit damage and enhances yield. Such biorational spray schedules offer an environmentally safe, residue-free and sustainable alternative to conventional insecticides and can be effectively integrated into IPM programmes for acid lime cultivation.

**Keywords**— Acid lime, Azadirachtin, Horticultural mineral oil, IPM, Spinosad, Thrips.

## I. INTRODUCTION

Acid lime (*Citrus aurantifolia* Swingle) is a commercially important citrus species cultivated extensively in southern India, particularly in Andhra Pradesh, where it contributes significantly to farm income and export-oriented horticulture. Productivity and fruit quality in acid lime are severely constrained by insect pests, among which thrips, especially *Scirtothrips dorsalis* Hood, are considered one of the most economically damaging pests in tropical and subtropical citrus-growing regions (Childers & Achor, 1995; Seal et al., 2006). Both nymphs and adults of *S. dorsalis* feed on meristematic tissues, including tender leaves, flower buds, and young fruits. Their feeding results in epidermal cell collapse, leading to leaf curling, bronzing, flower drop, and characteristic scab-like fruit scarring, which substantially reduces market acceptability and export value (Childers, 1997; Reddy & Kumar, 2012). Damage occurring during early fruit development is particularly critical, as even low thrips populations can result in severe cosmetic injury and economic loss. Management of *S. dorsalis* in citrus orchards has largely relied on repeated applications of broad-spectrum synthetic insecticides. However, the pest is highly polyphagous, multivoltine, and capable of rapid population buildup, leading to frequent spray interventions (Seal et al., 2006). Prolonged and indiscriminate use of chemical insecticides has resulted in resistance development, disruption of natural enemy complexes,

pest resurgence, and concerns related to pesticide residues on fruits, especially those destined for domestic consumption and export markets (Morse & Hoddle, 2006; Isman, 2006).

In recent years, biorational insecticides have gained considerable attention as environmentally safer alternatives to conventional chemicals. These include botanical insecticides, such as neem-based formulations, and microbial agents, such as entomopathogenic fungi. Azadirachtin, the principal bioactive compound in neem, functions primarily as an insect growth regulator, antifeedant, and oviposition deterrent, thereby suppressing pest populations without causing immediate mortality (Schmutterer, 1990; Isman, 2006). Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* infect insects through cuticular penetration, leading to systemic mycosis and death, and are generally considered compatible with beneficial arthropods (Shah & Pell, 2003; Vega et al., 2009). Although the efficacy of biorational insecticides against thrips has been demonstrated in vegetable and ornamental cropping systems, their field-level performance in perennial citrus orchards under tropical agroclimatic conditions remains inadequately validated. Moreover, information on optimized spray schedules and rotational use of biorationals for sustainable thrips management in acid lime is scarce. It is hypothesized that sequential application of neem-based formulations and microbial insecticides can effectively suppress *S. dorsalis* populations, reduce fruit damage, and minimize adverse impacts on natural enemies. In this context, the present study was undertaken to evaluate the efficacy of selected biorational insecticides and their spray schedules against citrus thrips in acid lime. Development of effective biorational-based spray schedules is expected to assist citrus growers in rational pesticide selection, resistance management, improved fruit quality, enhanced export potential, and promotion of sustainable eco-friendly agriculture.

## II. MATERIALS AND METHODS

The field experiment was conducted in an established acid lime (*Citrus aurantifolia* Swingle) orchard at Citrus Research Station, Petlur, Tirupati district of Andhra Pradesh, India during 2022–23 and 2023–24 to evaluate the efficacy of different spray schedules of biorational insecticides against citrus thrips (*Scirtothrips dorsalis* Hood). The experiment was laid out in a Randomized Block Design (RBD) with eight treatments, including an untreated control, and three replications. Acid lime trees of uniform age, size, and vigour were selected for the study to minimize variability. Eight treatments comprising different biorational insecticide spray schedules, including an untreated control, were evaluated against citrus thrips in acid lime. Each treatment involved two sequential sprays, with the first spray at petal fall stage and the second spray at pea-size fruit stage (Table 1). Each treatment in every replication consisted of three trees, and thus a total of nine trees per treatment were maintained for observation. Individual replications were separated by buffer rows to avoid spray drift and treatment interference.

**TABLE 1**  
**TREATMENT DETAILS**

| Treatment No. | Treatment Description                                                                                                   |
|---------------|-------------------------------------------------------------------------------------------------------------------------|
| T1            | Azadirachtin 1% EC (10000 ppm) @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit                                    |
| T2            | Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by Azadirachtin 1% EC (10000 ppm) @ 2 ml/lit                       |
| T3            | Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by HMO @ 10 ml/lit                                                 |
| T4            | <i>Metarhizium anisopliae</i> (1 x 10 <sup>9</sup> CFU's/gm) @ 5 g/lit followed by HMO @ 10 ml/lit                      |
| T5            | <i>Lecanicillium lecanii</i> (1 x 10 <sup>8</sup> CFU's/gm) @ 5 g/lit followed by Azadirachtin (10000 ppm) @ 2.0 ml/lit |
| T6            | Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit                                    |
| T7            | <i>Lecanicillium lecanii</i> (1 x 10 <sup>8</sup> CFU's/gm) @ 5 g/lit followed by Spinosad 48 SC @ 0.25 ml/lit          |
| T8            | Control (water spray)                                                                                                   |

Two rounds of spray applications were imposed as per the treatment schedule. The first spray was applied at the petal fall stage, which coincides with the initiation of thrips infestation. The second spray was carried out at the pea-size fruit stage, a critical period for thrips-induced fruit scarring. All treatments were applied using a hand-operated knapsack pneumatic sprayer, ensuring uniform coverage of the foliage and developing fruits. The spray volume was adjusted according to tree canopy size to achieve thorough wetting without runoff. Spraying was done during the early morning hours under calm weather conditions to ensure effective deposition and minimize spray drift. The untreated control trees were maintained without any insecticidal application throughout the experimental period. The observations were recorded at '0' days as pre-count and post-count at 3rd, 7th, 10th and 14th days after each spray. The data on number of thrips per tender shoot or flower bud was recorded. In addition to direct population counts, the intensity of thrips infestation and damage was also assessed using a 1–5 visual rating scale (1 = Low; 2 = Moderate; 3 = High; 4 = Severe; 5 = Very severe). Percent fruit infestation was recorded during harvest. The data on average population of thrips was transformed using square root transformation ( $\sqrt{x+0.5}$ ) and data in the form of percentage was transformed into arc sine values subjected to statistical analysis as suggested by Panse and Sukhatme (1985). The standard error (S.E.) and critical difference (C.D.) at 5% level of probability was calculated and yield data was subjected to statistical analysis.

### III. RESULTS

#### 3.1 Efficacy During 2022–23:

The results revealed that during the year 2022–23, significant differences were observed among the biorational spray schedules in reducing thrips incidence in acid lime. Among the treatments, T6, T1, and T3 recorded the lowest thrips population at 3, 7, and 14 days after spraying (DAS) and were statistically on par with each other, while differing significantly from the remaining treatments. Treatment T6 (Horticultural Mineral Oil @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) recorded 4.50, 3.18, and 1.74 thrips per shoot at 3, 7, and 14 DAS, respectively. This was closely followed by T1 (Azadirachtin 1% EC @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) with 4.64, 3.24, and 1.86 thrips per shoot, and T3 (Horticultural Mineral Oil @ 10 ml/lit applied twice) with 4.70, 3.30, and 1.98 thrips per shoot at the respective observation intervals. Similarly, minimum fruit infestation of 3.80% and 4.05% and maximum fruit yield of 22.40 t/ha and 21.90 t/ha were recorded in T6 and T1, respectively. These treatments were statistically on par with each other and significantly superior to the remaining treatments (Table 2).

#### 3.2 Efficacy During 2023–24:

During 2023–24, a similar trend was observed. Treatments T6, T1, and T3 again recorded the lowest thrips incidence at 3, 7, and 14 DAS and were statistically on par with each other, while differing significantly from other treatments. Treatment T6 recorded 5.50, 4.10, and 2.90 thrips per shoot at 3, 7, and 14 DAS, respectively, followed by T1 with 5.64, 4.20, and 3.04 thrips per shoot and T3 with 5.72, 4.24, and 3.12 thrips per shoot. Correspondingly, the lowest fruit infestation of 3.60% and 3.85% and the highest fruit yield of 21.40 t/ha and 20.90 t/ha were recorded in T6 and T1, respectively. These treatments remained statistically on par with each other and were significantly superior to the remaining spray schedules (Table 3).

Overall, across both seasons, T6 and T1 consistently proved superior in reducing thrips population, minimizing fruit infestation, and enhancing fruit yield, followed by T3, indicating the effectiveness of biorational spray schedules involving mineral oil and azadirachtin in rotation with Spinosad.

**TABLE 2**  
**EFFICACY OF BIORATIONALS AGAINST CITRUS THRIPS DURING 2022–23 AT CRS, PETLUR**

| Sl. No. | Treatments                                                    | Mean No. of Thrips/Shoot |                 |                 |                 | Fruit Infestation (%) | Yield (t/ha) |
|---------|---------------------------------------------------------------|--------------------------|-----------------|-----------------|-----------------|-----------------------|--------------|
|         |                                                               | 1 DBS                    | 3 DAS           | 7 DAS           | 14 DAS          |                       |              |
| 1       | Azadirachtin 1% EC @ 2 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit | 9.10<br>(3.10)*          | 4.64<br>(2.27)  | 3.24<br>(1.93)  | 1.86<br>(1.54)  | 4.05 (11.61)**        | 21.9         |
| 2       | HMO @ 10 ml/lit fb Azadirachtin 1% EC @ 2 ml/lit              | 8.70<br>(3.03)           | 6.42<br>(2.63)  | 4.82<br>(2.31)  | 3.24<br>(1.93)  | 4.81 (12.67)          | 19.58        |
| 3       | HMO @ 10 ml/lit fb HMO @ 10 ml/lit                            | 9.24<br>(3.12)           | 4.70<br>(2.28)  | 3.30<br>(1.95)  | 1.98<br>(1.57)  | 4.62 (12.41)          | 19.7         |
| 4       | <i>M. anisopliae</i> @ 5 g/lit fb HMO @ 10 ml/lit             | 8.94<br>(3.07)           | 6.54<br>(2.65)  | 4.98<br>(2.34)  | 3.40<br>(1.97)  | 5.42 (13.46)          | 18.2         |
| 5       | <i>L. lecanii</i> @ 5 g/lit fb Azadirachtin @ 2 ml/lit        | 9.18<br>(3.11)           | 6.62<br>(2.67)  | 5.05<br>(2.36)  | 3.52<br>(2.00)  | 5.20 (13.18)          | 18.44        |
| 6       | HMO @ 10 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit               | 8.96<br>(3.08)           | 4.50<br>(2.24)  | 3.18<br>(1.92)  | 1.74<br>(1.50)  | 3.80 (11.24)          | 22.4         |
| 7       | <i>L. lecanii</i> @ 5 g/lit fb Spinosad 48 SC @ 0.25 ml/lit   | 9.05<br>(3.09)           | 5.60<br>(2.47)  | 3.90<br>(2.10)  | 2.34<br>(1.69)  | 4.42 (12.14)          | 20.14        |
| 8       | Control (water spray)                                         | 9.10<br>(3.10)           | 11.80<br>(3.53) | 13.82<br>(3.78) | 16.10<br>(4.07) | 9.10 (17.56)          | 15.88        |
|         | SE.m.±                                                        | 0.09                     | 0.06            | 0.05            | 0.04            | 0.16                  | 0.39         |
|         | CD @ 5%                                                       | NS                       | 0.18            | 0.17            | 0.11            | 0.49                  | 1.12         |

DAS – Days after spray; DBS – Days before spray; fb – followed by; HMO – Horticultural Mineral Oil

Figures in parentheses are ( $\sqrt{x+0.5}$ ) transformed values

\*\* Figures in parentheses are arc sine transformed values

**TABLE 3**  
**EFFICACY OF BIORATIONALS AGAINST CITRUS THRIPS DURING 2023–24 AT CRS, PETLUR**

| Sl. No. | Treatments                                                      | Mean No. of Thrips/Shoot |                |                |                 | Fruit Infestation (%) | Yield (t/ha) |
|---------|-----------------------------------------------------------------|--------------------------|----------------|----------------|-----------------|-----------------------|--------------|
|         |                                                                 | 1 DBS                    | 3 DAS          | 7 DAS          | 14 DAS          |                       |              |
| 1       | Azadirachtin 1% EC @ 2 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit   | 8.20<br>(2.95)*          | 5.64<br>(2.48) | 4.20<br>(2.17) | 3.04<br>(1.88)  | 3.85 (11.32)**        | 20.9         |
| 2       | HMO @ 10 ml/lit fb Azadirachtin 1% EC @ 2 ml/lit                | 7.20<br>(2.77)           | 6.04<br>(2.56) | 4.70<br>(2.28) | 3.60<br>(2.02)  | 4.60 (12.38)          | 18.58        |
| 3       | HMO @ 10 ml/lit fb HMO @ 10 ml/lit                              | 8.80<br>(3.05)           | 5.72<br>(2.49) | 4.24<br>(2.18) | 3.12<br>(1.90)  | 4.42 (12.14)          | 18.7         |
| 4       | <i>M. anisopliae</i> @ 5 g/lit fb Azadirachtin 1% EC @ 2 ml/lit | 7.80<br>(2.88)           | 6.20<br>(2.59) | 5.04<br>(2.35) | 3.80<br>(2.07)  | 5.30 (13.31)          | 17.2         |
| 5       | <i>L. lecanii</i> @ 5 g/lit fb HMO @ 10 ml/lit                  | 7.10<br>(2.76)           | 6.10<br>(2.57) | 4.92<br>(2.33) | 3.50<br>(2.00)  | 5.18 (13.16)          | 17.44        |
| 6       | HMO @ 10 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit                 | 7.50<br>(2.83)           | 5.50<br>(2.45) | 4.10<br>(2.14) | 2.90<br>(1.84)  | 3.60 (10.94)          | 21.4         |
| 7       | <i>L. lecanii</i> @ 5 g/lit fb Spinosad 48 SC @ 0.25 ml/lit     | 8.00<br>(2.92)           | 6.18<br>(2.58) | 5.60<br>(2.47) | 4.20<br>(2.17)  | 4.30 (11.97)          | 19.14        |
| 8       | Control (water spray)                                           | 7.40<br>(2.81)           | 8.90<br>(3.07) | 9.50<br>(3.16) | 10.20<br>(3.27) | 7.10 (15.45)          | 16.5         |
|         | SE.m.±                                                          | 0.07                     | 0.02           | 0.03           | 0.03            | 0.27                  | 0.57         |
|         | CD @ 5%                                                         | NS                       | 0.06           | 0.09           | 0.09            | 0.81                  | 1.71         |

DAS – Days after spray; DBS – Days before spray; fb – followed by; HMO – Horticultural Mineral Oil

Figures in parentheses are ( $\sqrt{x+0.5}$ ) transformed values

\*\* Figures in parentheses are arc sine transformed values

#### IV. DISCUSSION

The present investigation demonstrated that biorational insecticide spray schedules, when applied sequentially at critical phenological stages of acid lime, effectively suppressed citrus thrips (*Scirtothrips dorsalis* Hood) and improved fruit yield and quality. Among the evaluated treatments, T6 (Horticultural Mineral Oil → Spinosad) and T1 (Azadirachtin → Spinosad) consistently recorded the lowest thrips population, minimum fruit infestation, and highest yield, highlighting the importance of rotating biorationals with different modes of action. The superior performance of horticultural mineral oil followed by Spinosad may be attributed to the initial physical and behavioral disruption caused by mineral oils, which interfere with respiration, feeding, and oviposition of thrips, leading to rapid suppression of early infestations (Beattie et al., 2002; Rae et al., 2014). The subsequent application of Spinosad, a biologically derived insecticide, ensured effective control of surviving individuals through its action on nicotinic acetylcholine and GABA receptors, resulting in quick mortality and prolonged suppression (Sparks et al., 2001). Similarly, the effectiveness of Azadirachtin followed by Spinosad underscores the value of integrating botanical insect growth regulators with bioinsecticides. Azadirachtin acts as an antifeedant and growth regulator, reducing feeding, molting, and reproduction of thrips, while Spinosad provides rapid knockdown of residual populations (Schmutterer, 1990; Isman, 2006). Comparable efficacy of azadirachtin-based IPM strategies against sucking pests has been widely reported. Treatments involving mineral oil alone provided moderate suppression, indicating that oils are more effective when used as part of a rotation rather than as standalone treatments, particularly under sustained pest pressure (Rae et al., 2014; Rao et al., 2013). In contrast, entomopathogenic fungi showed lower field efficacy, likely due to environmental constraints such as temperature, humidity, ultraviolet radiation, and slower speed of action under open field conditions (Shah & Pell, 2003; Vega et al., 2009).

Effective suppression of thrips during petal fall and pea-size stages significantly reduced fruit scarring and enhanced yield, emphasizing the importance of timely intervention at early fruit development stages, when thrips damage directly affects marketable quality (Childers & Achor, 1995). From an Integrated Pest Management (IPM) perspective, the study strongly supports the adoption of biorational spray rotations, which enhance control efficacy, reduce resistance risk, conserve natural enemies, and minimize pesticide residues on citrus fruits. Overall, the results confirm that biorational-based spray schedules integrating mineral oils, botanicals, and Spinosad provide an environmentally safe, economically viable, and sustainable strategy for citrus thrips management in acid lime.

#### V. CONCLUSION

The present study conclusively demonstrated that biorational insecticide spray schedules are effective in managing citrus thrips (*Scirtothrips dorsalis* Hood) in acid lime when applied at critical crop growth stages. Among the evaluated treatments, T6 (Horticultural Mineral Oil @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) and T1 (Azadirachtin 1% EC @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) were found to be the most effective, recording the lowest thrips population, minimum fruit infestation, and highest fruit yield. These treatments were statistically on par with each other and significantly superior to the remaining spray schedules. The study further established that sequential application of biorationals with different modes of action provided prolonged suppression of thrips populations up to 14 days after spraying. Integration of mineral oils or botanical insecticides with Spinosad proved particularly effective in reducing early pest pressure, minimizing fruit scarring, and enhancing marketable yield. Treatments involving entomopathogenic fungi alone showed comparatively lower field efficacy, highlighting the influence of environmental conditions on microbial performance.

Overall, the results emphasize that biorational-based spray rotations can serve as a viable, eco-friendly alternative to conventional insecticides and can be effectively incorporated into Integrated Pest Management (IPM) strategies for sustainable acid lime production.

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#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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