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FOREWORD

I am honoured to introduce this latest issue to the International Journal of Environment, Agriculture and Biotechnology (IJEAB). Our journal is dedicated to disseminating high-quality research and innovative findings that contribute to advancing knowledge in these critical fields.

In this issue, we present a collection of papers that exemplify the diversity and depth of contemporary environmental, agriculture, and biotechnology research. The articles include various topics, from sustainable agricultural practices and environmental conservation strategies to cutting-edge biotechnological innovations. Each contribution has undergone a rigorous peer-review process, ensuring the publication of only the most significant and original research.

Our commitment at IJEAB is to provide a robust platform for researchers, academicians, and practitioners to share their work and engage with a global audience. By fostering an interdisciplinary approach, we aim to bridge the gaps between different areas of study and promote holistic understanding and solutions to the challenges we face in these domains.

We are grateful to our dedicated authors, whose hard work and intellectual rigour are the backbone of our journal. We also extend our appreciation to our reviewers and editorial board members, whose expertise and diligence ensure the high standards of our publication. Finally, we thank our readers for their continued support and engagement.

We hope you find the articles insightful and inspiring as you explore this issue. We encourage you to contribute your research to future issues and join us in our mission to advance knowledge and drive positive change in the environment, agriculture, and biotechnology fields.

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Improving local farming systems in response to global climate change

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***Abstract*— *The purpose of the research is to identify the impact of biologized crop rotations and fertilizers on the content of organic matter - humus and grain yield in a changing climate. Field experiments were carried out in central Russia, in the steppe zone adjacent to the southern part of the Ural Mountains. The soil is medium loamy black soil. The weather conditions of the experimental work site were variable. In the first 3 years, warming was observed with an increase in the sum of effective air temperatures (SEAT) for a period of more than 10^0 C in the range of up to 2800^0 C. In the second three years, there was a cooling with a decrease in SEAT to 1900^0 C. In the first half of the years, precipitation of the growing season decreased to 84 and 71 mm, which is 2-2.6 times less than the long-term level. The second half of the years was characterized by an increase in atmospheric moisture up to 167-280 mm during the growing season. Under the influence of sharply changing weather conditions, crop rotations formed unstable productivity, when deviations by the years of the experiment reached 2 times or more. The greatest deviations from the average grain productivity were observed in the control grain-fallow crop rotation. Productivity changes in biologized crop rotations are 8-9% less. A moderate correlation (r = 0.55) was found between grain productivity of crop rotations and soil humus content. In the soil under biologized crop rotations, the average humus content was 0.7-1.0% higher. To increase the stability of grain productivity in the face of climate change in the steppe zone of the South Urals, it is advisable to improve the farming system based on the use of biologized crop rotations.*

***Keywords*— Agriculture, climate, crop rotation, chernozems, humus.**

I. INTRODUCTION

Global climate change also affects various regions of Russia. In recent decades, precipitation in the country as a whole has increased by 2.1% over 10 years. However, precipitation decreases in the summer in the European part of Russia, including in the Volga Federal District, part of the Ural District, where we conduct research. Since the beginning of the 1990s, there has been a rapid increase in the number of months with elevated air temperatures in Russia as a whole [1]. However, the increase in air temperature in certain territories is unstable. In the Trans-Ural steppe of the South Urals, a noticeable increase in air temperature for a period of more than 10 0 C occurred only in 2016... 2021, reaching a total of 2420 ^{0} C (Table 1).

Table 1. Climate change in the Trans-Ural steppe of the Southern Urals on the territory of the Republic of Bashkortostan of the Russian Federation for 1996... 2025 (30 years)

Indicators	Years				
	1996-2005	2006-2010	2011-2015	2016-2021	2022-2025
Sum of effective air temperatures for the period	2200	2280	2210	2420	2160

more than 10^0 C					
The amount of precipitation of the growing season, mm	186	162	171	117	214
Hydrothermal coefficient of growing season	0,84	0,71	0,77	0,48	0,98
Degree of aridity of the year according to the Selyaninov scale	Dry	Very dry	Dry	Very Dry	Dry

Then there was an excess of the indicator recorded at the beginning of the accounting interval from 1996-2005 by 220 ^{0} C. The relative increase in the sum of effective air temperatures (SEAT) is 10%, which is already a lot. But in the newest period, for 2022-2025, there is a decrease in the thermal component of the growth conditions of cultivated crops to 2160 ^{0} C. Such a difference is considered insignificant, but indicates at least at the time of stopping the growth of climate warming in a given area. Another important factor of crop vegetation is changing more contrastingly - precipitation (Table 1 and Fig. 1).

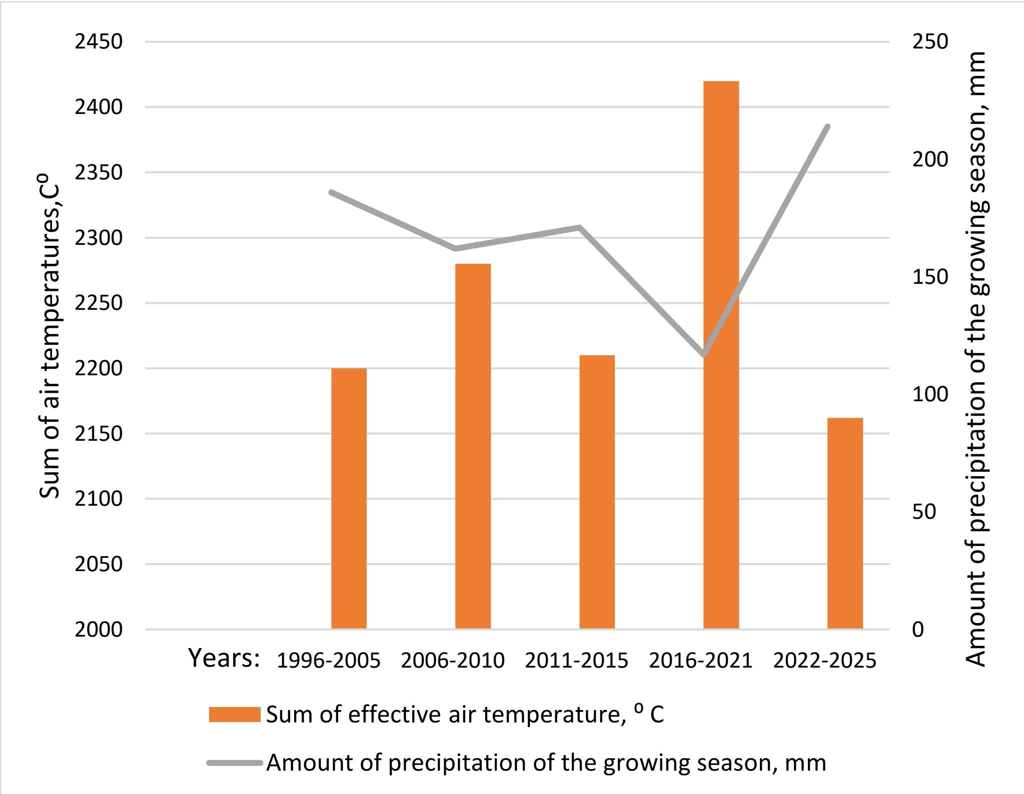

Fig.1. Climate change in the Trans-Ural steppe of the South Urals in the territory Republic of Bashkortostan of the Russian Federation for 1996-2025 (30 years)

As can be seen from the illustrations, over the past 30 years, the amount of atmospheric precipitation of the growing season has decreased significantly. If in the initial period from 1996-2005 it was 186 mm, then already in 2006-2010 and 2011-2015 decreased to 162 and 171 mm, respectively. Relative to the initial level, the indicators decreased by 13 and 8%. The greatest deficit of humidification of the territory was observed in 2016-2021, when the indicator reached the value of 117 mm - a record decrease of 37% from the initial reference level. However, over the past 4 years, precipitation has increased again, reaching 214 mm, which is even higher by 28 mm than in the initial 1996-2005. Hydrothermal coefficients (HTC) of the indicated accounting periods, gradually decreasing, reached the mark of 0.48 in 2016-2021. Moisture supply, correlated with the sum of effective air temperatures, decreased 1.8 times compared to the initial indicator observed in 1996-2005. In accordance with the increase in precipitation, in the final 2022-2025 HTC rose sharply to a value of 0.98. Thus, as on a global scale, drastic climate changes are taking place in the territory of our field experiments, which requires the development of more resistant farming systems to these changes.

In the special literature, a number of measures are proposed to adapt agricultural technologies, including agriculture, to changing climate conditions. Attention is drawn to the need to select species of crops and their predecessors in crop rotation, the most adapted to the local climate. In the conditions of the central forest-steppe aero-landscape region of the Novosibirsk region of the Russian Federation with chernozems leached on the basis of field experiments conducted in 2000-2016 revealed the most adapted crops. The least sensitive to changing conditions of growing seasons, when the hydrothermal coefficient (HTC) in some years ranged from 0.78 (drought) to 1.55 (moderate moisture) against an extensive background without fertilizers, were wheat after steam and wheat after clover. Mineral fertilizers have reduced the negative impact of drought on spring wheat yields [2].

Soil organic matter management is proposed as a decisive measure in climate change mitigation and adaptation [3, 4, 5]. For southern Africa, minimal tillage, cover crops, crop diversification are recommended to improve soil, reduce production costs and mitigate climate risks [6]. In long-term field experiments and on the basis of statistical processing of long-term data on yields in agricultural enterprises, it was shown that the stability of agriculture can be increased by selecting crops and using fertilizers. It is reported that climate-related risks are reduced in a number of spring wheat, barley, winter wheat. Optimization of mineral nutrition reduces the risk of crop shortages in the event of drought by one gradation in most cases [7]. It is possible for all farms to improve the drought resilience of their crops by investing in improving soil health. It is noted that organic soil matter, which performs numerous agroecological functions, is the main indicator of soil health. Measures that increase soil organic matter can increase its moisture capacity, water permeability and reduce runoff during intense rainfall. Conservation tillage and crop cover are effective methods of handling organic substances [8]. Indirect indicators of increasing the resistance of field crops to drought - improving water infiltration and reducing surface runoff through the use of cover crops are indicated in a review compiled by Samuel I. Haruna, Stephen H. Anderson, Ranjith P. Udawalta et all [9]. A study in India's Rangareddy of Telangana district showed high awareness among farmers about climate change in their area of residence. But only a small part of the surveyed study participants could name the reasons and effective measures to adapt production to these climate changes. The majority of respondents pointed to the use of organic and green fertilizers in crop rotation as effective measures to adapt to climate change [10].

According to our literature review, soil organic matter management is presented as a crucial measure in climate change mitigation and adaptation. Based on the studies carried out, directions for improving agricultural systems are recommended, contributing to the extended reproduction of organic soil matter. Among the studied agrotechnological solutions, the correct choice of cultivated crops and their alternation in crop rotation, the use of fertilizers and cover crops, and minimal tillage are listed. However, experimental data on the influence of these factors on the organic matter of the soil and the yield of cultivated crops under climate change are clearly insufficient. Experiments conducted in various territories are especially lacking, covering more soil and climatic conditions.

We set a goal - to identify the impact of biologized crop rotations and fertilizers on the content of organic matter - total humus and grain yield in a changing climate. To achieve the goal, field experiments and laboratory analyzes of soil and plant samples were carried out.

II. MATERIALS AND METHODS

Experimental fields are located in central Russia, in the steppe zone adjacent to the southern part of the Ural Mountains. The soil is medium-loamy black soil, with a humus horizon thickness of 45-48 cm. The initial (in 2019) soil condition of the experimental site was characterized by the following indicators in the arable layer 0-20 cm. The content of total humus is 7.6... 8.2%, mobile phosphorus 108…114 mg/kg, exchange potassium 140... 148 mg/kg. The reaction of the soil environment is close to neutral, with a pH of 5.6... 5.8.

The experiment scheme included 3 field rotations with the corresponding placement of crops (Table 2).

Table 2. Crop rotations and sequence of crops studied in the experiment

No.	Name of crop rotation	Sequence of crop placement						
		1	2	3	4	5	6	7
1	Grain-fallow	Bare fallow	Spring wheat	Spring wheat	Peas	Spring wheat	Barley	
2	Biologized type I	Bare fallow and green fallow	Spring wheat	Spring wheat + alfalfa	Alfalfa	Alfalfa	Spring wheat	Barley
3	Biologized type II	Peas	Spring wheat	Spring wheat + alfalfa	Alfalfa	Alfalfa	Spring wheat	Barley

The influence of crop rotations on the content of humus in the soil and the grain productivity of arable land was studied against the background of the use of straw of grain crops, sideral fertilizer from peas. In addition to organic fertilizers, mineral fertilizers were used - nitrogen in a dose of 30 kg of active substance (AS) per 1 hectare for grain crops and phosphorus - 20 kg AS per 1 hectare for all crop rotation crops when sown in rows. Nitrogen fertilizers for the joint sowing of alfalfa with wheat and in two fields with independent alfalfa were not introduced, relying on the use of nitrogen from the atmosphere by symbiotic bacteria. Straw in the form of crushed post-harvest residues at a dose of 1.5-2 t/ha, depending on yield, was scattered in the fields of grain crops and peas as fertilizer for subsequent crops. In the field where they planned to create green fallow in the spring, in the first decade of May, they sowed small-seeded peas and fertilizer plowdown in the flowering phase of the culture in the first decade of July. The yield of the green mass of the peas at the time of plowing into the soil was 165-180 c from 1 ha.

The laying of experimental plots was carried out according to the method of B.A. Dospekhov (1985). The placement of options is systematic in one tier. The repetition in the experiment is three times in space and two times in time. The plot area with the crop rotation field is 660 m^2, the elementary plot with the background of fertilizers is 165 m^2. Soil samples in a layer of 0-20 cm to determine the humus content were taken with a reed drill annually, before sowing crop rotation crops. The content of total humus was determined by the Tyurin method in the modification of CNAO, according to GOST 26213. The method is based on the oxidation of organic matter with a solution of potassium dihydroxide in sulfuric acid and the subsequent determination of trivalent chromium, equivalent to the content of organic matter, on a photoelectrocolorimeter. Yields of spring wheat, barley and pea grains were determined by the direct method using a combine according to the method of B. A. Dospekhov (1985). The yield of alfalfa green mass was determined by mowing in test sites with subsequent conversion to air-dry mass. Grain productivity of crop rotations was determined by the method of converting crop yields into grain units using conversion factors according to the methodology of the Ministry of Agriculture of Russia (2017).

III. RESULTS AND DISCUSSION

The weather conditions of the growing season of cultivated crops in the experiment by the years of the experiment are presented in Table 3.

Table 3. Weather conditions of the growing season (May... September) during the years of field experiments

Indicators	Years						Average for 6 years
	2019	2020	2021	2022	2023	2024	
Sum of effective air temperatures for the period more than 10^0 C	2667	2800	2630	2569	1991	1855	2418
The amount of precipitation of the growing season, mm	160	84	71	167	145	280	151
Hydrothermal coefficient of growing season	0,60	0,30	0,27	0,65	0,72	1,51	0,62
Degree of aridity of the year according to the Selyaninov scale	Veri dry	Droughtly	Droughtly	Veri dry	Veri dry	Humid	Veri dry

The climate of the area where we conducted field experiments has undergone an even sharper change. This is demonstrated by indicators of weather conditions during the growing seasons of individual years. In the first 3 years - from 2019 to 2021, the sum of effective air temperatures (SEAT) for a period of more than 10^0 C was kept within the range of 2600-28000 C, which is 400-600^0 C higher than the baseline level (BL) of 1996-2005 (Table 3). The relative difference was 18-27%, which is sufficient to characterize the first half of the years of field experiments as significantly warmer. In the second three-year period, in 2022-2024, there was already a gradual cooling with a decrease in the SEAT to an average of 2500-1900^0 C, which is 4-32% less than in 2019-2021. The amount of precipitation changed more sharply during the years of the experiments. In the first half of the years, the precipitation of the growing season continued to decrease compared to the 1996-2005 starting point. The largest decrease in precipitation occurred in 2020 and 2021 with values of 84 and 71 mm, which is 2-2.6 times less than BL. The HTCs of the above period of years of field experiments decreased to 0.60-0.27, which gives reason to assign the degree of aridity to the years under consideration as very dry and dry according to the Selyaninov classification (1958). The second half of the years, 2022-2024, was characterized by an increase in atmospheric moisture up to 167-280 mm during the growing season and a decrease in the sum of effective temperatures to 1850-20,000 C. Accordingly, the sums of temperatures and precipitation, in the second half of the years of experiments, HTCs sharply increased to values 0.65-1.51, with an increase in the degree of moisture in years from very dry to humid. Illustrative changes in the climate and weather of our research sites are presented in Fig. 2.

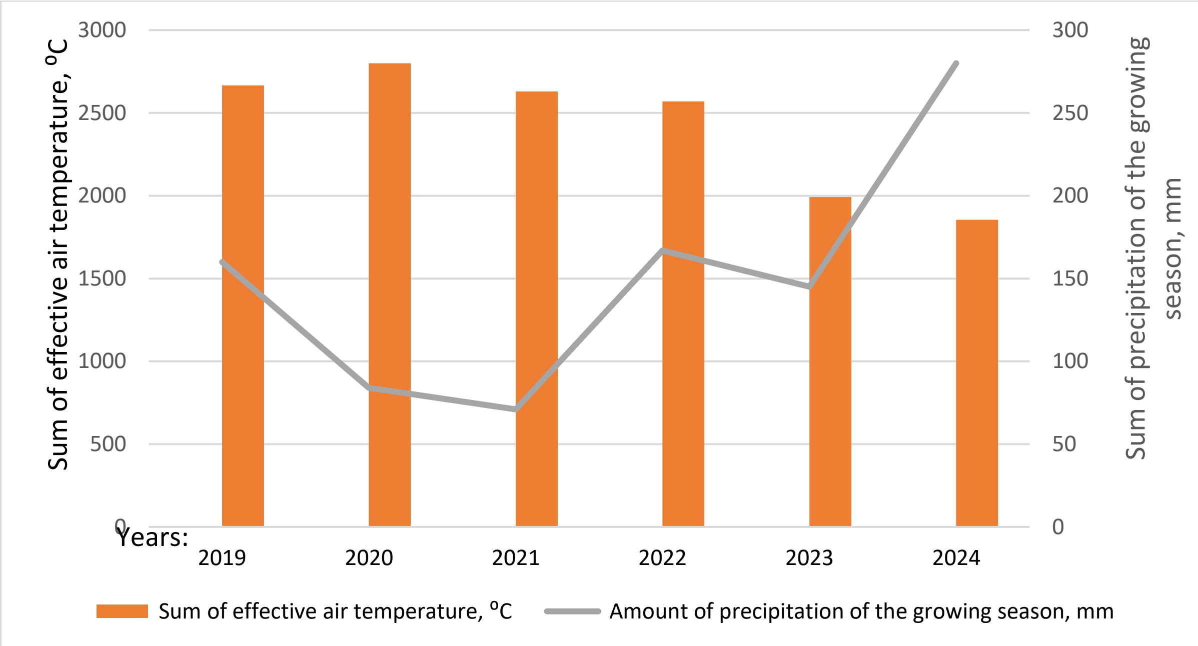

Fig.2. Weather conditions of the growing season (May-September) during the years of field experiments

The grain productivity of crop rotations in the experimental field primarily depended on the precipitation of the growing season, which is a factor of the minimum in the study area. This is evidenced by multiple changes in productivity indicators depending on the same multiple changes in the amount of precipitation over the years (Fig. 3). As can be seen from Figure 3, in 2020 and 2021 the amount of precipitation was 84 and 71 mm, which is about 2 times less than the level of 160 mm in 2019. Grain productivity of crop rotations averaged: in 2020 and 2021 7.5 and 8.0 c/ha, in 2019 - 18 c/ha. The multiplicity of changes in the productivity of crop rotations in the corresponding years is expressed by the number 2.4, which approximately coincides with the ratio of changes in precipitation. In the next 2022 and 2023 Crop rotations provided grain collection in the amount of 22-26 centners from an area of 1 hectare, with an excess of the 2019 indicator by 22-33%. At the same time, the amount of precipitation of the growing season in the above years was almost the same: 167, 148 and 160 mm. Significant differences the grain productivity of crop rotations here is most likely due to the thermal factor. Starting in 2022, the sum of effective temperatures began to decline, reducing the stress effect of drought, which caused an increase in the productivity of crop rotations in comparison with the initial value in 2019.

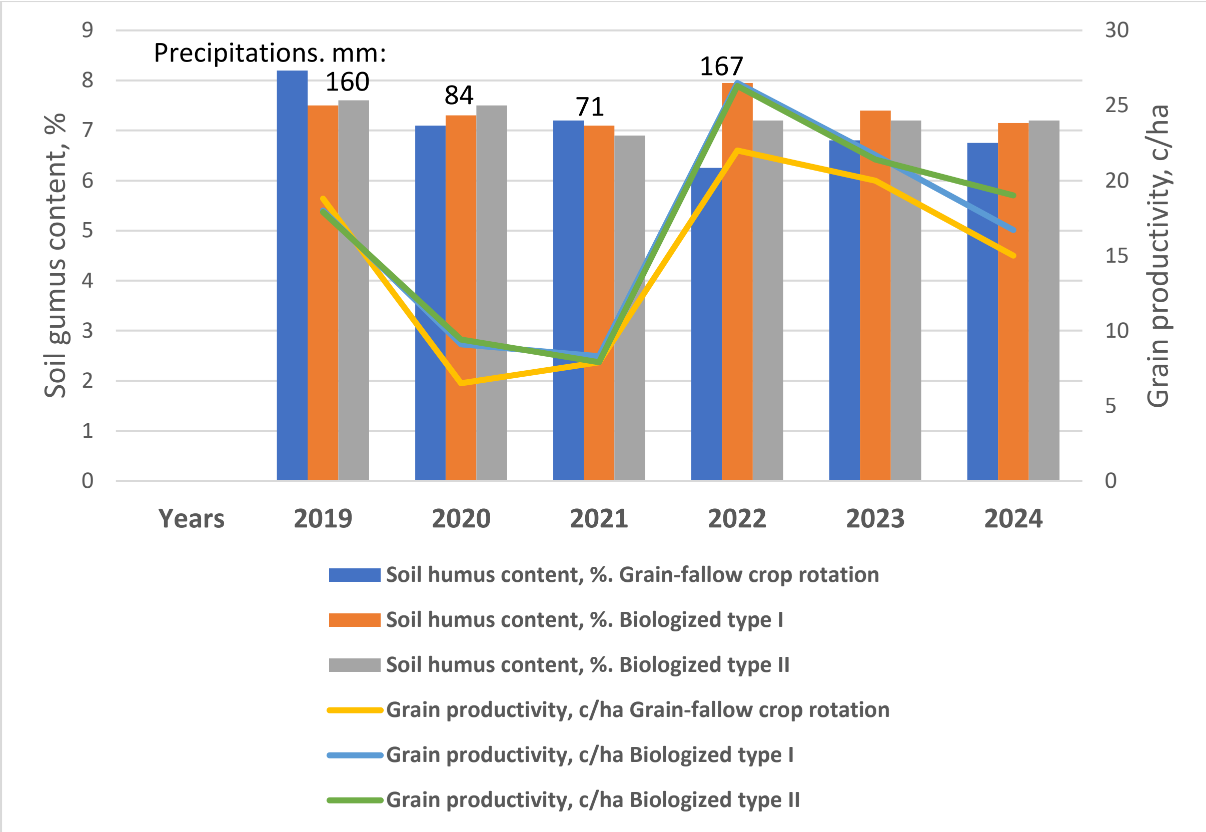

Fig.3. Dynamics of changes in precipitation, humus content in the soil and grain productivity of crop rotations for 2019-2024

In the final 2024, two unfavorable factors acted on the productivity of crop rotations at once - low air temperatures and increased precipitation. The sum of effective temperatures was 1855^0 C - 23% less than the average for the years of experiments; and the amount of precipitation is 280 mm, which is almost 2 times higher than the average for the same years (Table 2 and Fig. 2). As a result, in the wet year of 2024, the grain productivity of crop rotations was even lower compared to the dry years 2022 and 2023, amounting to 15-18 c/ha. Thus, under the influence of dramatically changing weather conditions, crop rotations formed an unstable productivity when deviations over the years of the experiment reached two times or more. Variational analysis shows that the greatest deviations from average productivity are observed in the control grain-fallow crop rotation. With an average annual productivity of 15 c/ha, the average coefficients of variation over 6 years with a plus sign were 35%, with a minus 52% sign. In biologized crop rotations, the corresponding coefficients were significantly lower and amounted to 32% and 48%. Relative differences in variations reach 8-9%, which is already a lot. In addition to variational statistics, the advantage of biologized crop rotations is more convincingly confirmed by their average grain productivity during the years of the experiment (Table 4).

Table 4. Average grain productivity of crop rotation over the years of field experience

Crop rotation	For the entire period 2019 - 2024			For the last 2022 - 2024		
	c/ha	Control deviations		c/ha	Control deviations	
		c/ha	%		c/ha	%
Grain-fallow (control)	15,0	—	—	19,0	—	—
Biologized type I	16,7	1,7	11,2	21,6	2,6	13,9
Biologized type II	17,0	2,0	13,0	22,2	3,2	17,0
Smallest significant difference (SSD_{05})		1,2			1,8	

The lowest grain productivity for the entire period of the experiments was 15.0 c/ha, the control grain-fallow crop rotation showed. Biologized crop rotations provided an additional productivity of 1.7-2.0 c/ha to the level of grain-fallow crop rotation. Over the past 2022-2024. grain harvest in biologized crop rotations increased by an even higher amount, by 2.6-3.2 c/ha, compared to grain-fallow crop rotation. This shows that the biologized crop rotations we are developing provide higher stability in grain productivity compared to traditional grain-fallow crop rotation in conditions of increasing climate variability.

We also analyzed the change in the humus content in the soil and its correlation with the grain productivity of experimental crop rotations. The initial content of humus in the plots of experience was not much different, which was explained by the spatial variability of this feature. In 2019, 8.2% of humus was contained in the fields of control grain-fallow crop rotation, and slightly less in biologized crop rotations - 7.5-7.6% (Fig. 3). In 2020, under the influence of an acute moisture deficit caused by drought and hot weather, and a slowdown in the decomposition of aboveground and root debris, there was a general decrease in humus content in all three crop rotations. As can be seen from Fig. 3, in grain-fallow crop rotation humus decreased to the greatest extent - to 7.2%, and in biologized crop rotations it decreased slightly - to 7.3 and 7.5%, remaining practically at the level of the initial values.

Semenov V.M., Lebedeva T.N., Zinyakova N.V. et al. In laboratory studies, they showed a rapid decrease in the content of soil organic matter during drought and a gradual recovery to the initial level when the wet period occurs [12]. Under the influence of repeated drought in 2021, the humus content in the arable soil layer in experimental crop rotations remained still low, in the range of 6.9-7.2%. Under conditions of increasing atmospheric moisture in 2022, the root and crop residues of perennial grasses (alfalfa) accumulated in previous years decomposed better, supplying building material for the synthesis of new organic substances in the soil. As a result, the humus content in biologized crop rotations increased to 7.2-7.9%, exceeding the level of grain-steam crop rotation by 0.9-1.5%. In 2023-2024 the humus content in the soil of biologized crop rotations remained consistently higher compared to grain-steam crop rotation, with differences of 0.4-0.5% in favor of biologized crop rotations.

A regression analysis of the interdependence of two features - the humus content in the soil and the grain productivity of crop rotations was carried out using the method of B. A. Dospekhov (1985) [13]. The conjugacy index of these features was calculated in the form of a correlation coefficient, which was expressed as r = 0.55. According to the method, this correlation size indicates the presence of an average relationship between the two features indicated above (interval r = from 0.3 to 0.7). However, the amount of correlation we calculated between the two paired features according to strict estimates is still low. To obtain higher correlation coefficients, when the condition r > 0.7 is met, it is necessary to increase the number of observations of the studied features in the experiment. This dependence is clearly explained when analyzing the formula by which the standard error of the correlation coefficient is determined:

$$S_r = \sqrt{\frac{1-r^2}{n-2}}$$

where n is the number of observations. As n increases, the error Sr will decrease, and the accuracy in determining the correlation coefficient r will increase. In our experiment, the sample size can only be increased by continuing the number of years of field experience. Thus, at present, we can only talk about the tendency to increase the stability of grain productivity of crop rotations as the humus content in the soil increases, depending on the use of biologization factors. Further field studies are required to improve the reliability of the patterns of interaction of humus content and other soil indicators on the stability of grain productivity of crop rotations in conditions of increasing variability of the local climate.

IV. CONCLUSION

In addition to many years of variability, the climate of the field experiment site, located in the steppe zone of the south of the Ural Mountains of the Russian Federation, continued to change. Under the influence of sharply changing weather conditions and the course of accumulation and decomposition of plant residues, there was a change in the dynamics of the content of total humus in the soil. By the end of the field experience, in 2023-2024 the humus content in the soil of biologized crop rotations remained consistently higher compared to grain-fallow crop rotation, with differences of 0.4-0.5% in favor of biologized crop rotations. Under the influence of sharply changing weather conditions, crop rotations formed unstable productivity, when deviations by the years of the experiment reached 2 times or more. The greatest deviations from the average grain productivity were observed in the control grain-fallow crop rotation. Productivity changes in biologized crop rotations are 8-9% less. Biologized crop rotations provided an average annual productivity of 1.7-2.0 c/ha of grain units, which was additional to the level of grain- fallow crop rotation. A moderate correlation (r = 0.55) was found between grain productivity of crop rotations and soil humus content. In the soil under biologized crop rotations, the average humus content over the years of research turned out to be 0.7-1.0% higher, which was accompanied by their higher grain productivity compared to grain-fallow crop rotation. Thus, biologized crop rotations in the steppe zone of the Southern Urals provide higher and more stable grain productivity under climate change conditions compared to traditional grain-fallow crop rotation. The leading factor contributing to the increase in the stability of the productivity of biologized crop rotations is an increase in the content of organic matter in the soil.

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Maize Production and Climate Variability: Evidences from Haryana

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***Abstract*— This paper examines the influence of climatic factors—rainfall, temperature, and humidity—on maize production in Haryana, India. The study also explores how enhancing maize productivity can contribute to achieving several Sustainable Development Goals (SDGs), particularly those related to food security, sustainable agriculture, renewable energy, and water conservation. Using secondary data for the last ten years and applying multivariate regression and deviation analysis, the study assesses how variations in climatic conditions affect maize yield in Panchkula district, the major maize-producing region of Haryana. The results show that among the three climatic factors, rainfall had a relatively greater influence on maize yield, though none of the factors were found to have a statistically significant effect during the study period. These findings underline that while climate variability does not directly determine yield outcomes in every season, rainfall patterns remain a key driver of maize productivity. The study suggests that adopting climate-resilient farming practices, efficient water-use technologies, and improved maize varieties can help stabilise yields and enhance farmers' income. Such measures would also support India's broader developmental goals by promoting sustainable agriculture and strengthening rural livelihoods within the SDG framework.*

***Keywords*— Maize, Climate Variability, Rainfall, Sustainable Development Goals, Haryana**

I. INTRODUCTION

This paper looks at how climate factors affect maize production in Haryana. It also discusses how improving maize production can help achieve some Sustainable Development Goals (SDGs). In the race of economic development, mankind has exploited natural resources to a great extent (**Alex Acheampong and Evans Osei Opoku, 2023**). As a result, there has been a great increase in global warming and natural disasters over the last few decades (**Sarah S. Abdul-Nabo et al., 2025**). The earth's temperature has been higher than expected and projected (**Thomas C. et al., 2008**). This has become a threat to human existence (**Umair S., 2015**). Along with this, starvation and unavailability of basic needs are also becoming a threat to mankind. To keep all these challenges in high concern, UN Members have set some targets for 2030 known as SDGs-17 goals. The main objectives of these goals are to protect the environment as well as human lives. The current research paper is also affined to this series. The present research paper illuminates the importance of the maize crop in achieving SDG goals in possible manners. Further, in this context, the research also endeavours to know the effect of climate factors on maize production in Haryana. The basic intent behind this approach was to understand how maize production can be predicted and improved under different climatic conditions.

Maize is grown in almost every part of the world. From ancient times maize has been established as a rich source of human food. Maize contributes 20 percent of calories of human food (**Olaf Ehrenstein et al., 2022**). Maize is the staple food crop in many parts of the world. Due to its lower cost as compared to rice and wheat, maize is also a good source of nutrition for the poor (**Peter Ranwn et al., 2014**). Many studies proved that the production of maize is economically cheaper than other important cereals (**John Baffies et al., 2024**). In this way, we can foreshow that increasing the production of maize can reduce the problem of hunger and fulfil every important nutrient regarding human growth at the world level (**A. Saritha et al., 2020**). It can be believed that increasing the production of maize will also be helpful in achieving SDG-17 Goals (2.1- Universal Access to safe and nutritious food and 2.2- End all forms of Malnutrition) (**Sherry A. Tanumihardjo et al., 2020**).

The Government of India has done commendable work in the last few years in the direction of increasing the production of ethanol for biofuel (**Ayush Saxena et al., 2024**). After experiencing positive results, the Government of India amended the National Policy of Biofuel-2018 in 2022 and set the target for 20 percent blending of ethanol in fuel (**Sarah Mark et al., 2025**). It will lead to reduced carbon emissions, strengthen the green fuel policy and reduce the oil import bill of the country (**Mahesh K. Saini et al., 2010**). Maize is a good source of ethanol (**Adewale Allen Sokan-Adeage et al., 2024**). Maize is being used as a major source of biofuel across the world; some states of India have also made remarkable progress in this direction (**Pranav Kumar, 2024**). In this way, it can be assumed that by increasing the production of maize, the supply of biofuel can be increased and that will help in achieving the SDG goals (7.1- Universal access to modern energy and 7.2- Increasing the global percentage of renewable energy).

The present research work has been conducted in Haryana. Maize is sown in the Kharif season in the state (**Dept. of Agriculture, Govt. of Haryana**). Rice is the main crop of this season, which is a very high water-intensive crop (**Report by Indian Council of Food and Agriculture (ICFA)**, **report by International Rice Research Institute (IRRI)**). In Haryana, the rice area has increased sharply in the last three decades; it was 661.2 (000 hectares) in 1990 which increased to 1525 (000 hectares) in 2020 according to **Haryana Statistical Abstract 2022-23**. The increasing area poses a threat to water resources, especially the groundwater of the state. As a result, 14 districts of the state were declared as red zones for groundwater (**Dharam Pal et al., 2022**). To deal with this problem, various options were explored to substitute the rice crop in the state. Maize is being seen as a valuable alternative to rice which has the chance of increasing farmers' income along with conserving water resources (**Mukta Nainwal et al., 2023**) and (**M. Uma Devi et al., 2020**). If the state succeeds in increasing the area under the maize crop, it will be a good effort to achieve SDG goals (2.4- Sustainable food production and 6.6- Protect and restore water-related ecosystems).

Along with this advantage, the maize pod stem is also a good source of food for animals. The fodder of maize includes valuable nutrients for cows and buffaloes (**D.P. Chaudhary et al., 2014**). Due to favourable climate and soil, there are a lot of possibilities for promoting maize cultivation in Haryana. According to various agricultural experts, the appropriate temperature required for maize is between 25-30 degrees Celsius and fertile alluvial or sandy loam soils are appropriate for the growth of the crop (**Muhammad Ahmed Waqas et al., 2021**, **M.A. Ansari et al., 2015**). On the other hand, production of maize also depends on different varieties. As a result of the sincere efforts of agricultural scientists, there are many variety options available for maize in Haryana (**Narender Singh et al., 2017**). Several research studies concluded strong evidence that maize production is highly correlated with climatic factors such as temperature, rainfall and humidity. Only an optimum condition of these factors can be beneficial for crop production, where less or more than the optimum level has an inverse impact on production (**Phrasia M. et al., 2020**, and **Usman Ahmad et al., 2024**).

To understand the impact of climatic factors on maize production in more depth, some selected research studies were analysed profoundly; the review of selected research work is as follows.

Mansoor M. et al., 2021 in their research work investigated the impact of climate on grain and silage in the Czech Republic during 2002-19. The study was based on secondary data and the data was processed with the help of T-Test and Pearson correlation. The study concluded that there was a low to moderate negative correlation between grain yield and average temperature. Moreover, a positive correlation was found between profit and grain yield rate and the precipitation and water deficit. Farmers' profit from maize was significantly associated with water deficit, precipitation and temperature. **Maiyo J.K. et al., 2024** in their research examined the effect of rainfall variability on maize production among small-scale farmers during 2008-18. The study was based on primary as well as secondary data. The study concluded that there was a positive relationship between rainfall and maize yield. Moreover, the study also highlighted that forests help reduce the amount of carbon gas in the atmosphere, which is the main cause of climate change that normally led to rainfall variability effects.

Suiven John P.T., 2024 in their research paper examined rainfall reliability and established the impact of rainfall reliability on maize production. The study was based on secondary data. For rainfall measurement, the author developed a standardised precipitation index (SPI) for measuring the difference from the standard value of rainfall.

Time series data on maize output were collected from annual reports. The study concluded that rainfall reliability ranged from 9.62 percent to 30.90 percent in the Bamenda highlands while maize production had been variable with decreasing trends. Finally, the study suggested that farmers need to engage in sustainable livelihood practices to ensure food security. **Emmanuel M.A. et al., 2013** in their research paper examined the impact of variability in rainfall characteristics on maize yield in a tropical setting. The study was based on secondary data; statistical tools like correlation and regression were used to find out the answers to the research questions. The study concluded that there was a high variability in rainfall characteristics which translated into a high yield of maize. The number of rainfall days and annual rainfall amount had a strong impact on maize yield per hectare in the study area. Finally, the study concluded that the study area and Benue state, in general, were found unsuitable for the optimum growth of maize. **Noah Eledi Kiguhi et al., 2025** in their research paper examined the impact of rainfall on maize production. The main objective of the study was to examine rainfall variability and its impacts on crops. The study was based on a mixed-method research design. Primary data was obtained by a scheduled questionnaire. The study concluded that rainfall variability was significantly linked with maize yield. The rainfall variability had the potential to affect future maize production. The study recommended that proper climate forecasts could be helpful in this regard. **K.M. Mehedi Adnam et al., 2021** in their study examined the responsible factors for profit in maize production. Multistage stratified random sampling techniques were used for the purpose of data collection. The study concluded that the maize crop is profitable for farmers. Factors such as age, education level, extension experiences and non-farm incomes were the main factors for profit inefficiency. There were several hybrid varieties of the crop that can lead to more profit. Finally, the study mentioned some significant measures for the betterment of the crop cycle and marketing facilities. **Phrasia M. et al., 2020** in their research explored the impact of rainfall variability on maize yield. The study found a weak negative correlation between rainfall and maize in Kwazulu-Natal and Free State Provinces; on the other hand, a weak positive correlation was found in the North-West province. Both the excess and deficit conditions of rainfall were not favourable for the productivity of maize.

After exploring the existing research work, the present research work is framed in the following research objectives.

Research Objectives of the Study:

1. To highlight the comparison of production and yield of maize
2. To examine the rainfall variability and its impact on the maize crop during the last ten years
3. To explore the deviation from optimum climatic conditions and actual climatic conditions from optimum production of maize

II. RESEARCH METHODOLOGY

As mentioned above, the maize crop is grown in Haryana during the Kharif season. Paddy is the main crop of the Kharif season in the state. During the basic observation of maize production data, it was found that the Panchkula district is the major producer of the maize crop. Considering this fact, Panchkula district was selected for the study.

The study is based on secondary data. Data for ten years for different variables were collected from various sources. Data regarding rainfall for ten years were collected from various sources of Haryana Statistical Abstracts. Data regarding temperature and humidity were collected from the website **www.aqi.com**. Data regarding the production and yield of maize in India and the world were collected from the website **ourworldindata.org**.

Statistical tools including multivariate regression and deviation methods were used.

Based on the objectives and methods, the study proposes the following hypotheses for testing.

Hypotheses of the Study:

- H1: Rainfall variation has a significant impact on maize yield in Haryana.
- H2: Temperature variation affects maize yield in Haryana.
- H3: Humidity variation affects maize yield in Haryana.
- H4: The impact of rainfall on maize yield is greater than that of temperature and humidity.

The data collected were analysed, and the results are given below.

2.1 Maize Yield in India and Haryana

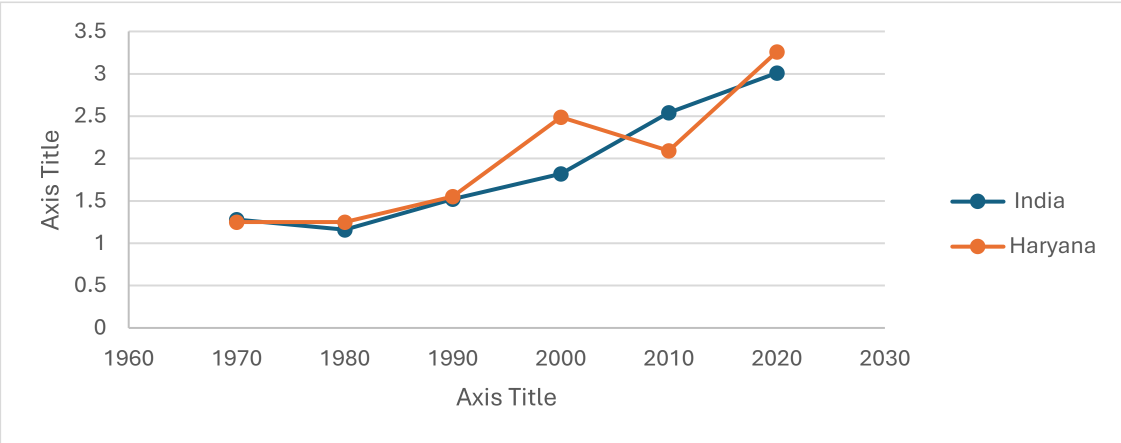
This part of the research paper presents a simple picture of maize productivity comparison on both horizontal and vertical bases. This part will help to understand the scope of increasing the productivity of maize in India as well as in Haryana.

Table-1: Maize Yield In India and Haryana-

Year	Tonnes/Hec yield in India	Tonnes/Hec yield in Haryana
1970	1.28	1.25
1980	1.16	1.25
1990	1.52	1.55
2000	1.82	2.49
2010	2.54	2.09
2020	3.01	3.26

Table 1 highlight the productivity comparison of maize in Haryana and India in last 70 years. Table shows that there was productivity difference in India and Haryana since 1970. The productive gap was maximum during 2000, it was 2.49 tonnes/Hec. In Haryana while it was 1.82 tonnes/Hec. Aggregate for India. On the other hand the productivity was high in aggregate level of India as compare to Haryana. Finally in 2020 the productivity level was high again in Haryana as compare to all India aggregate.

Chart-1: Maize Yield In India and Haryana-



Source- Our world in data (www.ourworldindata.org/maize-yiled

https://ourworldindata.org/grapher/maize-yields

Haryana Statistical Abstract- (2022-23)

This chart compare maize yield in India and Haryana from 1970 to 2020. Haryana started with slightly lower yields than India but later caught up. By 2020, Haryana's yield was higher than the national average, showing improvement in productivity over time. It reflects better farming practices and crop management in the state.

2.2 Yield of Maize in Different Countries

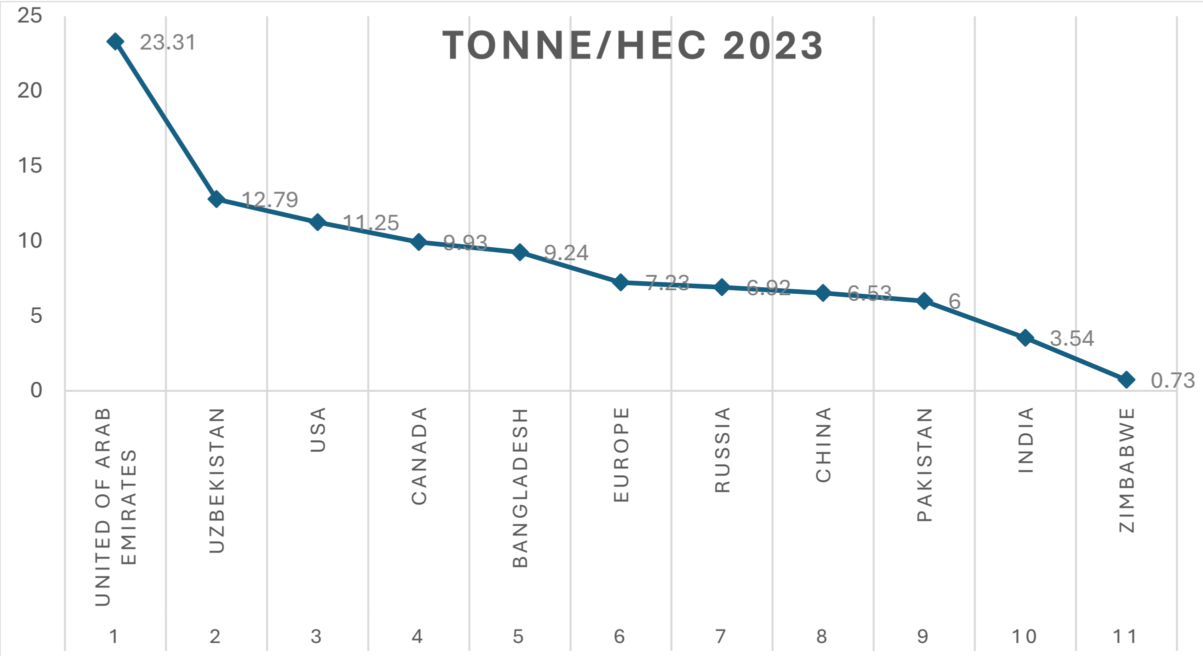
Table-2: Yield of Maize In Different Countries

Sr. No.	Name of Country	Tonne/Hectare
1.	United of Arab Emirates	23.31
2.	Uzbekistan	12.79
3.	USA	11.25
4.	Canada	9.93
5.	Bangladesh	9.24
6.	Europe	7.23
7.	Russia	6.92

8.	China	6.53
9.	Pakistan	6.00
10.	India	3.54
11.	Zimbabwe	0.73

Table 2 shows the productivity of maize across the world for the year of 2023. There were huge difference of yield among different countries. It was highest in UAE followed by Uzbekistan and USA. In case of India it was almost seven times low as compare to UAE and almost half as compare to neighbours Pakistan and China. It may be observed from the above results that there is a great potential and scope to expend the production of maize in India.

Chart-2: Yield of Maize In Different Countries



Source- Our world in data (www.ourworldindata.org/maize-yiled https://ourworldindata.org/grapher/maize-yields

This chart compares maize yields across countries in 2023. UAE shows the highest yield, followed by Uzbekistan and the USA, while India's yield is far below many developed countries. The wide gap highlights the potential for India to adopt improved technology and practices to boost maize productivity.

The country-wise comparison shows the gap in maize productivity between India and other nations. Next, we look at how rainfall variation affects maize yield over the years in Haryana.

3.3 Percentage Difference from Optimum Yield and Rainfall

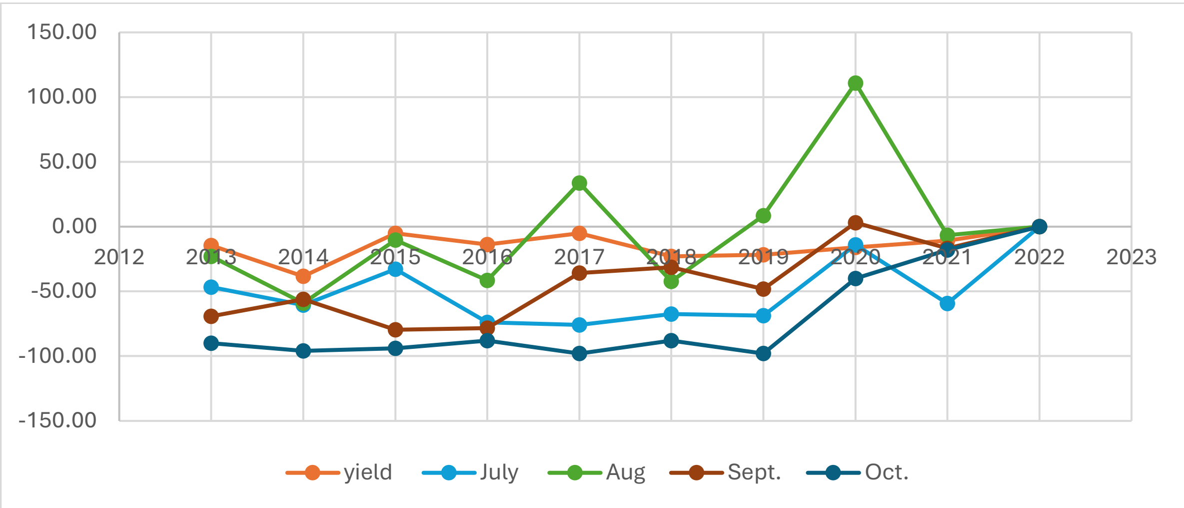
Table-3: Percentage Difference form Optimum Yield and Rain Fall of Maize

Year	*Yield*	*July*	*Aug*	*Sept.*	*Oct.*
2013	-14.64	-46.80	-22.89	-69.14	-90.00
2014	-38.38	-60.47	-59.04	-56.17	-96.00
2015	-5.14	-32.85	-10.24	-79.63	-94.00
2016	-13.80	-73.84	-41.57	-78.40	-88.00

2017	-5.05	-75.87	33.73	-35.80	-98.00
2018	-22.93	-67.44	-42.17	-31.48	-88.00
2019	-21.67	-68.60	8.43	-48.15	-98.00
2020	-15.99	-13.95	110.84	3.09	-40.00
2021	-10.94	-59.30	-6.63	-16.67	-18.00
2022	0.00	0.00	0.00	0.00	0.00

This table compares actual rainfall with optimum rainfall required for maize in different months and years. Positive and negative values show where rainfall was above or below the requirement. Such variations explain why yield fluctuates in different years, as rainfall shortage or excess directly affects maize growth.

Chart-3: Difference form Optimum Yield and Rain Fall of Maize



After rainfall variation, the next tables show how temperature and humidity influence maize yield.

3.4 Temperature impact on Maize yield

Table-4 Temperature impact on Maize yield Regression Statistics

Multiple R	0.53341491
R Square	0.2845
Adjusted R Square	-0.2878
Standard Error	416.3219135
Significance F	0.7409856
F	0.4971068

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	7289.199816	7075.27814	1.030235091	0.350133512
July	34.95148978	485.6085284	0.071974621	0.94541245
Aug	-513.9299398	586.6438029	-0.876051085	0.421088903
Sept.	302.0297938	413.0737161	0.7311765	0.49748235
Oct.	30.25185083	222.9661418	0.135679124	0.897368182

(Temperature data of Panchkula, Haryana) source- www.aqi.in

https://www.aqi.in/au/climate-change/india/haryana/panchkula

The regression table shows how temperature in different months affected maize yield. Coefficient values indicate whether higher temperatures increased or reduced yield. However, the p-values suggest that temperature alone did not have a strong or statistically significant impact on maize yield in the study period.

3.5 Humidity impact on Maize yield

Table-5 Humidity impact on Maize yield

Regression Statistics

Multiple R	0.70807
R Square	0.55015
Adjusted R Square	0.10280
Standard Error	347.485
F	1.2578
Significance F	0.3953

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1952.925773	2187.90858	0.892599348	0.41296461
Hum. July	22.08205649	22.70305389	0.972646966	0.37540013
Hum. Aug	18.92792844	29.04552512	0.651664185	0.54337991
Hum. Sept.	-37.22239947	25.41334058	-1.46467952	0.20289479
Hum. Oct.	13.62877801	19.18671809	0.710323566	0.50925148

(Humidity data of Panchkula, Haryana) source- www.aqi.in

https://www.aqi.in/au/climate-change/india/haryana/panchkula

This table presents how humidity levels in July to October influenced maize yield. Some months show a positive effect while others negative, but none are statistically significant. It suggests that humidity alone cannot explain the changes in yield over the years.

3.6 Rainfall impact on Maize yield

Table-6: Rainfall impact on Maize yield

Regression Statistics

Multiple R	0.652652484
R Square	0.425955265
Adjusted R Square	-0.033280523
Standard Error	372.9087199
Significance F	0.515538234
F	0.927530642

	Coefficients	Standard Error	t Stat	P-value
Intercept	2789.040163	391.4800005	7.124349032	0.000845298
Rain July	-0.276461727	2.059902958	-0.134211044	0.898470678
Rain Aug	2.617630052	2.217774469	1.180295873	0.29096972
Rain Sept.	-6.352837649	5.137236035	-1.236625611	0.271141623
Rain Oct.	18.99275809	14.03052004	1.353674564	0.233813066

(Source- rainfall data of Panchkula, different vol. of Haryana Statistical abstract)

The table-6 shows that the independent variable (rainfall) did not have significant and equal impact on the yield. The rainfall of August and October had a positive correlation (2.61 and 18.99 respectively) with yield where the rainfall of July and September had a negative correlation (-0.27 and -6.35 respectively) with yield. rainfall of October had more impact full as compare to rainfall of other months. In case of R Square table shows that almost 42 percent of variation happens due to the rainfall but F value is less than 4 that means R-Square value is not significant. Since P value is greater than 0.05, which is our level of significance, therefore, we may conclude that the study did not enough evidence to claim any significant impact of independent variables on the dependent variables.

III. SUMMARY & CONCLUSION

The results from all three factors—rainfall, temperature, and humidity—are now combined to draw overall conclusions.

On the basis of tables, no 4, 5 and 6, it is concluded that among the three major climate factors, rainfall was more impactful as compare to temperature and humidity. The value of R-square for rainfall is 42 percent whereas for temperature it is 31 percent and for humidity it is 8 percent. In case of coefficient correlation, the tables show that in both positive and negative cases, the correlation of temperature with yield is higher than that with rainfall and humidity. The F-value of the three independent variables is less than 4, which shows that the value of P-square is not significant. Among the other three independent variables, rainfall has the least p value followed by temperature and humidity. But the p value of none of the variables is less than 5 percent which shows that none of the independent variables have any significant impact on the dependent variable. The p value of rainfall is less than that of humidity and temperature which shows that rainfall is more significant than humidity and temperature

The study finds that rainfall had more effect on maize yield than temperature or humidity, but none of the factors showed a strong impact in the data period. Even so, the results suggest that better water use, improved seeds, and climate-resilient farming can help increase maize production in Haryana. This will also support progress toward food security and environmental goals.

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Integrating Traditional Ecological Knowledge and Technology for Enhanced Environmental Sustainability: A Dual-Framework Theoretical Study

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***Abstract*— *Background: Environmental sustainability necessitates the incorporation of various knowledge systems to enhance resource management and bolster resilience against climate change. Traditional Ecological Knowledge (TEK), rooted on the insights of Indigenous and local people, offers a holistic and adaptable framework for environmental stewardship. In contrast, technology-driven methods employ digital breakthroughs to improve resource efficiency and enable comprehensive ecological monitoring. This theoretical study analyzes the interplay between traditional ecological knowledge and technological methodologies, aiming to elucidate their mechanisms, synergies, limitations, and possible avenues for integration. Methods: This study adopts a dual-framework methodology to bring together current literature on traditional ecological knowledge and technology-based sustainability methods. The work conducts a full conceptual mapping of both paradigms, generating comparative system dynamics diagrams, developing novel metrics such as resilience quotient and integrated stewardship score, and outlining simulation scenarios. The proposed frameworks seek to promote equitable partnerships and collaboratively design policies to improve hybrid models. This study utilizes a qualitative methodology, focusing on the creation of theoretical frameworks and the examination of scenarios to inform future empirical validation initiatives. Results: Through adaptive, place-based practices, TEK systems foster cultural cohesion, promote biodiversity conservation, and manifest enhanced long-term ecosystem stability. Systems driven by technology provide swift enhancements in the efficiency of resource utilization, enable real-time monitoring, and allow for scalable interventions; however, they may also pose risks related to infrastructural vulnerabilities and cultural disconnection. Hybrid models that combine traditional ecological knowledge with technological advancements are anticipated to yield synergistic advantages, such as improved resilience, inclusivity, and adaptive management strategies. The proposed metrics provide comparative tools for the evaluation of integrative systems. Conclusion: This dual-framework study emphasizes the synergistic functions of Traditional Ecological Knowledge and technology in promoting environmental sustainability. Through the conceptualization of integration pathways and the development of theoretical metrics, it establishes a foundation for evidence-based policy and rigorous empirical research. Future research must emphasize participatory approaches, validation of metrics, and pilot testing of hybrid sustainability models to promote equitable, adaptive, and resilient global stewardship.*

Keywords*— Traditional Ecological Knowledge, technology-driven sustainability, environmental resilience, hybrid models, system dynamics, adaptive management, participatory governance.

I. INTRODUCTION

Environmental sustainability, a cornerstone of global well-being, implicates equitable stewardship and management of the Earth's natural resources to ensure quality of life for present and future generations. Current policy and research frequently emphasize technical interventions and extensive innovation; nevertheless, sustainability is intrinsically linked to local context and cultural heritage. Consequently, effective sustainability management requires an integration of Traditional Ecological Knowledge (TEK) with technology-based approaches, as each offers unique advantages and presents specific challenges for the sustainable utilization of resources [1, 2]. TEK is fundamentally based on the experiences, traditions, and intergenerational knowledge of Indigenous and local communities, emphasizing the role of human beings as integral components within broader ecological systems. Indigenous communities, comprising less than seven percent of the global population, oversee the stewardship of over one-third of the planet's remaining natural areas. This underscores the significant influence of traditional ecological knowledge and its lasting adaptive management approaches. This framework conceptualizes resource utilization as a reciprocal process, wherein practices such as rotational farming, water harvesting, and controlled burning have evolved over centuries through environmental adaptation and the aggregation of collective knowledge. The practices outlined, underpinned by the Social-Ecological Systems Theory, contribute to resilience, biodiversity, and cultural cohesion through the establishment of intricate feedback loops that connect cultural and ecological contexts [3, 4]. The theoretical foundations of TEK emphasize the significance of place-based observations, qualitative analysis, and the transmission of knowledge across generations as fundamental mechanisms. For instance, the implementation of fire management practices in the Kimberley region of Australia, along with the use of controlled burns in North America, has demonstrated effectiveness in promoting ecosystem stability and adaptability, while also fostering the ongoing cultural and spiritual connections to the land. Empirical research consistently demonstrates that communities guided by traditional ecological knowledge display enhanced adaptive capacity and sustained ecosystem stability when compared to systems managed exclusively through scientific or market-based methods. Despite its potential, the widespread application of Traditional Ecological Knowledge encounters several obstacles, such as undervaluation, challenges in knowledge transfer, and a lack of compatibility with Western scientific frameworks. These issues necessitate focused efforts to achieve effective integration [5, 6]. On the other hand, technology-driven sustainability draws power from digital transformation and systemic innovation. Recent developments in artificial intelligence (AI), the Internet of Things (IoT), smart grids, and remote sensing provide enhanced capabilities for large-scale monitoring, resource optimization, and swift response to mitigation efforts. The implementation of these systems, through the operationalization of closed-loop resource cycles and the adoption of renewable energy, has facilitated the development of circular economy models and led to notable decreases in greenhouse gas emissions. Digital platforms currently enable the monitoring, evaluation, and clarity of sustainability metrics, equipping users and decision-makers with immediate insights and technical efficiency [7, 8, 9]. Behavioral and social innovation play a crucial role in driving systemic change. Gamified education platforms, shared mobility solutions, and autonomous resource management systems are instrumental in transforming daily habits, steering them towards more environmentally sustainable practices. The efficacy of policy is improved by the ability to oversee and modify resource distributions, pollution patterns, and societal involvement on a notable scale and speed. However, overreliance on infrastructure, risks of cultural disconnect, and vulnerabilities to systemic disruption remain salient drawbacks for purely technology-driven models [8, 10]. The integration of traditional ecological knowledge with technological advancements represents a complex yet promising area of inquiry in the realm of sustainability science. Theoretical frameworks are progressively endorsing participatory models in environmental management, highlighting the collaborative design of stewardship protocols that incorporate Indigenous knowledge alongside sophisticated monitoring systems. Schematic diagrams, such as resource flowcharts and feedback loop maps, function as valuable instruments for illustrating comparative system dynamics. The distinct strengths in adaptability, resilience, and efficiency are illustrated among pure traditional ecological knowledge, pure technological approaches, and hybrid models. The suggested indices, such as the "resilience quotient," "technology efficiency index," and "integrative stewardship score," present innovative measures for evaluating efficacy and guiding future empirical research [11, 12]. The literature mapping of recent studies highlights the trade-offs and synergies that are intrinsic to these paradigms. TEK exhibits remarkable proficiency in local adaptation, continuous ecological observation, and cultural heritage protection, while technology-driven approaches improve reach, speed, and monitoring precision. The conceptual synthesis highlights the potential for policy frameworks that emphasize equitable collaborations, ethical protections, and inclusive co-design processes with Indigenous communities. As a result, hybrid methodologies, bolstered by advancements in agent-based modeling, possess the capacity to enhance efficiency, resilience, social inclusiveness, and adaptive management, thereby laying the groundwork for transformative sustainability initiatives.

II. METHODOLOGY

This research employs a theoretical methodology that combines qualitative synthesis, conceptual modeling, and framework creation to evaluate and contrast the contributions of Traditional Ecological Knowledge (TEK) and technology-driven practices to environmental sustainability.

Literature Mapping and Conceptual Extraction

An expansive literature mapping is involved in the first stage, utilizing current academic databases and targeted keyword searches related to TEK, technology-driven sustainability, and hybrid systems. Relevance is prioritized for studies published within the last five years. Theoretical models, mechanisms, and empirical insights are systematically extracted from selected literature, with data organized around concepts such as resilience, stewardship, efficiency, and equity.

Framework Synthesis

The methodology, informed by extracted themes, produces conceptual frameworks that facilitate the visualization of system dynamics pertaining to TEK, technological, and hybrid models. Schematic diagrams, resource flowcharts, and feedback loop maps are created to illustrate critical variables, including the resilience quotient, energy efficiency, and biodiversity index. The interconnections, trade-offs, and potential synergies among the paradigms are clarified through comparative modeling.

Indicator and Metric Development

Within the framework, theoretical indicators including "resilience quotient," "technology efficiency index," and "integrative stewardship score" are defined and structurally organized. These metrics are grounded in literature to allow systematic comparative analysis and form the basis for future empirical validation.

Scenario Simulation Design

The methodology proposes hypothetical scenario simulations, such as drought responses utilizing either TEK or sensor-driven smart irrigation. It is recommended that agent-based modeling and system dynamics simulation software be used to test adaptive capacity, resource optimization, and policy responsiveness in simulated policy environments. Theoretical emphasis is placed on the design, logic, and structure of future empirical inquiry in this step.

Policy Model and Integration Guidelines

Policy model construction synthesizes knowledge for equitable integration of TEK and technology, emphasizing guidelines for participatory co-design, ethical safeguards, and culturally sensitive implementation. The methodology foregrounds best practices from cross-sector case studies and proposes structured principles for future hybrid interventions and pilot programs.

Limitations and Future Directions

Finally, the methodology acknowledges theoretical constraints, notably the absence of empirical data, site-specific variables, and possible unintended consequences. Recommendations are made for future empirical studies, such as pilot projects and metric validation in real-world settings.

III. RESULTS

Theoretical results from this dual-framework study indicate that integrating Traditional Ecological Knowledge (TEK) with technology-driven practices creates robust avenues for advancing global environmental sustainability. Both paradigms, when examined separately and in tandem, reveal unique mechanisms, strengths, and adaptation capacities for resource management, climate change mitigation, and resilience-building across diverse ecological contexts.

TEK Systems: Adaptive Capacity and Biodiversity Conservation

TEK systems exhibit remarkable proficiency in sustaining ecosystem stability and executing adaptive management, grounded in centuries of localized observation and the transmission of experiential knowledge. Indigenous practices, including rotational agriculture, water harvesting, and controlled burning, demonstrate measurable benefits in domains such as soil restoration, forest management, and biodiversity conservation. Investigations, both empirical and theoretical, indicate that communities focused on traditional ecological knowledge manage risk effectively through strategies including seasonal mobility, resource storage, and pooling, which in turn enhances their resilience to environmental stressors. Regions where Traditional Ecological Knowledge (TEK) is successfully utilized and passed down through generations demonstrate elevated biodiversity indices and enhanced long-term resilience of ecosystems [13]. In addition to ecological outcomes, traditional ecological knowledge enhances biocultural diversity by integrating environmental decision-making with cultural, spiritual, and social dimensions. This integration facilitates the prioritization of localized concerns, in contrast to more extensive global challenges such as climate variability, which may appear less urgent to local populations. Examples include the management of water pollution or deforestation, both of which are driven by pressing threats to livelihoods. The facilitation of self-reliance and the cultivation of relevant knowledge through Traditional Ecological Knowledge (TEK) support the ongoing adaptation and restructuring of communities in response to disturbances. Conversely, the data suggest that the TEK knowledge reservoirs are still being eroded by modernization, market integration, and external forces. In the context of global change, hybridization is a critical pathway for the preservation of the fundamental adaptive potential of traditional knowledge (TEK) through the adaptation and integration of new technologies [14].

Technology-Driven Models: Efficiency and Scale

Sustainability-focused systems that use digital infrastructures, intelligent sensors, and AI-powered analytics considerably enhance resource use and pollution management efficiency. System dynamics models show considerable short-term benefits in agricultural input management, forest health monitoring, and water efficiency optimization. Metrics such as the "technology efficiency index" highlight progress in energy optimization, waste reduction, and carbon mitigation at the regional and national level. Social innovation platforms promote participatory monitoring and facilitate environmentally sustainable behavior change among diverse populations. While these strengths are notable, an excessive dependence on technological infrastructure can lead to vulnerabilities, including systemic risks, cultural disconnection, and disparities in equity, particularly in areas where access to or the ability to sustain digital systems is constrained. Theoretical findings indicate that systems that rely exclusively on technology may experience deficiencies in long-term resilience and adaptability when lacking locally grounded knowledge and context-responsive practices.

Hybrid Models: Synergistic Pathways and Resilience

Hybrid sustainability models that systematically integrate traditional ecological knowledge and technology are expected to produce synergistic benefits, such as improved resource efficiency, increased ecosystem resilience, and greater social inclusivity. Case studies and scenario simulations demonstrate that the co-design of solutions, such as the integration of tradition-based ecological monitoring with remote sensing and digital mapping, yields more comprehensive, adaptive, and culturally relevant strategies for enhancing climate resilience and protecting biodiversity. The integrative stewardship scores and resilience quotients introduced in this study serve as comparative metrics, indicating that hybrid models demonstrate superior performance over pure-paradigm approaches across the majority of simulated policy and environmental scenarios. For instance, drought scenarios simulated using agent-based methods demonstrated that communities utilizing integrated approaches exhibited more efficient responses, sustained ecosystem services for extended periods, and adapted policies more rapidly compared to those that depended solely on traditional ecological knowledge or technology.

IV. DISCUSSION

The integration of Traditional Ecological Knowledge (TEK) with technology-driven approaches in sustainability represents more than just a simple combination of past and present practices; it embodies a deep, ongoing dialogue among various knowledge systems, ethical implications, and practical applications. Recent literature illustrates that utilizing these distinct paradigms requires meticulous consideration of trade-offs, governance, participation, and adaptivity. This section presents a thorough examination of the implications, risks, and transformative potential of the dual-framework in relation to global sustainability initiatives [16]. TEK demonstrates essential strengths, encompassing enduring environmental stewardship, significant site-specific adaptation, and a diverse biocultural heritage, all grounded in collective memory and established practices. Nevertheless, given the escalating urgency of sustainability challenges influenced by climate change, demographic changes, and economic transformations, it is clear that low-tech solutions may prove insufficient in addressing pressing issues such as waste management, energy transitions, and rapid habitat restoration. Recent observations concerning Singapore's Marina One and Tesla's energy storage solutions demonstrate that the contextual implementation of green technology can improve efficiency, optimize resource use, and produce favorable environmental results on a significant scale. This method aids in diminishing energy use and fostering biodiversity, dependent on robust governance and successful integration into local systems [17]. Conversely, technology-driven methods, particularly those relying on advanced analytics and IoT enable real-time data acquisition, predictive modeling, and scalable mitigation, but expose social-ecological systems to new forms of risk, like overreliance on infrastructure, digital exclusion, and disruptions caused by system failures. The measurement and documentation of a technology's total carbon footprint, such as the climate impacts traced in blockchain and AI deployment, highlight the paradoxes of tech sustainability: innovation can accelerate positive change, but also introduce unintended consequences [18]. The emphasis on "the power of and," as advanced by contemporary theorists and UN climate advocates, reinforces the necessity of integrating all available tools to achieve future-ready sustainability. This includes recognizing the distinct purposes and pathways of both knowledge traditions and advanced innovations. The success of sustainability transitions has been significantly influenced by citizen participation and empowerment. The S-O-R (Stimulus-Organism-Response) framework reveals that the frequency and type of technology engagement drive greater pro-environmental behaviors and a sense of agency among citizens, notably within local energy communities and participatory management schemes. Gamification and social innovation platforms, by making sustainability interactive and rewarding, boost adoption and foster new habits, but they succeed only when connected to meaningful involvement and not superficial engagement [19].

Moreover, participatory modeling methods, especially within the contexts of energy and landscape management, enhance the effectiveness and reliability of collaborative initiatives, aligning technological solutions with local knowledge and preferences. The literature review of participatory approaches indicates that the incorporation of various knowledge systems and value frameworks promotes equitable representation, reduces the risks of exclusion or marginalization, and enhances adaptive capacity in response to systemic disruptions [20, 21]. The integration of ethical frameworks into digital initiatives and governance is becoming more prevalent in the field of sustainability, where the reliance on technology is increasingly contingent upon ethical innovation. In the context of organizational innovation processes, there exists a significant risk of overlooking environmental responsibility and social well-being if there is no designated role focused on sustainable digitalization or clearly defined responsibilities that emphasize ethical considerations. Empirical evidence has substantiated this claim. Centralized initiatives, such as CSR officers advocating for sustainability within corporate frameworks or acting in advisory roles within governmental bodies, facilitate the integration of ethical safeguards. However, these projects require ongoing support and organized management to avoid producing only tokenistic or surface results [22, 23]. Institutions must prioritize increasing equity. The potential for technology-driven solutions to increase socioeconomic inequities in locations with restricted access, poor literacy levels, or inadequate infrastructure emphasizes the need for deliberate policies aimed at closing the digital gap and protecting vulnerable groups. The existing research on hybrid entrepreneurship in relation to sustainability transitions is extensive. The literature on hybrid entrepreneurship in sustainability transitions finds that justice, diversity, and fairness are necessary dimensions for just and inclusive transformations, especially as hybridity can amplify innovation but also introduce new social and regulatory complexities [24]. Hybrid models where TEK and technology converge provide both resilience and efficiency, if designed with respect for plurality, autonomy, and local priorities. Recent investigations into participatory modeling and scenario simulation highlight the efficacy of these integrated methodologies in improving adaptive capacity, accelerating mitigation initiatives, and fostering learning across diverse scales and contexts. An examination of archetypes within the interactions of Sustainable Development Goals (SDGs) reveals that synergy does not arise spontaneously; it necessitates intentional mediation, thorough metrics, and designs tailored to the specific context to transform potential trade-offs into tangible benefits [25, 26, 27]. Frameworks for corporate social responsibility and principles of the circular economy, informed by both traditional ecological knowledge and technological insights, uncover transformative pathways for industries and urban environments. These methodologies encourage regenerative practices and set new standards for social and ecological responsibility. Distributed and participatory planning processes, augmented by artificial intelligence and large datasets, offer avenues to democratize the design of policies, track sustainability impacts in real time, and continuously refine strategies for enhancement [28]. Despite its potential, the dual framework has significant challenges. Organizational frameworks, cognitive biases, and established siloed paradigms impede the incorporation of ethical and cultural aspects into technology design. The research underscores practical constraints, such as limited time, complexity, and perceived costs, which may lead to the marginalization of holistic models in favor of more immediate technocratic methods. Thus, enacting sustainable change requires not just technology innovations or expanded knowledge but also the establishment of structural reforms, incentives, and accountability mechanisms [29]. Ongoing research is essential to investigate effective participatory modeling, foster cross-disciplinary collaboration, and implement iterative policy evaluation drawing insights from both failures and successes. It is crucial to acknowledge the significance of context and understand that no singular solution can address the diverse sustainability challenges faced by societies globally.

Limitations and Critical Insights

The theoretical implications of these findings necessitate recognition of certain limitations. The lack of site-specific empirical data, combined with the intricate nature of socio-ecological systems, indicates that the projected indices should be regarded primarily as frameworks for guiding future research and policy evaluation. Furthermore, the potential risks associated with knowledge erosion, cultural marginalization, and unintended consequences arising from hybridization or the adoption of technology are identified as critical areas that require ethical safeguards and participatory governance.

Implications for Policy and Practice

The results underscore the imperative for equitable partnerships between Indigenous communities and policymakers, promoting an inclusive strategy wherein local objectives shape the formulation and implementation of initiatives. In sustainable science and governance, the facilitation of information exchanges among diverse perspectives is considered crucial, with cultural integrity and autonomy being maintained. Strong, scalable, and adaptable solutions to the pressing global environmental concerns that are faced will be implemented through this methodology, which will be critical. This theoretical projection posits that the amalgamation of traditional ecological knowledge along with technology not only safeguards cultural and ecological diversity but also possesses the capacity to formulate new benchmarks for evidence-based, great-impact sustainability practices in the forthcoming decades.

V. CONCLUSION

This study emphasizes the importance of Traditional Ecological Knowledge (TEK) and technology-driven practices as vital and interconnected elements for achieving environmental sustainability. Traditional Ecological Knowledge, deeply rooted in Indigenous and local community wisdom, represents a dynamic and culturally embedded system that has historically promoted ecosystem stewardship, biodiversity conservation, and climate resilience through adaptive practices transmitted across generations. At the same time, technology-driven solutions offer unmatched capabilities in data collection, resource optimization, and rapid intervention, reaching levels of scale and speed that conventional methods cannot achieve. This study investigates the amalgamation of these paradigms, facilitating the utilization of their distinct advantages while mitigating their intrinsic constraints. A significant discovery is that the resilience of traditional knowledge systems resides not in their static preservation but in their capacity to evolve and assimilate new technologies, thereby sustaining their relevance in rapidly changing environments. Collaborating respectfully with Indigenous communities makes sustainability efforts stronger by combining the experiential knowledge and adaptability of Traditional Ecological Knowledge with the accuracy and scalability of modern technology. This synthesis helps ecosystems stay strong, keeps cultural practices going, and improves measures of resource efficiency. But there are still problems to solve. Cultural, ethical, and institutional barriers frequently obstruct equitable integration, jeopardizing the incorporation of Indigenous knowledge and exacerbating technological disparities. To build trust and give knowledge holders power, it is important to protect intellectual property rights, make governance more open, and make sure that everyone gets a fair share of the benefits. Additionally, it is important to be very careful about possible unintended effects, such as weak infrastructure or too much dependence on technology. In future endeavors, it is imperative that research prioritizes the empirical validation of theoretical models, the development of precise integrative metrics, and the execution of participatory pilot projects that assess hybrid frameworks across diverse social-ecological contexts. These efforts will improve policies based on evidence that honor different ways of knowing, promote fairness, and encourage regenerative stewardship around the world. In conclusion, combining traditional ecological knowledge with modern technology is necessary for making strategies that are strong, flexible, and fair in order to protect the environment around the world.

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White Aphids: Pose Significant Challenges to Agricultural Productivity

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***Abstract*— *Bareilly its Surrounding area falls within the "Tarai Zone " where white aphids are found in abundance. These are small insects that suck the juice of the crop cycle. There are a few species of white aphids in the world, but the species found on grass, flowers, and vegetable crops create significant problems for the yield and health of the plants. They affect the ecological environment in terms of biological cycling of the soil and environmental conditions, which can be focused on along with the plants. But for the identification and management of the insects that spread on a large scale, many predator species, like maintenance and parasitoid wasps, have been considered as the experts for biological control and prevention of the effects. However, this paper, we focus on how chemical dynamic control of impacts can enhance agricultural productivity and crop protection.*

***Keywords*— Practices, Transgenic, Lady beetles.**

I. INTRODUCTION

Aphids- superfamily Aphidoidea, and are commonly known as whiteflies. They exhibit a wide range of colours within the same species and include fluffy white woolly aphids. The life cycle of aphids has revealed that these insects are capable of producing offspring without a male. This process is called "telegonous generation," in which females give birth to new offspring through parthenogenesis. This type of reproduction leads to rapid population growth. These insects mature quickly and produce many offspring in a short period of time, causing their numbers to increase rapidly in fields. Depending on climatic conditions, especially during favorable seasons (such as spring and autumn), they exhibit their winged forms (alate forms). These winged stages fly to new plants or areas, thus spreading across different crops and locations. Aphids' habitats are often temporary, shifting locations with seasonal changes (such as autumn or winter). During the winter season, they usually go into an inactive state or survive in the form of eggs, which develop again in the next season.

Life cycles of some species of aphid complicated involves alternating joining two types of entertainer plants, such as age groups crops and a Ligneous plants. While about struggle specialize in a single Kind of flora, futher are polymath and can colonize a variety of plant groups. There are about 5,000 described species of aphids, all within the group Aphididae.

Families

- Aphididae Latreille, 1802
- Bajsaphididae Homan, Zyla & We Gierek, 2015

- Canadaphididae Richards, 1966
- Cretamyzidae Heie, 1992
- Drepanochaitophoridae Zhang & Hong, 1999
- Oviparosiphidae Shaposhnikov, 1979
- Parvaverrucosidae Poinar & Brown, 2006
- Sinaphididae Zhang, Zhang, Hou & Ma, 1989
- incertae sedis
- Palaeoforda tajmyrensis Kononova, 1977
- Penaphis Lin, 1980
- Plioaphis subhercynica Heie, 1968
- Sbenaphis Scudder, 1890
- Sunaphis Hong & Wang, 1990
- Xilutiancallis Wang, 1991
- Yueaphis Wang, 1993

As you all know that aphids are considered to be the smallest insects in size which, besides being parasites, maintain a mutual relationship with other living organisms like ants, lady birds, beetles, and take care of them, due to which it play an important role in protecting them from predators. They are particularly harmful to plants and weaken them by sucking the juice of plants and their leaves, fruits, flowers etc. due to which they act as vectors for plant viruses. Apart from this, they spoil ornamental plants due to city deposits in the form of a sticky substance, which grows in the form of a fungus or black mold. Along with this, their ecological success and capabilities increase rapidly day by day.

White aphids are difficult to control, but not impossible. They can be treated with insecticides from a different perspective, as aphids possess a unique resistance and prefer to nest on the underside of leaves. Spraying soap in a water tank using a small spray tool can be effective. Natural predators, including box ladybirds, wasps, aphids, and their midge larvae, can also be used as parthenogenic fungi, which can be used as biological control agents. Furthermore, management in controlled environments, such as greenhouses, has been shown to be quite effective.

Distribution

The species of aphid is ubiquitous or cosmopolitan. They exhibit their habitat in temperate zones, where their diversity may be much lower than in temperate zones, but more species have been observed in temperate zones. Many species also follow a migration process, as winged aphids can fly up to about 600 m, where they can spread their wings in the air along with secure breeze. for instance: the character aphids (*Acyrthosiphon pisum*) are accepting on have grown from Uttarakhand India to Chaina and Pakistan by easterly winds throughout 2022

The phylogenetic tree of the Aphididae, as derived from studies by Papasotiropoulos (2013), Kim (2011), and Ortiz-Rivas and Martinez-Torres (2009), presents a detailed internal phylogeny of this family. One approach to elucidating the phylogeny of aphid groups is through the examination of their bacterial endosymbionts, particularly the require endosymbiont *Buchnera*. This method relies on the expectation that these symbionts are transmitted rigorously Perpendicularly from one generation to the next. Evidence strongly supports this assumption, and several phylogenetic relationships within the Aphididae have been inferred from endosymbiont studies.

Carotenoids and photoheterotrophy:

White aphids have been shown to possess the ability to produce red carotenoids through horizontal gene transfer from fungi. This mucus, secreted by white aphids, appears red in color, called red carotenoids. This makes aphids, along with two-spotted spider mites and Oriental hornets, unique among animals with this ability. Aphids use their carotenoids to mop up solar energy and transform it into usable cellular energy, ATP. This phenomenon is the only known example of Chemoheterotroph in organism. Aphids have carotenoid pigments near the surface of their cuticle, positioning them well to absorb sunlight. When these carotenoids are stimulated by sunlight, they convert NAD to NADH. NADH is then oxidized in the mitochondria, helping to produce animation for the aphid.

Ant-Aphid Mutualism

A Few White aphids and ants form a bond with each other. This relationship is called mutualism. It is often observed that during farming or crop rotation, aphids work with ants to avoid predators and drink the sticky substance secreted by the aphids, which provides them with food. In return, the aphids receive protection. Sometimes, along with food, they also find a place and create a habitat. For example, some ant species collect aphid eggs from their nests during the winter and carry them to new plants in the spring. Ants found on European as well as many yellow grasses form a colony or swarm with their aphids, who help them care for each other and provide protection and care.

Bacterial Endosymbiosis

Aphids maintain an ancient and essential association with the intracellular bacterium Buchnera aphidicola, which occupy within Professional cells called bacteriocytes. The endosymbiosis partnership of Buchnera is primarily responsible for the aphid's nutrition, as the aphid's phloem sap is not a source of food, and it is also believed that their twin groups diverged between 280 and 160 million years ago. Additionally, the aphid constantly uses the phloem sap as its food source.

Ecological Impact and Conservation:

Aphids have a unique role in the environment and ecosystem as they play a key role in the reproductive stage and symbiotic conditions because their behavior with other species of termites, ants, and bacteria is considered efficient. If seen, it reflects the ecological condition in the form of endosymbiosis, that is, it is considered the right medium of pest control for protection. According to nature, biodiversity, in which both plants and animals affect each other, along with infection and intercommunication, promotes biological methods and support, which proves to be helpful in the balance of the forest ecosystem as well as biodiversity.ecological niche. Insights into their biology can support more sustainable agricultural practices and conservation strategies, contributing to the long-term balance of managed and wild ecosystems.

Life Cycle: White aphids have a very short lifespan because their life cycle is affected by temperature as well as the environment. Their numbers can be seen changing within about 8-10 days as they lay eggs. Most generations are affected by changes in the weather. Their population increases in mild or high temperatures due to warm winds. White aphids prefer to lay eggs in a place different from the winter. After laying, the eggs are fertilized and migrate to different leaves, flowers, crops, and grasses. After several generations, they develop wings that migrate to the host plant and continue their successive cycles. In larger species, these eggs are genetically similar depending on the season, but most females lay eggs after 5 to 15 days. The first spawning period varies between species, averaging 8 to 10 days. The breeding period can range from 10 to 12 days. If predators are absent, spawning occurs at intervals of approximately 22 to 24 days. Whitefly species multiply rapidly and disrupt crop cycles. They maintain their dominance during the summer, as they will be extinct by March 2025 this year. As of June 2025, it has been observed that the species of white acid attacks several crop cycles, such as hibiscus flowers, parthenogenic grasses, chilli plants, and the effects of which have been demonstrated through this cycle, besides growing in large quantities on tobacco and winter crops like potatoes.

Spring Emergence:

- **Egg Hatching:** Overwintering eggs hatch as temperatures warm and plants start to grow.
- **Founding Females:** The hatched aphids are all feminine. These feminine develop to Cultivating plant to begin sustain.
- **Asexual Reproduction:**
- **Live Births:** these establish feminine new young daughter that are tiny duplicate
- **Rapid Population Growth:** Under favourable conditions, the population can grow quickly. All colony members are wingless females that produce female offspring. This phase causes the population to grow rapidly..

Host Switching:

i. **Complex Life Cycles**: Some aphid species have complex life cycles that involve switching between primary and secondary host plants.

ii. **Repeated Infestations:** These species can repeatedly infest secondary hosts, which vary by location and time of year.

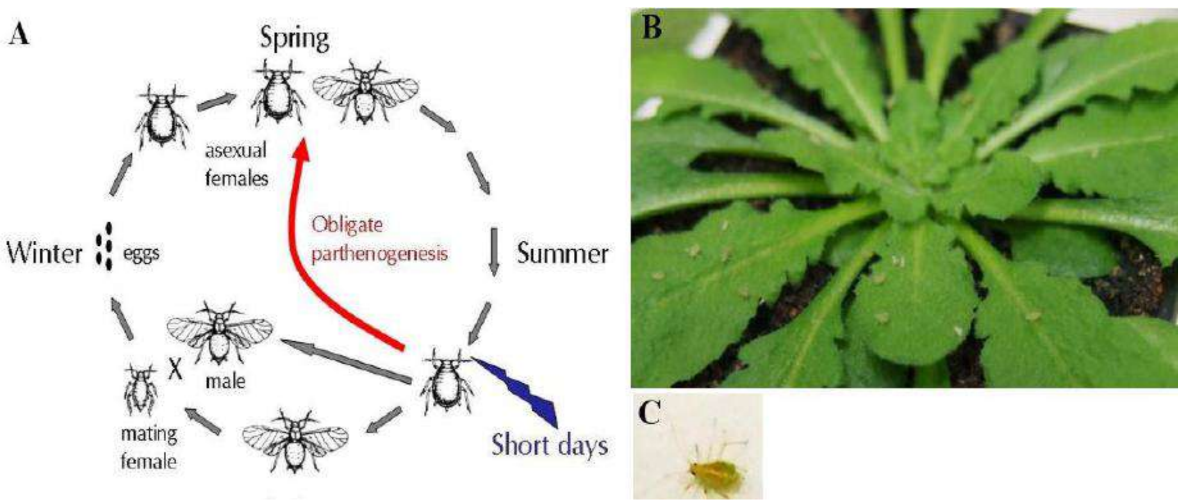

Fig:01 Life Cycle of Aphid in Host Plants

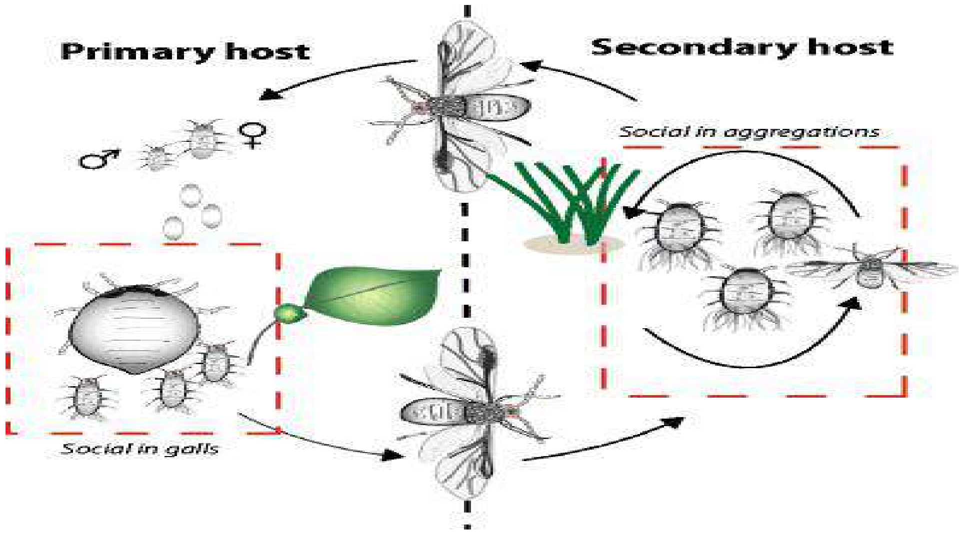

Fig:2 Life Cycle of Aphid in different stage

Production of Winged Forms:

1. Environmental stress: If the host plant becomes too crowded, winged females may leave the group to reduce the quality of the food source.
2. Dispersal: These winged females disperse to find new habitat and begin producing wingless females.
3. Fall reproduction/sexual form: As days shorten and temperatures cool in autumn, both male and female offspring are produced.
4. Mating and egg laying: These sexual forms mate, and the resulting eggs are laid in protected locations (such as in bark crevices and under lichens) so they can survive the harsh winter conditions.

Predators: Environmental Impacts on Aphids

White aphids are eaten by a variety of birds and insects. The investigation conducted on a grange in North Carolina revealed that Siberian birds consume approximately 10 to 12 lakh white aphids daily. Similarly, the Indian sparrow can consume approximately 83% of its diet. Apart from small birds, larger birds include species like herons, etc.

Other creatures that prey on white aphids include adult ladybirds and larvae, parasitic wasps, and spiders. Among ladybirds, Myzia oblongoguttata is a specialist, feeding exclusively on conifer aphids, while generalists such as Adalia bipunctata and Coccinella septempunctata feed on a variety of aphid species. Female ladybirds lay eggs in batches, with each female capable of laying several hundred eggs.

Pathogens and Weather

White aphid infections have some sensitivity to bacteria, viruses, and fungi. With changing seasons, increased rainfall and heat, they play a significant role in increasing the aphid population, along with environmental factors. Infections also affect their populations. Some diseases, including *Neozoites fresenii*, *Entomophthora*, *Beauveria bassiana*, *Metarhizium anisopliae*, and *Lecanicillium lecanii*, play a significant role. Except for microscopic aphid species, they adhere to adhesive substances and parts of their bodies to feed on them, which they then extract from the air. Rain, due to inclement weather, can increase fertility rates because it kills bacteria and prevents the aphid from spreading. This is considered beneficial for aphid control.

Anti-predator defences: Most aphids have limited defences against predators. However, some species form galls—abnormal plant tissue swellings—that provide protection from predators and environmental hazards. Within these galls, certain aphids produce specialized "soldier" forms, sterile nymphs with defensive adaptations to protect the gall. For instance, Alexander's horned aphids possess a hard exoskeleton and pincer-like mouthparts for defence.

Primitive white aphids are flightless but drop to the ground to avoid being preyed upon by herbivorous animals. Some species find permanent protection in the soil, feeding on root vascular systems and staying underground. These underground aphids are often attended by ants, which transport them between plants through tunnels in exchange for honeydew. "Woolly aphids" *(Eriosomatinae)* excrete a fluffy wax coating for added protection. The cabbage aphid, *Brevicoryne brassicae*, stores secondary metabolites from its host and releases chemicals that create a mustard oil smell to repel predators. Aphids also produce peptides known as thaumatin, which may provide resistance to certain fungi. Contrary to some outdated references, honeydew is secreted from the anus, not the cornicles, which primarily produce defensive chemicals like waxes. Cornicle wax can attract predators of aphids in some cases. Additionally, certain clones of *Aphis craccivora* are toxic to the invasive ladybird *Harmonia axyridis*, suppressing its population and favouring other ladybird species.

Parasitoids: Aphids are both abundant and widespread, acting as hosts to a diverse array of parasitoids, including many very small parasitoid wasps, typically around 0.1 inches (2.5 mm) in length. For example, the species *Aphis ruborum* hosts at least 12 species of parasitoid wasps. These parasitoids have been extensively studied as potential biological control agents and are profit-oriented utilized for this impetus.

Plant-aphid interactions

Plants employ both local and systemic defences against aphid attacks. In some plants, young leaves contain chemicals that deter aphid attacks, whereas older leaves lose this resistance. The resistance of older tissue to infection allows for its growth on other plants, leading to weakening of crop plants and their parts.

For example, feral potato, Solanum bertholtii, releases an aphid agitation fragrance, (E)-β farnesene, which repels the aphid *Myzus persicae* from up to 3 millimetres away. This wild potato species, like others, also has glandular hairs that, when broken, release a sticky substance, preventing up to 30% of aphids infesting the plant from moving. Furthermore, onion and potato plants can deter nearby aphid attacks by increasing the production of terpenoids, which are used in interplanting. Furthermore, plants adjacent to infested plants may experience increased root growth but reduced apical growth.

Aphid damage can include reduced photosynthesis growth rates, leaf spots, yellowing, stunted growth, leaf curling, browning, wilting, reduced yields, or even plant death. The aphid's excrement weakens the plant, and its saliva is toxic. In addition, aphids often spread plant viruses, such as those affecting potatoes, cereals, sugar beets, and citrus. Virus transmission between aphids and plants occurs in two ways: calcified and non-calcified transmission. In this channeling, viruses form clusters on the aphid's mouthparts and are released to another body part. The green peach aphid (*Myzus persicae*) is a vector for over 110 plant viruses, while cotton aphids (*Aphis gossypii*) commonly infect sugarcane, papaya, and peanuts with viruses.

In plants producing phytoestrogens like coumetarol, such as alfalfa, aphid damage correlates with higher concentrations of coumetarol. The honeydew excreted by aphids can also foster the growth of fungi that harm plants and turn down the productiveness of antifungal. The Conjecture suggested in the mid-1970s proposed that nourish might enhance Botanical wellness by nourishing soil microorganisms, including nitrogen fixers, through excess honeydew. However, observational evidence does not support this hypothesis.

Interactions with humans

Around 5,000 species of aphids have been documented, and among them, approximately 450 species have been found to infect food and fibre crops. These insects, feeding directly on plant sap, are responsible for crop damage and yield reduction. However, their impact is amplified as they serve as vectors for plant viruses. The virus infection on aphids depends on their behavior because the virus infection depends on different parts of the plant. The effect on the plant is called the taste and behavior of aphids after feeding on them, which is harmful for them as well as productivity in the place for a long time. The movement of acid is considered to play a role in an epidemic in a virus.

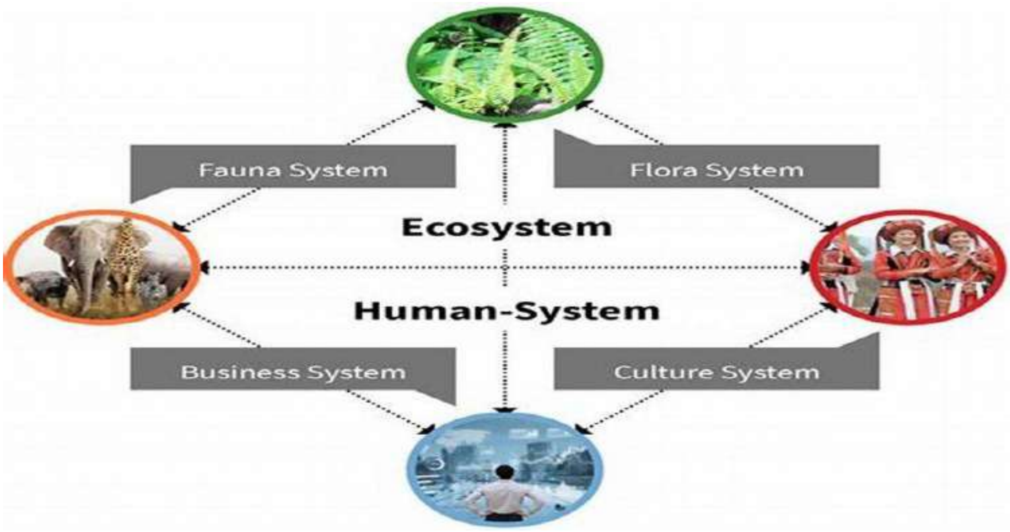

Fig:03 Aphid: Ecosystem fauna and Flora

Fig:05 White Aphid on Vegetable Plants (Green chili) and Others, Grow in Grasses

Vegetable and Food crops are particularly warm, humid, and stable environmental condition. Common greenhouse aphid species include the green peach aphid (*Myzus persicae*), cotton or melon aphid (*Aphis gossypii*), potato aphid (*Macrosiphum euphorbiae*), foxglove aphid (*Aulacorthum solani*), and chrysanthemum aphid (*Macrosiphoniella sanborni*). If you notice symptoms like yellowing of leaves, curling of leaves and stunted growth of plants, then you can assume that there is an infestation of aphids. The honeydew excreted by aphids serves as a substrate for various Fungal infection, including black sooty Molds, which further inhibit plant thickening by bring down photosynthesis. Additionally, during large outbreaks, aphids have been known to trigger allergic soporific inhalant reactions in diplomatic individuals. Aphids disperse through various means, including walking, flight, instinctual dispersal, or transhumance. Winged aphids are not strong fliers and typically lose their wings after a few days. Their flight patterns are influenced by factors such as wind conditions, gravity, hailstones, and other environmental components. Circulation may also occur accidentally through the fluctuation of plant materials, organisms, farm gadgetry, agency, or airship.

II. METHODOLOGY & MANAGEMENT

Material for the aphid species was gathered for this Field cytological investigation from the Rohilkhand villages of Bareilly, Uttar Pradesh, in India. In and around the villages of the Bareilly Region, the samples of aphids are gathered from a variety of plants. Additionally, natural and horticultural plants were examined for aphids. Aphid samples were gathered from the fields together with their host plants in polythene bags were secured with rubber bands to prevent them from escaping. Scissors were used to carefully cut away a twig from the infected host plant.

The material was kept in it gradually to avoid upsetting the aphid colony, together with its ant companions, parasites, and predators, if any were present. These were delivered to the lab for additional cytological processing. The gathered material was used to create the cytological slides (aphids). The specimens (alatae, apterae, and nymphs) were kept in 70% alcohol side by side, for each sample was collected for use in taxonomic identification. After gathering all aphid material in 70% alcohol, all the unidentified host plants were also collected, transported to the lab, and kept as a herbarium in order to be identified at a later time. A similar process was used for the outstation collection. Daily cytological slides were created using these samples, like squqnder from the Crop area. The aphids were removed from their host plants using a fine camel brush. The ideal aphids for cytological preparations are live ones. Additionally, these aphids were preserved in a 3:1 mixture of glacial acetic acid and methanol for potential usage in the event of a shortage.

Management

- **Aphid Control and Natural Enemies** Aphid populations in landscapes are typically kept under control by natural enemies. Key aphid predators include:
- **Lady Beetles:** Lady beetles are voracious predators of aphids.
- **Lacewing Larvae**: Lacewing larvae, often called "aphid lions," are effective aphid predators, attacking aphids with their strong mandibles.
- **Hoverfly Larvae**: Hoverfly larvae also prey on aphids, contributing significantly to natural aphid control.
- **Parasitic Wasps***:* Parasitic bee, yellojacket stow their nit inside aphids, and the yellojacket imago begin by consuming the aphid from the inside. As a result, parasitized aphids become enlarged and turn a dark brown or shiny black, frequently go into as "mummies."
- **Exit Holes:** When the adult wasp emerges, it leaves a distinctive exit hole in the aphid mummy.
- **Seasonal Considerations:** In spring, natural enemy densities are lower, which can lead to aphid population outbreaks.

Management Recommendations:

- **Avoid Nitrogen Fertilizers**: If the aphid infestation forms dense colonies on the grass, avoid applying nitrogen dressings.
- **Insecticidal Soap and Horticultural Oil:** These can be used to suppress aphid populations. They are effective only when applied directly onto aphids, requiring thorough coverage of affected plants.
- **Systemic Insecticides**: These are also effective against aphids but must be used carefully to avoid harming beneficial insects and pollinators. Always follow the instructions on the insecticide label.
- **Visual Reference:** Lady beetles consume aphids as food.
- Natural enemies and integrated pest management strategies are crucial for maintaining aphid populations at manageable levels while minimizing the impact on beneficial insects and the environment.

III. CONCLUSION

The present study reveals a significant abundance of white aphids on various crops cycle across the Bareilly district and adjoining areas of Rohilkhand. These aphids play a notable role in local trophic dynamics, forming integral links within the food chain and food web. The diverse agricultural landscape of the region—characterized by mixed cropping systems involving cereals, vegetables, and flowering plants—creates conditions conducive to aphid proliferation, potentially leading to ecological imbalances and reduced crop productivity. Aphids are well known among farmers and horticulturists as major agricultural pests. Field observations conducted by our team corroborate historical accounts, such as Gilbert White’s description of aphid infestations in the Bareilly region during early 2025, where massive swarms were observed covering vegetation and producing copious amounts of honeydew. These outbreaks underline the pest’s potential to cause extensive physiological stress and aesthetic damage to host plants.

Biological control measures, including the introduction of natural predators such as ladybird beetles (Coccinellidae) and parasitic wasps (Aphidiinae), offer eco-friendly management strategies. However, the transient retention of adult beetles and the need for repeated releases reduce long-term efficacy. Recent advances in molecular biotechnology have explored transgenic approaches, such as the expression of Eβf synthase genes in Arabidopsis thaliana, to produce allomones capable of repelling aphids and attracting natural enemies. Although initial field results suggest limited success under crop conditions, synthetic analogues of these compounds have shown promise in enhancing the efficiency of fungal biocontrol agents and insecticides.

Overall, sustainable aphid management in the Bareilly region requires an integrated pest management (IPM) approach that combines ecological understanding, biological control, and biotechnological innovation to maintain agricultural stability and minimize environmental impact.

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Soil Carbon Sequestration in Agro-ecosystems: Mechanisms, Management, and the Role in Climate Change Mitigation

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***Abstract*— *Soils represent one of the largest terrestrial carbon reservoirs, and the improved management of soil organic carbon (SOC) offers considerable potential for mitigating climate change, enhancing soil health, and improving agricultural productivity. This review synthesizes current knowledge on the dynamics and mechanisms of SOC storage, key environmental and land-use factors influencing it, agronomic and chemical management strategies for enhancing sequestration in agro-ecosystems, the limitations and uncertainties in quantifying its role for greenhouse-gas (GHG) mitigation, and the policy and research outlook for scaling up soil-based climate solutions. While the potential is significant, the saturation risk, measurement challenges, trade-offs, and context-specificity must be recognized. For semi-arid and dryland systems in particular, integrating SOC-based management into sustainable intensification pathways will require region-specific calibration, long-term monitoring, and alignment with socio-economic incentives.*

Keywords*— Soil organic carbon, sequestration, climate change mitigation, agro-ecosystems, semi-arid, soil health, management practices

I. INTRODUCTION

The global climate challenge demands multiple mitigation avenues that extend beyond energy and land-use change. Among nature-based solutions, soils play a pivotal role: the top meter of global soils holds up to three times as much carbon as the atmosphere [1, 2]. Agricultural soils represent both a risk [3] and FAO (2017, 2022) have emphasized soil carbon management as a crucial land-based strategy for achieving sustainable climate solutions.

This review updates current knowledge, summarises management strategies for enhancing soil carbon storage, identifies limitations, and offers perspectives for dryland and semi-arid agro-ecosystems under climate variability.

II. MECHANISMS OF SOIL CARBON SEQUESTRATION

SOC accumulation is governed by input, transformation, and stabilization processes [4, 5].

- Inputs: Plant residues, root exudates, and organic amendments such as manure and compost contribute to carbon inputs [6, 7].
- Transformation: Microbial decomposition, aggregation, and biochemical stabilization determine carbon turnover rates [8, 9].
- Stabilization: SOC is retained through physical protection within aggregates, chemical adsorption to minerals, and biochemical recalcitrance [1, 4].

Biochar has gained attention as a recalcitrant amendment that adds stable carbon pools and modifies microbial activity [10, 11, 12]. Mineral–organic associations also play critical roles in long-term stabilization [4].

III. FACTORS INFLUENCING SOC STORAGE

SOC storage potential varies with several biophysical and management factors

[13, 1].

- Climate: Temperature and moisture regulate decomposition; warmer, drier conditions enhance mineralization and carbon loss [14, 15].
- Soil texture and mineralogy: Clay-rich soils protect SOC more effectively than sandy soils [5, 4].
- Land use and disturbance: Conversion of forests or grasslands to cropland often reduces SOC by 25–50%, whereas restoration or reduced tillage can recover part of this loss [16].
- Management intensity: Fertilization, irrigation, residue handling, and cropping diversity influence SOC inputs and turnover [17, 18].
- Saturation and residence time: Soils reach an equilibrium carbon level beyond which sequestration slows—termed "carbon saturation" [4].
- Climate feedbacks: Rising temperatures may reduce SOC stability, potentially converting soils from sinks to sources [19].

Table 1. Average Soil Organic Carbon Sequestration Potential under Various Land Uses and Climatic Conditions

Land use / System	**SOC Sequestration Potential (Mg C ha^{-1} yr^{-1})**	**Climate Zone**	**Major Mechanism**	**Reference**
No-till cropping	0.3 – 0.6	Temperate	Reduced disturbance, aggregate stability	Jian et al. (2020); Pittelkow et al. (2015)
Cover cropping	0.4 – 0.8	Humid-subtropical	Enhanced biomass and root carbon input	Joshi et al. (2023)
Manure application	0.2 – 0.5	Semi-arid	Organic carbon addition	Ghosh et al. (2024)
Agroforestry	1.0 – 3.0	Tropical	Tree litter, deep roots	Lal (2020); Pandao et al. (2024)
Biochar amendment	0.3 – 1.2	Semi-arid	Stable carbon addition, microbial modulation	Bekchanova et al. (2024); Gross et al. (2021)
Enhanced rock weathering	0.5 – 2.0	Humid-temperate	Mineral carbonation and CO_2 capture	Beerling et al. (2025)

IV. MANAGEMENT STRATEGIES FOR ENHANCING SOIL ORGANIC CARBON (SOC) IN AGRO-ECOSYSTEMS

Sustainable soil carbon management requires a combination of agronomic, biological, and ecological practices that enhance carbon inputs while minimizing losses through decomposition and erosion. The following management interventions have been widely recognized as practical approaches to increase SOC sequestration and improve soil health.

4.1 Conservation Tillage and No-Till Systems

Conservation tillage, particularly no-till farming, has emerged as one of the most effective methods for retaining soil organic matter and improving carbon stabilization. By minimizing soil disturbance, these systems protect soil aggregates and reduce the exposure of organic matter to oxidation [18, 20]. Global meta-analyses indicate that no-till practices can significantly enhance SOC concentrations, especially in the upper 0–10 cm soil layer, where residues accumulate and microbial activity is high [20]. These benefits are particularly evident in temperate and humid regions, where soil moisture is more conducive to biological activity. However, some studies suggest that while surface SOC increases, the total profile carbon may remain unchanged due to vertical redistribution of carbon [1]. The long-term adoption of reduced tillage also enhances soil structure, improves water infiltration, and facilitates nutrient cycling, thereby further supporting ecosystem resilience under changing climatic conditions.

4.2 Cover Crops and Crop Rotations

The inclusion of cover crops and diversified crop rotations plays a vital role in maintaining continuous carbon inputs into the soil system. Cover crops—especially legume-grass mixtures—enhance root biomass production, stimulate microbial activity, and improve soil aggregation, collectively contributing to greater soil carbon sequestration [17, 8]. Long-term experimental data indicate annual SOC gains ranging from 0.3 to 0.6 Mg C ha^{-1} yr^{-1} under well-managed cover cropping systems [17]. In addition to carbon sequestration, diversified rotations reduce pest and disease pressure, improve nutrient-use efficiency, and stabilize crop yields—key benefits for sustainable agroecosystem functioning.

4.3 Organic Amendments and Residue Management

The addition of organic amendments—such as farmyard manure, compost, and crop residues—directly increases both labile and recalcitrant carbon fractions in soils. These inputs enrich microbial habitats, enhance nutrient availability, and foster aggregate formation [6, 7]. Residue retention on the soil surface reduces evaporation and erosion while promoting moisture conservation and energy flow within the soil food web. However, the C:N ratio of residues must be balanced through appropriate nitrogen management to prevent immobilization and maintain crop productivity. The long-term integration of manure or compost with mineral fertilizers has been shown to enhance soil carbon stability and resilience against degradation.

Table 2. Representative SOC management practices and co-benefits

Practice	SOC impact	Co-benefits	Limitations
No-till	Moderate SOC gain in surface layers	Improved infiltration, erosion control	Potential yield variability
Cover crops	High SOC potential	Soil structure, biodiversity	Water competition in dry areas
Organic amendments	Direct C addition	Improved fertility	Cost and logistics
Agroforestry	Large, long-term SOC	Biodiversity, shade, income	Land competition
Biochar	Long-term stable C	Water holding, yield	Production costs
Enhanced weathering	CO_2 removal via minerals	Nutrient enrichment	Scaling uncertainty

4.4 Agroforestry and Perennial Systems

Agroforestry and perennial cropping systems serve as highly efficient biological sinks for atmospheric carbon. Integrating trees, shrubs, and deep-rooted perennials into farmlands not only enhances belowground carbon storage but also promotes litter deposition and soil biodiversity [21, 9]. Empirical studies suggest that well-designed agroforestry systems can sequester between 1 and 3 Mg C ha^{-1} yr^{-1}, depending on tree species composition, soil type, and climatic conditions [1]. Moreover, the long-term presence of perennials stabilizes soil structure, improves nutrient recycling, and mitigates the impacts of extreme weather events, aligning with climate-smart agricultural principles.

4.5 Biochar and Advanced Carbon Amendments

4.6 Biochar, a carbon-rich product derived from the pyrolysis of biomass, represents a promising technology for long-term carbon sequestration in soils. Its high stability and porous structure contribute to improved soil aeration, water-holding capacity, and nutrient retention [10, 11]. Meta-analytical evidence shows mean SOC increases of 18–30% following biochar application, depending on feedstock and application rate [12]. Additionally, biochar enhances microbial habitat quality and may reduce nitrous oxide emissions, providing a dual benefit for climate change mitigation and improving soil fertility.

4.6 Enhanced Rock Weathering

Enhanced rock weathering [22, 23, 24]. This emerging strategy not only captures atmospheric CO_2 but also releases essential nutrients, such as calcium, magnesium, and potassium, which can enhance soil fertility. ERW offers a potentially scalable and durable pathway for carbon removal; however, uncertainties remain regarding its large-scale feasibility, energy costs, and potential ecological impacts. Further long-term field studies and life-cycle assessments are needed to evaluate its integration into sustainable farming systems.

V. LIMITATIONS, UNCERTAINTIES, AND RESEARCH GAPS

Despite the promise, SOC sequestration faces key challenges:

Saturation and permanence: Carbon gains slow as soils approach equilibrium, and reversal can occur due to land-use change or erosion [4, 1].

Measurement challenges: SOC changes are slow, spatially variable, and costly to monitor accurately [5].

Trade-offs: Some practices may increase N_2O emissions or require additional inputs [1].

Timescales: Detectable carbon increases often take 10–20 years [9].

Climate feedbacks: Warming may accelerate decomposition, especially in semi-arid regions [14, 19].

VI. POLICY AND OUTLOOK FOR SEMI-ARID AGROECOSYSTEMS

Integrating SOC sequestration into national climate policy aligns with land degradation neutrality and SDG 13 [25, 26].

In India's semi-arid regions, soil carbon enhancement must complement productivity goals and climate resilience [9]. Incentive mechanisms—such as carbon credit schemes and payments for ecosystem services—can motivate adoption of carbon-positive practices [2, 27].

Emerging technologies [28]. Long-term adoption depends on capacity building, farmer engagement, and integration of soil health indicators into policy frameworks [5, 1].

VII. CONCLUSIONS

Soils are vital components of the global carbon balance and a cornerstone of sustainable agriculture. Enhancing SOC offers co-benefits of improved fertility, resilience, and climate mitigation. However, sequestration potential is finite and context-dependent. Region-specific approaches, particularly for dryland and semi-arid systems, are essential. Future efforts must combine agronomic innovation, digital monitoring, and enabling policy to achieve meaningful and lasting soil carbon gains.

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Evaluation of Inorganic Nutrient Sources and Organic Manures on Growth, Yield and Quality of Wheat (*Triticum aestivum* L.)

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***Abstract*— *A field study was conducted during the Rabi Season of 2022–23 and 2023–24 at the Department of Agriculture, Sri Guru Granth Sahib World University, Fatehgarh Sahib on the effect inorganic nutrient sources and organic manures on the growth, yield, and quality of wheat (Triticum aestivum L.). The experiment followed a Randomized Block Design with 14 treatments replicated thrice. Results indicated that treatment T_9 (100% RDN through chemical fertilizer + 25% RDN through poultry manure) recorded the highest values for growth parameters -plant height (101.62 cm), leaf area (6.14 m²), dry matter (302.48 q ha^{-1} row), and number of tillers (124.33 m^{-1} row) and yield parameters, including grain yield (58.82 q ha^{-1}), straw yield (74.25 q ha^{-1}), biological yield (131.30 q ha^{-1}), harvest index (45%), and protein content (12.18%). These were statistically at par with T_2 (100% RDF), T5 (100% RDN + 25% FYM), and T_7 (75% RDN + 25% poultry manure). The lowest values across all parameters were recorded in the control (T_1). The study concluded that integrating organic manures with inorganic fertilizers significantly enhances wheat growth, yield, and quality over sole application of chemical or organic sources.*

***Keywords*— Wheat, FYM, Poultry manure, Biogas Slurry, Nitrogen.**

I. INTRODUCTION

Wheat (*Triticum aestivum* L.) a member of family *Poaceae,* is chief staple food which supplies approximately 35 percent of total food consumed by the global population (Mohammadi-Joo *et al* 2015). It is one of the most important cereal crops of the world, which globally stand in second position both in terms of area and production next to rice. In Punjab, it is cultivated over an area of 35.17 lakh hectares with annul production of 165.67 lakh tonnes and average productivity of 47.10 quintals ha^{-1} (Anonymous, 2024). The demand for wheat is expected to increase due to increase in population and affordability due to improved income status of the people (Gangwar *et al* 2018).

Integrated nutrient management refers to the combination of all possible sources of nutrients like organic, inorganic and biological sources in a judicious way for obtaining an ecologically sound environment and economically optimal farming system (Jat *et al* 2015). Integrated use of organic and inorganic nutrient sources helps in gaining sustainable yield and improved soil quality for enhanced production (Brar *et al* 2015). Continuous application of organic manures year after year improves physical and chemical conditions by providing a favourable soil structure, enhanced soil cation exchange capacity, increased quantity and availability of plant nutrients, increase humus content and substrate for microbial activities (Bohme and Bohme, 2006).

The use of organics in an integrated way renders the benefits through, the maintenance or adjustment of soil fertility and plant nutrient supply at an optimum level for sustaining the desired productivity. (Abdulrahimzai, 2019). As poultry waste contains a high concentration of nutrients so addition of small quantity of poultry manure in an integrated nutrient management system could meet the shortage of FYM to some extent (Ghosh *et al* 2004). Poultry manure carried out rapid mineralization.

II. MATERIAL AND METHODS

The present studies were carried out at Agriculture Farm, Sri Guru Granth Sahib World University, Fatehgarh Sahib during *rabi* season in the year 2022-2023 and 2023-2024. The experimental site for the current study is located in Fatehgarh Sahib district, Punjab, India. Geographically situated at approximately 30.65° N latitude and 76.40° E longitude, the region falls under the agro-climatic zone of the central plain region of Punjab. The area experiences a subtropical climate characterized by hot summers, cold winters, and a monsoon season from July to September. The average annual rainfall is around 700-800 mm, with most of it occurring during the monsoon. It was 14 treatments and three replications with RBD design. The crop was sown in the first week of November in both years. Seeds should be sown at 5 cm depth in furrows 20 cm apart with uniform seed rate of 100 kg ha^{-1}. The variety was sown in PBW-826. Observations were collected for Growth attributes viz., Plant height (cm), Leaf area index (m^2), Dry matter accumulation (q ha^{-1}) and Number of tillers per meter row length, grain yield (q ha^{-1}), straw yield (q ha^{-1}), biological yield (q ha^{-1}), harvest index (%) and protein content (%).

III. RESULT AND DISCUSSION

Growth Attributes

The study evaluated the effect of different nutrient sources on plant growth attributes, including plant height, leaf area index, dry matter accumulation and the number of tillers per meter row length, for two consecutive years (2023 and 2024) data were show in table 1 and figure 1. The highest plant height, leaf area, dry matter and number of tillers per meter row length were recorded in T_9 (100% RDN through poultry manure) with 101.00 cm, 6.16 m², 133.45 q ha^{-1} and 124.33 and in 2024 and 102.23 cm, 6.16 m^2, 133.22 q ha^{-1} and 124.67 in 2023. This was statistically at par with T_2 – (100 % RDF (125 kg ha^{-1}) from chemical fertilizers), T_5 – (100 % RDN through chemical fertilizer + 25 % RDN through FYM), T_7 - (75% RDN through chemical fertilizer + 25% RDN through poultry manure) and T_{13} - (100% RDN through chemical fertilizer + 25% RDN through biogas slurry) in both the years. The control treatment (T_1) showed the lowest result in all the growth parameters. Due to this, the study concludes that nutrient management significantly influences plant growth parameters. Among the treatments, T_9 exhibited the best results across all growth attributes, including plant height, leaf area index, dry matter production, and tiller count, making it a promising organic nutrient source for sustainable crop production. However, the control treatment (T_1) resulted in significantly lower growth attributes, emphasizing the necessity of nutrient application for optimal plant development.

Table 1: Effect of inorganic nutrient sources and organic manures on growth of wheat

	Growth attributes	Plant Height (cm)			Leaf area index (m^2)			Dry matter accumulation (q ha^{-1})			Number of tillers per meter row length		
		2023 year	2024 year	Pooled	2023 year	2024 year	Pooled	2023 year	2024 year	Pooled	2023 year	2024 year	Pooled
T_1	Control (No nutrient sources)	85.70	86.80	86.25	4.38	4.61	4.50	119.51	120.24	119.87	102.00	104.33	103.17
T_2	100 % RDF (125 kg a^{-1}) from chemical fertilizers	100.43	101.13	100.78	6.13	6.14	6.14	132.05	132.93	132.49	123.67	124.33	124.00
T_3	75 % RDN (93.75 kg ha^{-1}) through chemical fertilizer + 25% RDN through farm yard manure (FYM)	98.40	99.07	98.73	5.68	5.81	5.75	129.94	130.83	130.39	120.33	122.33	121.67
T_4	50 % RDN (62.5 kg ha^{-1}) through chemical fertilizer + 50 % RDN through FYM	96.37	97.17	96.77	5.56	5.62	5.59	127.82	128.38	128.10	120.00	121.00	120.50
T_5	100 % RDN through chemical fertilizer + 25 % RDN through FYM	100.29	100.95	100.62	6.10	6.13	6.12	131.61	132.23	131.92	122.67	123.67	123.17
T_6	100 % RDN through FYM	96.03	96.87	96.45	4.53	4.74	4.64	122.24	122.95	122.59	117.33	119.33	118.33
T_7	75 % RDN through chemical fertilizer + 25% RDN through poultry manure (PM)	99.59	100.40	99.99	6.12	6.14	6.13	131.81	132.60	132.21	123.00	124.33	123.67

T_8	50 % RDN through chemical fertilizer + 50 % RDN through PM	95.87	96.27	96.07	5.53	5.66	5.60	127.13	127.80	127.46	119.33	120.00	119.67
T_9	100 % RDN through chemical fertilizer through PM + 25% RDN through poultry manure (PM)	101.00	102.23	101.62	6.16	6.16	6.16	133.22	133.45	133.33	124.33	124.67	124.33
T_{10}	100 % RDN through PM	95.80	96.43	96.12	5.45	5.54	5.49	124.76	125.48	125.12	118.00	119.00	118.50
T_{11}	75 % RDN through chemical fertilizer + 25% RDN through Biogas Slurry	95.63	96.80	96.22	5.63	5.70	5.66	129.86	129.80	129.83	120.33	122.00	121.50
T_{12}	50 % RDN through chemical fertilizer + 50 % RDN through Biogas Slurry	93.53	96.37	94.95	5.45	5.52	5.48	123.46	124.36	123.91	117.00	120.00	118.50
T_{13}	100 % RDN through chemical fertilizer + 25 % RDN through Biogas Slurry	99.29	100.15	99.72	6.09	6.13	6.11	131.36	132.04	131.70	122.00	123.00	122.50
T_{14}	100 % RDN through Biogas Slurry	93.37	94.87	94.12	4.92	5.08	5.00	121.01	122.25	121.63	114.67	116.00	115.33
	SEM	0.62	0.63	0.54	0.16	0.11	0.13	0.68	0.52	0.52	1.19	0.59	0.72
	C.D. (0.05)	1.80	1.84	1.56	0.47	0.33	0.37	1.98	1.51	1.50	3.45	1.73	2.08
	C.V. (%)	0.09	0.10	0.09	0.36	0.25	0.28	0.92	0.70	0.05	1.73	0.86	0.07

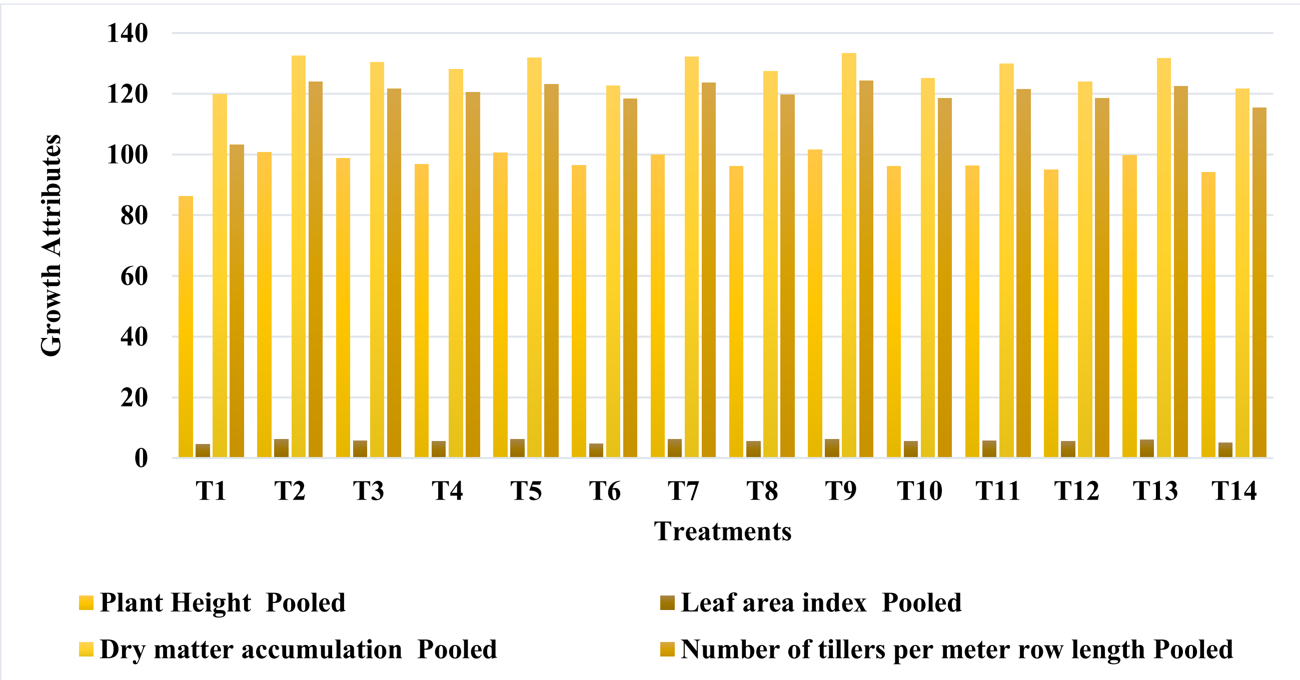

Fig.1: Effect of inorganic nutrient sources and organic manures on growth attributes of wheat

Yield Attributes

The analysis of yield attributes across different treatments reveals significant variations under the integrated nutrient management strategies show in table 2 and figure 2. The highest grain yield, straw yield, biological and harvest index were observed in treatment T_9 - (100% RDN through chemical fertilizer + 25% RDN through poultry manure) with 58.33 q ha^{-1}, 74.53 q ha^{-1}, 130.90 q ha^{-1} and0.45 % in 2023 and 59.30 q ha^{-1}, 73.97 q ha^{-1}, 131.70 q ha^{-1} and 0.45 % in 2024. Because of this, the findings suggest that T_9 resulted in the highest grain yield, straw yield, biological yield and harvest index of wheat. This is due to the balanced nutrient supply from both inorganic and organic sources, which enhanced soil fertility and nutrient availability. The organic manure improved soil structure and microbial activity, while the RDF provided essential nutrients, promoting overall plant growth, increased photosynthetic efficiency, and optimal yield formation. This synergistic approach effectively boosted both the quantity and quality of wheat production. The lowest number of spikes was recorded in the treatment T_1 - control (no nutrient source) in all the yield attributes parameters.

Table 2: Effect of inorganic nutrient sources and organic manures on yield of wheat

Treatments		Grain yield (q ha^{-1})			Straw yield (q ha^{-1})			Biological yield (q ha^{-1})			Harvest Index (%)		
		2023	2024	Pooled	2024	Pooled	Pooled	2023	2024	Pooled	2023	2024	Pooled
T_1	Control (No nutrient sources)	44.47	47.43	45.95	59.33	63.00	61.17	103.80	110.43	107.12	0.43	0.43	0.43
T_2	100 % RDN (125 kg ha^{-1}) from fertilizers	55.90	57.10	56.50	72.21	72.33	72.27	128.11	128.77	128.44	0.44	0.44	0.44
T_3	75 % RDN (93.75 kg ha^{-1}) through fertilizer + 25% RDN through farm yard manure (FYM) (6 tons ha^{-1})	53.33	55.47	54.40	70.90	70.87	70.88	124.23	126.33	125.28	0.43	0.44	0.43
T_4	50 % RDN (62.5 kg ha^{-1}) through fertilizer + 50 % RDN through FYM (12 tons ha^{-1})	52.50	53.60	53.05	68.84	70.40	69.62	121.34	124.00	122.67	0.43	0.43	0.43
T_5	100 % RDN through fertilizer + 25 % RDN through FYM (6 tons ha^{-1})	55.80	56.80	56.30	71.96	71.39	71.67	127.76	128.19	127.97	0.44	0.44	0.44
T_6	100 % RDN through FYM (24 tons ha^{-1})	51.79	50.83	51.31	66.46	67.52	66.99	118.25	118.36	118.30	0.44	0.43	0.43
T_7	75 % RDN through fertilizer + 25% RDN through poultry manure (PM) (1.2 tons ha^{-1})	55.73	56.73	56.23	72.00	71.48	71.74	127.73	128.21	127.97	0.44	0.44	0.44
T_8	50 % RDN through fertilizer + 50 % RDN through PM (2.4 tons ha^{-1})	52.33	54.43	53.38	69.78	70.37	70.07	122.11	124.80	123.46	0.43	0.44	0.43
T_9	100 % RDN through fertilizer through PM + 25 % RDN through PM (1.2 tons ha^{-1})	58.33	59.30	58.82	74.53	73.97	74.25	130.90	131.70	131.30	0.45	0.45	0.45
T_{10}	100 % RDN through PM (4.8 tons ha^{-1})	51.83	52.17	52.00	66.95	68.02	67.48	118.78	120.18	119.48	0.44	0.43	0.44
T_{11}	75 % RDN through fertilizer + 25% RDN through Biogas Slurry (3.75 tons ha^{-1})	51.33	53.80	52.57	70.80	70.81	70.81	122.13	124.61	123.37	0.42	0.43	0.43
T_{12}	50 % RDN through fertilizer + 50 % RDN through Biogas Slurry (7.5 tons ha^{-1})	50.07	49.97	50.02	63.00	67.74	65.37	113.07	117.71	115.39	0.44	0.42	0.43
T_{13}	100 % RDN through fertilizer + 25 % RDN through Biogas Slurry (3.75 tons ha^{-1})	54.80	56.23	55.52	71.32	71.09	71.21	126.12	127.33	126.72	0.43	0.44	0.44
T_{14}	100 % RDN through Biogas Slurry (15 tons ha^{-1})	49.90	52.73	51.32	66.35	67.77	67.06	116.25	120.50	118.37	0.43	0.44	0.43
	SEm ±	0.80	1.27	0.83	0.78	0.64	0.55	1.19	1.09	1.11	0.00	0.01	0.00
	CD at 5%	2.32	3.68	2.41	2.45	1.86	1.60	3.47	3.17	3.26	0.01	0.02	0.01
	C.V. (%)	2.62	4.06	0.19	2.12	1.58	0.10	1.70	1.55	0.11	1.73	2.62	0.11

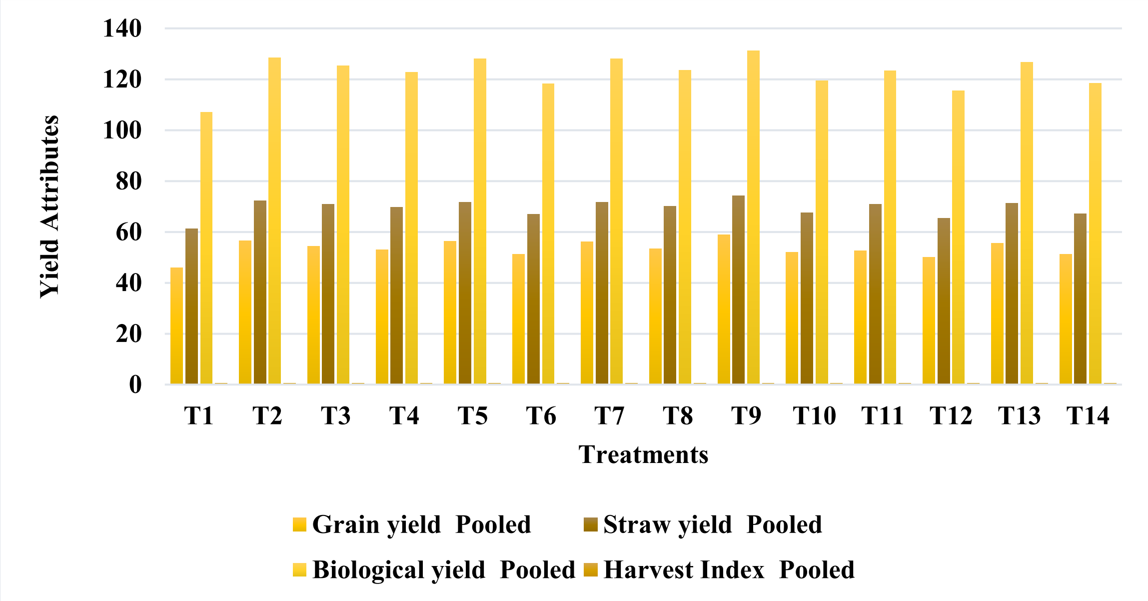

Fig.2: Effect of inorganic nutrient sources and organic manures on yield attributes of wheat

Quality parameter

The protein content significantly higher recorded in T_9 - (100 % RDN through fertilizers + 25% RDN through poultry manure) with 12.18 % during both the years present in table 3 and figure 3 which was statistically at par with T_2 – (100 % RDF (125 kg ha^{-1}) from fertilizers) (12.07 %), T_5 – (100 % RDN through fertilizer + 25 % RDN through FYM) (12.03 %), T_7 - (75% RDN through fertilizer + 25% RDN through poultry manure) (12.05 %) and T_{13} - (100% RDN through fertilizer + 25% RDN through biogas slurry) (12.03 %) during year 2023 and 2024. Due to this, Organic manures contribute to sustainable agriculture by enhancing nutrient uptake, improving soil microbial activity, and reducing dependence on synthetic fertilizers while maintaining superior crop quality.

Table 3: Effect of inorganic nutrient sources and organic manures on quality parameter of wheat

Treatments		2023	2024	Pooled
T1	Control (No nutrient sources)	10.77	10.65	10.71
T2	100 % RDN (125 kg ha-1) from fertilizers	12.04	12.10	12.07
T3	75 % RDN (93.75 kg ha-1) through fertilizer + 25% RDN through farm yard manure (FYM) (6 tons ha-1)	11.83	11.90	11.86
T4	50 % RDN (62.5 kg ha-1) through fertilizer + 50 % RDN through FYM (12 tons ha-1)	11.71	11.83	11.77
T5	100 % RDN through fertilizer + 25 % RDN through FYM (6 tons ha-1)	12.00	12.06	12.03
T6	100 % RDN through FYM (24 tons ha-1)	11.63	11.73	11.68
T7	75 % RDN through fertilizer + 25% RDN through poultry manure (PM) (1.2 tons ha-1)	12.06	12.04	12.05
T8	50 % RDN through fertilizer + 50 % RDN through PM (2.4 tons ha-1)	11.58	11.58	11.58
T9	100 % RDN through fertilizer through PM + 25 % RDN through PM (1.2 tons ha-1)	12.15	12.21	12.18
T10	100 % RDN through PM (4.8 tons ha-1)	11.52	11.60	11.56
T11	75 % RDN through fertilizer + 25% RDN through Biogas Slurry (3.75 tons ha-1)	11.63	11.69	11.66

T12	50 % RDN through fertilizer + 50 % RDN through Biogas Slurry (7.5 tons ha-1)	11.54	11.60	11.57
T13	100 % RDN through fertilizer + 25 % RDN through Biogas Slurry (3.75 tons ha-1)	12.02	12.04	12.03
T14	100 % RDN through Biogas Slurry (15 tons ha-1)	11.46	11.52	11.49
	SEm ±	0.09	0.09	0.08
	CD at 5%	0.26	0.27	0.24
	C.V. (%)	1.31	1.36	0.09

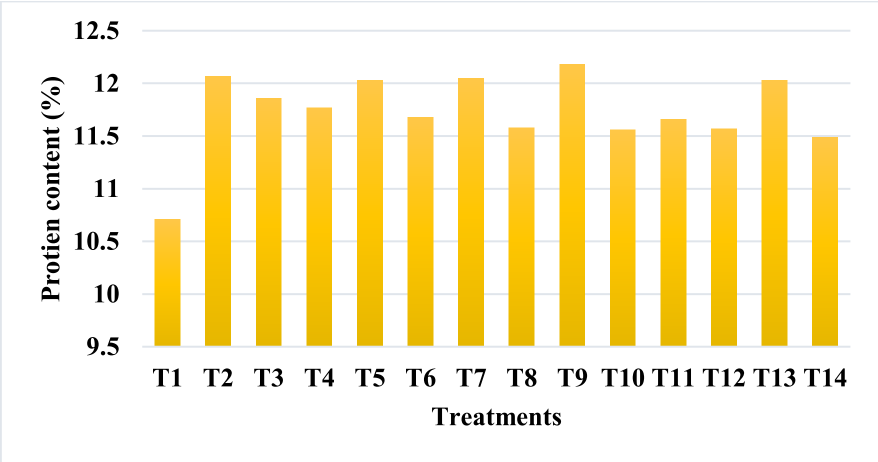

Fig.3: Effect of inorganic nutrient sources and organic manures on quality parameter of wheat

IV. CONCLUSION

Based on present study it was concluded that the combination of RDF and organic amendments helps to improve the growth and yield attributes of wheat which plays important role in the sustainable agriculture. Moreover, the significant improvement in growth parameters viz. plant height, leaf area index, dry matter accumulation and number of tillers per meter row length and yield parameters such as grain yield, straw yield, biological yield and harvest index were also recorded under T_9 (100% RDN through chemical fertilizer + 25% RDN through poultry manure) as compared to other treatments. Moreover, similar results were found under protein content in wheat which was maximum in T_9. The treatment T_1 Control (no nutrient source) recorded minimum results under all the growth and yield attributes of wheat in both the years.

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The Projection of Rainfall and the Effect on Rice (*Oryza sativa* L.) Productivity until 2045 Based on the *Representative Concentration Pathways* (RCP) Scenario

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***Abstract*— *Rainfall is one of the factors that causes a decrease in rice productivity. The study of rainfall and productivity projections in East Java province is important because it is one of the provinces that contributes the most to rice production in Indonesia. The research aims to study the projection of rainfall and rice productivity until 2045 using the Global Climate Model in the RCP 2.6 and RCP 8.5 scenarios in Malang and Banyuwangi regencies. The study was conducted by examining rainfall variability and its effect on rice productivity in Malang and Banyuwangi regencies in April–May 2024 using BMKG and NASA MERRA-2 rainfall data for 1993–2022, rice productivity for 2003–2022 in Malang and Banyuwangi regencies, and the global climate model until 2045 using the linear scaling method. The results showed that the MOHC-HadGEM2-ES model has a fairly good accuracy in projecting rainfall. Rainfall projections in RCP 2.6 and 8.5 scenarios show changes in rainfall patterns and intensity, with peak rainfall in April-June, where Malang and Banyuwangi regencies have monsoonal rainfall types; in those months the rainy season should have decreased or entered the dry season. The projection of rice productivity until 2045 in the RCP 2.6 scenario shows an increase in productivity in 2045 in Malang and Banyuwangi regencies of 8.02 tons ha^{-1} and 6.87 tons ha^{-1}. The RCP 8.5 scenario shows a decrease in productivity in 2045 in Malang and Banyuwangi regencies of 7.83 tons ha^{-1} and 6.85 tons ha^{-1}.*

***Keywords*— Climate Projection, Rice Productivity, RCP**

I. INTRODUCTION

Rice (*Oryza sativa* L.) play an important role in the economy and national food security and as a main commodity for the Indonesian population. Nationally, the need for the provision of rice consumption in Indonesia always increases every year, in line with the increase in population, so it must be balanced with increased production. National rice production in 2003-2010 increased every year but decreased in 2018 and fluctuated until 2022. In 2018, there was a decrease in production of 21.95 million tons or 27.05% compared to 2017 with a production of 81.15 million tons and a productivity of 5.20 tons ha^{-1}. National data on the highest average rice production in 2017-2022 was in East Java province, which was 17.4% (Kementerian Pertanian Republik Indonesia, 2023).

East Java province as one of the highest rice producing centers in Indonesia. Malang and Banyuwangi regencies as the highest rice producing areas. Rice productivity in Malang regency over the past 20 years has fluctuated with the highest productivity in 2013, which was 7.08 tons ha^{-1}, and experienced a decline in productivity until 2022 to 5.92 tons ha^{-1}. Rice productivity in Banyuwangi regency over the past 20 years showed the highest productivity in 2016, which was 6.61 tons ha^{-1}, and experienced a decline until 2022 to 6.02 tons ha^{-1}. Increasing rice production is a major challenge to meet the consumption needs of the Indonesian population which is increasing every year in the future will be even more difficult due to the phenomenon of climate change (Suryana et al., 2022).

Climate change has an impact on the decline in rice production and productivity due to shifts in climate variables, one of which is rainfall. Rainfall is one of the important factors in determining the high and low rice production. Excessive rainfall levels can reduce rice production due to the plants being easily attacked by pests and diseases, thus reducing the quantity of production (Mardawilis and Ritonga, 2016). However, low rainfall can also disrupt rice productivity because it causes drought on the land so that the rice plants dry out, wilt and cause crop failure (Medika et al., 2016). Annual rainfall in 2022 in Malang regency is 3,098 mm (Central Statistics Agency of Malang Regency, 2023) and Banyuwangi regency has an annual rainfall of 1,841.3 mm (Central Statistics Agency of Banyuwangi Regency, 2023). The difference in the amount of rainfall in the two regencies was taken into consideration in selecting the study area where rainfall affected rice productivity, although it had a low level of relationship of 4.43% and the remaining 95.57% was influenced by other factors (Nafisha and Suwarsito, 2018).

The year 2045 is Indonesia's golden year, where Indonesia will be 100 years old. The Ministry of Agriculture is determined to increase food security by realizing food independence and becoming the world food storage. To achieve food security, it is necessary to conduct climate projections until 2045 using a global climate model or Global Climate Model (GCM). The resolution of the GCM is relatively coarse or still on a global scale, so it is necessary to provide more regional or local information in climate change scenarios using RCM and conducting statistical downscaling modeling (Farhan et al., 2022). Statistical downscaling is a statistical model that connects global climate data variables such as GCMs with local-scale climate variables (Fernandez, 2005 *in* Sahriman *et al*., 2019)

The use of climate projections can be applied in various fields, one of which is agriculture. The application of climate change projections in the future can use the Representative Concentration Pathways (RCP) scenario which has four scenarios, namely RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Based on the problems that have been described, climate projections were carried out, one of which was on the rainfall variable and its effect on rice productivity until 2045 in the rice centers of East Java province, namely in Malang and Banyuwangi regencies using RCP scenarios on different scales, namely RCP 2.6 and RCP 8.5. The purpose of the study was to study the projection of rainfall and rice productivity until 2045 based on the RCP 2.6 and RCP 8.5 scenarios in Malang and Banyuwangi regencies so that it can predict the realization of Indonesia as the World Food Storage and food independence in 2045.

II. MATERIALS AND METHODS

The research examined rainfall variability and the effect on rice productivity in Malang and Banyuwangi regencies in April–May 2024. Malang regency is located between 112°17'10.90" to 112°57'00" E; between 7°44'55.11'' to 8°26'35.45" S and Banyuwangi regency is located at coordinates 7°45'15" to 8°43'2" S and 113°38'10" E.

The tools used were Microsoft Excel, Statistical Package for the Social Sciences (SPSS) v23, ArcMAP 10.6, Coordinated Regional Climate Downscaling Experiment (CORDEX) and NASA Prediction of Worldwide Energy Resources (NASA POWER). Materials used : BMKG and MERRA-2 NASA rainfall data for 1993–2022, rice productivity for 2003–2022 in Malang and Banyuwangi regencies, and global climate models until 2045. Data analysis was conducted by analyzing changed in monthly rainfall in historical data before and after correction; global climate model validation test; monthly rainfall projection analysis for the periods 2021–2025, 2026–2030, 2031–2035, 2036–2040 and 2041–2045; and simple linear regression analysis to project rice productivity.

Research data

1. Meteorology, Climatology, and Geophysics Agency (BMKG) Rainfall Data

Daily rainfall data for 1993–2022 from the WEB Data Online of the Meteorology, Climatology, and Geophysics Agency (BMKG) Database Center accessed via the page https://dataonline.bmkg.go.id. The station points used are presented in Table 1.

Table 1. BMKG Station Points in Malang and Banyuwangi Regencies

No	Station Name	Longitude	Latitude	Elevate (masl)
1	Climatology Clas II East Java Station	112.59	-7.90	590
2	Meteorology Banyuwangi Station	114.35	-8.21	52

2. Reanalisis MERRA-2 NASA

The Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) from The

National Aeronautics and Space Administration (NASA) data can complement the unrecorded BMKG observation rainfall data. NASA's MERRA-2 for 1993–2022 obtained from the NASA POWER WEB is accessed via the page https://power.larc.nasa.gov.

3. Global Climate Model

Global climate model comes from WEB Coordinated Regional Climate Downscaling Experiment (CORDEX) 1993–2045, accessed through the page https://esgf-data.dkrz.de. The period 1992–2005 is used as historical data, 2006–2022 is used as a baseline, and 2022–2045 as a projection model. GCM used is MOHC-HadGEM2, MPI-M-MPI-ESM-MR, and NCC-NorESM1-M. The GCM model is in net CDF (.nc) format, so it is necessary to extract it using ArcMap 10.6 by entering the coordinates of the study area (Table 1).

4. Rice Productivity

Rice productivity data for Malang and Banyuwangi regencies for 2003–2022 was obtained from the East Java Central Statistics Agency.

Data Analysis

1. Bias Correction

Bias correction is used to correct NASA's MERRA-2 data and global climate models because the data has a fairly wide coverage so that it has a fairly high bias value, therefore bias correction needs to be carried out so that it is accurate or can represent the research area to be able to complete observation data or BMKG data (Krismianto, 2015). The method used is Linear Scaling (LS). Linear scaling (LS) is the simplest bias correction method, which only corrects the average model rainfall against the average observed rainfall (Kurnia et al., 2020).

$$P_{cor,m} = P_{raw,m} x \frac{\mu(P_{obs,m})}{\mu(P_{raw,m})}$$

Information:

Pcor, m = Corrected rainfall in month m

Praw, m = Model rainfall in month m

μ(Pobs, m) = Average rainfall observed in month m

μ(Praw, m) = Model average rainfall in month m

2. Validation Test

The validation test uses Root Mean Square Error (RMSE) to determine the magnitude of the error in the Global Climate Model against BMKG observation data. The data used for the validation test is BMKG historical data with model data for 1993–2022 in the RCP 2.6 and 8.5 scenarios. The best model is the model with a smaller RMSE value or closer to 0, meaning it has more accurate prediction results or has a model value that is close to the BMKG data value (Wang and Lu, 2018).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{i=n}(Yi - Y')^2}{n}}$$

Information:

Yi = Observation rainfall

Y' = Model rainfall

n = Number of data

3. Grouping of Projected Rainfall Changes

Monthly rainfall projections are grouped into 5 periods, namely 2021–2025, 2026–2030, 2031–2035, 2036–2040, and 2041–2045. In these five periods, an analysis of changes in annual rainfall patterns and intensity will be carried out each month in Malang and Banyuwangi Regencies.

4. Projection of Rice Productivity until 2045

The projection of rice productivity until 2045 was carried out using historical observation data from BMKG by analyzing simple linear regression with the dependent variable, namely rice productivity in 2003–2022 and the independent variable, namely observation rainfall data in 2003–2022 in Malang and Banyuwangi regencies using SPSS v23 software.

$$Y = a + bX$$

Keterangan:

Y = Rice plant productivity

a = Constant value

b = Simple linear regression coefficient

x = Rainfall

(Ghozali, 2016).

III. RESULT AND DISCUSION

Completion of Empty Historical Rainfall Observation Data

Bias correction was performed to complement BMKG historical rainfall data using NASA MERRA-2 reanalysis data from 1993–2022. In Malang Regency, the highest average was in February, which was 342.32 mm month^{-1} with a difference of 12.03 mm month^{-1}, while the lowest rainfall was in August, which was 21.15 mm month^{-1} with a difference of 0.87 mm month^{-1}. The wet months were in October–April or a total of 7 wet months, while the dry months were in May–September or a total of 5 dry months (Figure 1). Meanwhile, the average monthly rainfall in Banyuwangi regency with the highest average was in January, which was 270.60 mm month^{-1} with a difference of 38.26 mm month^{-1}, while the lowest rainfall was in September, which was 41.87 mm month^{-1} with a difference of 7.45 mm month^{-1}. The wet months are November–April with 6 wet months, while the dry months are May–October with 6 dry months (Figure 2). Based on rainfall in the two study areas, Malang regency has a higher rainfall compared to Banyuwangi regency (Figures 1 and 2). This is because Malang regency has a topography surrounded by several mountains. The statement by Lesik et al. (2020) that topography and altitude are one of the factors that control the climate in tropical areas, where the higher a place is above sea level, the higher the rainfall level. In mountainous or hilly areas, winds carry water vapor vertically, causing air pressure to decrease, condensation to occur, clouds to form, and rain to fall. In addition to altitude and topography, geographical location is also a factor in rainfall levels. Geographical location is also a factor that influences rainfall patterns in Indonesia because it is close to the equator so that each region does not have the same rainfall (Oktavianingsih et al., 2018). In addition, it is influenced by Sea Surface Temperature (SST), such as the phenomenon that occurs in the Indian Ocean called the Indian Ocean Dipole (IOD), which has an impact on decreasing rainfall in the western part of Indonesia and the El Nino Southern Oscillation (ENSO) in the Pacific Ocean which consists of El Nino and La Nina. El Nino and La Nina have various impacts in Indonesia, especially the impact on monthly and seasonal rainfall. El Nino causes a decrease in rainfall in most parts of Indonesia, especially in June–August and However, several regions in Indonesia September–November by more than 40%.

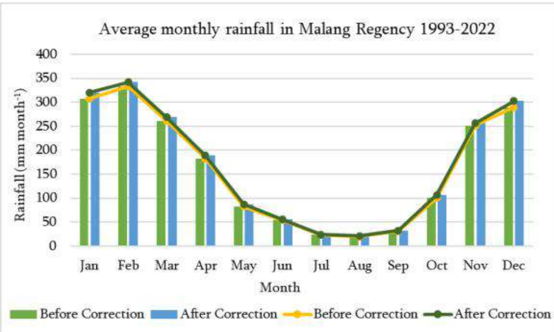

Fig.1. Average Monthly Rainfall in Malang Regency 1993–2022 Before and After Correction

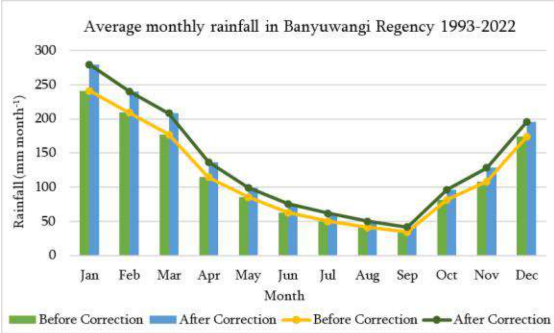

Fig.2. Average Monthly Rainfall in Banyuwangi Regency 1993–2022 Before and After Correction.

experienced increased rainfall in the December–February and March–May periods even though it was El Nino. Meanwhile, La Nina causes increased rainfall in most parts of Indonesia in June–August. The increase in rainfall during La Nina is generally around 20–40% higher compared to neutral rainfall. However, there are several areas that experienced an increase in rainfall of more than 40% (Kedeputian Bidang Klimatologi BMKG, 2020).

Climate Model Validation Test

The results of the RMSE test on the three models in the two study areas obtained the smallest RMSE values in Malang and Banyuwangi regencies in both scenarios, namely RCP 2.6 and RCP 8.5 in the Global Climate Model MOHC-HadGEM2 with values in Malang regency of 13.97 and 13.87; in Banyuwangi regency of 11.80 and 11,57 (Table 2). The MOHC-HadGEM2 model has the lowest prediction error when compared to the MPI-M-MPI-ESM-MR and NCC-NorESM1-M models. So it can be concluded that the MOHC-HadGEM2 global climate model has a prediction with a fairly good level of accuracy in projecting rainfall or has a value close to the BMKG rainfall data so that the MOHC-HadGEM2 model becomes the model that will be used in climate projections and rice productivity until 2045.

Rainfall Projection Until 2045

Rainfall projection using the Global Climate Model in 2 different scenarios, namely RCP 2.6 and RCP 8.5. Based on the results of the validation test between BMKG observation data and global climate model data, it was found that among the three climate models used, the HadGEM2-ES model is the best model when compared to other models (Table 3). The RCP 2.6 scenario is a scenario that makes very strict efforts to reduce the impact of climate change. Meanwhile, the RCP 8.5 scenario is a scenario that assumes a high increase in greenhouse gas emissions, resulting in more extreme climate change. The RCP scenarios are distinguished by differences in radiative forcing (Wm^{-2}) which is a change in the amount of energy entering and leaving the atmosphere due to climate change, such as changes in solar radiation so that this has an impact on the high and low rainfall projections (Agard et al., 2014). The change in radiative forcing in the RCP 2.6 scenario peaks in 2050 at 3 W m^{-2} and decreases to 2.6 W m^{-2} in 2100, while in the RCP 8.5 scenario the radiative forcing continues to increase until 2100, reaching a value of 8.5 W m-^{2}. This causes the rainfall projection to show an increase in rainfall intensity in line with the increase in radiative forcing (van Vuuren et al., 2011).

Rainfall projections in Malang and Banyuwangi regencies in both scenarios show fluctuating rainfall and differences in monthly rainfall distribution during 2021–2045 (Figures 3-8)

Table 2. RMSE Test Results for Projections

GCM	Study Areas	Scenario	*RMSE
MOHC-HadGEM2	Malang Regency	RCP 2.6	13.97
		RCP 8.5	13.87
	Banyuwangi Regency	RCP 2.6	11.80
		RCP 8.5	11.57
MPI-M-MPI-ESM-MR	Malang Regency	RCP 2.6	15.26
		RCP 8.5	14.94
	Banyuwangi Regency	RCP 2.6	13.32
		RCP 8.5	13.15
NCC-NorESM1-M	Malang Regency	RCP 2.6	16.38
		RCP 8.5	15.70
	Banyuwangi Regency	RCP 2.6	12.07
		RCP 8.5	12.21

*Root Mean Square Error

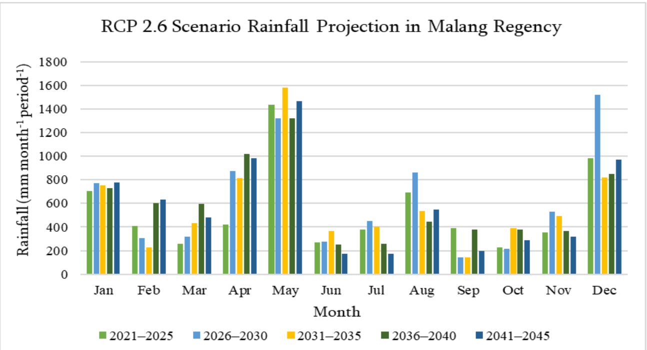

Fig.3. Monthly Rainfall Projection in Malang Regency in RCP 2.6 Scenario

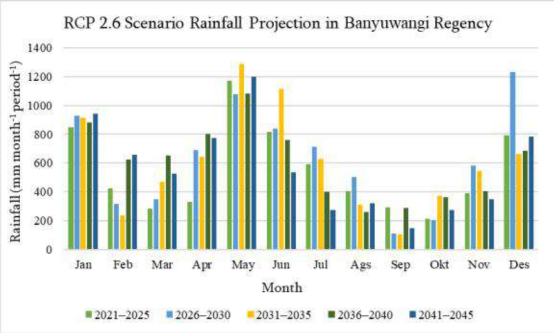

Fig.4. Monthly Rainfall Projection in Banyuwangi Regency in RCP 2.6 Scenario

The projected rainfall has the highest average in May 2031–2035, which is 1,578.42 mm month^{-1}. The lowest rainfall is in September 2031–2035, which is 142.84 mm month^{-1} (Figure 3). The rainfall pattern with peak rainfall occurs in April–May and a decrease in rainfall in the dry season occurs in June–July. The projected rainfall has the highest average for each period in May 2031–2035, which is 1,289.12 mm month^{-1} and the lowest rainfall is in September 2031–2035, which is 107.94 mm month^{-1} (Figure 4). The rainfall pattern with peak rainfall occurs in May–June and decreased rainfall in the dry season occurs in August–October.

In RCP 2.6 scenario, the rainfall projection in Malang regency shows peak rainfall in April–May and decreased rainfall in June–July. Meanwhile, in Banyuwangi regency, the peak rainfall occurs in May–June and decreased rainfall occurs in August–October. This shows that despite the increase in rainfall in some months, the RCP 2.6 projection maintains a relatively stable rainfall pattern and intensity, with peak rainfall in the early months of the rainy season and decreased rainfall during the dry season. The RCP 2.6 scenario predicts that it is likely to maintain global temperature increases of less than 2 °C by 2100 and will maintain that there is no drastic climate change. Compared to 1850–1900, global surface temperature changes by the end of the 21st century or by 2081–2100 are projected to be unlikely to exceed 2 °C or by 0.3 °C to 1.7 °C in the RCP 2.6 scenario (IPCC, 2014). The projected rainfall has the highest average for each period in May 2041–2045, which is 1,716.55 mm month^{-1}. The lowest rainfall is in June 2041–2045, which is 165.19 mm month^{-1} (Figure 5). The rainfall pattern with peak rainfall occurs in April–May and a decrease in rainfall in the dry season occurs in June–July. The projected rainfall has the highest average for each period in May 2041–2045, which is 1,500.57 mm month^{-1}. The lowest rainfall is in September 2031–2035, which is 154.16 mm month^{-1} (Figure 6). The rainfall pattern with peak rainfall occurs in

May–June and a decrease in rainfall in the dry season occurs in August–October.

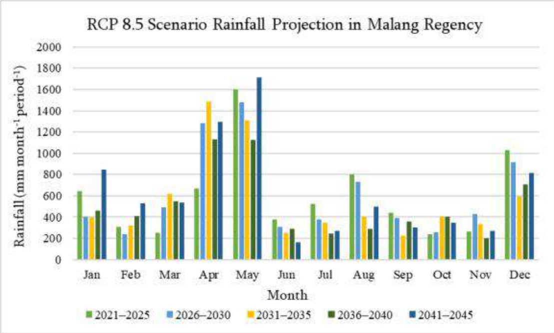

Fig.5. Monthly Rainfall Projection in Malang Regency in RCP 8.5 Scenario

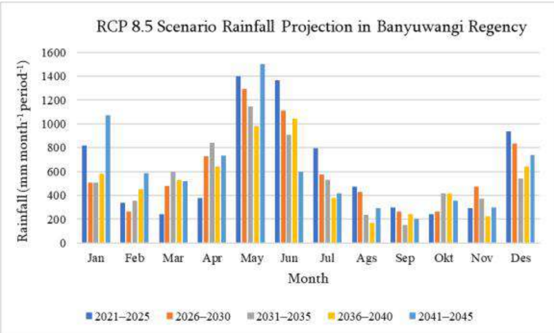

Fig.6. Monthly Rainfall Projection in Banyuwangi Regency in RCP 8.5 Scenario

Meeting the water needs of aquatic plants is very important for the growth and development of rice plants because rice plants are highly dependent on water availability, especially during their growth phase, where the more water is available during the growth phase, the better the growth and production of rice (Rusmawan et al., 2018). The water requirement of rice plants during planting requires water of around 60-70 mm of *dasarian*$^{-1}$ or at least 4 wet months with rainfall above 200 mm month^{-1} consecutively or as much as 1,500-2,000 mm year^{-1}. The water requirement is quite large when the rice plants are in the vegetative phase until the rice grain filling phase and 15-20 days before harvest the rice plants no longer need water (Indratmoko et al., 2017). Rice plants will have a higher productivity value if rainfall in the vegetative phase is higher than in the generative phase because it is to meet the water requirement of rice plants in the vegetative phase of 200-372 mm month^{-1} (Mardawilis and Ritonga, 2016).

Projection of Rice Productivity until 2045

The projection of rice productivity until 2045 was carried out by analyzing simple linear regression to obtain a regression equation, knowing the effect of historical data from BMKG in 2003–2022 as an independent variable on rice productivity data in 2003–2022 as a dependent variable in Malang and Banyuwangi regencies, the equation obtained was $Y = 5.558 + 0.000279x$ in Malang regency and $Y = 5.817 + 0.000126x$ in Banyuwangi regency. The results of the equation obtained were used for the projection of rice productivity until 2045 in Malang and Banyuwangi regencies (Figures 7-8). The results of the projections that have been carried out in both regions, in the RCP 2.6 scenario projected an increase in productivity of 18.58% or rice productivity of 8.02 tons ha^{-1} and the RCP 8.5 scenario projected a decrease in rice plant productivity of 3.75% productivity of 7.83 tons ha^{-1} in Malang regency (Figure 7). In Banyuwangi regency, the RCP 2.6 scenario projected an increase in productivity of 8.67% or productivity of 6.87 tons ha^{-1} and the RCP 8.5 scenario projected a decrease in rice productivity of 0.80% or productivity of 6.85 tons ha^{-1} in Banyuwangi regency in 2045 (Figure 8). The results of the projection of rice productivity until 2045 in Malang and Banyuwangi regencies were only based on 1 aspect, namely rainfall. Rainfall can affect rice productivity even though it has a low relationship level of 4.43% and the remaining 95.57% is influenced by other factors (Nafisha and Suwarsito, 2018).

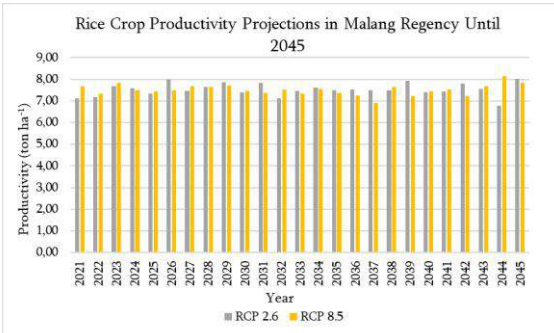

Fig.7. Projection of Rice Productivity in Malang Regency until 2045

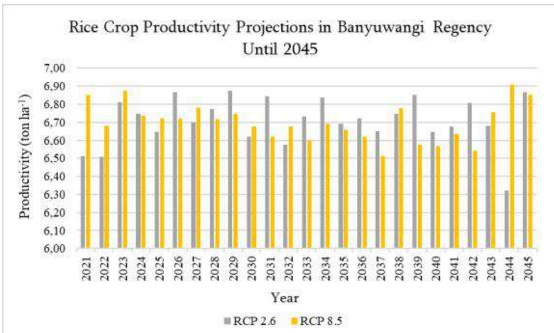

Fig.8. Projection of Rice Productivity in Banyuwangi Regency until 2045

Based on the projections that have been made, it indicates that there is an opportunity for rice productivity in Malang and Banyuwangi regencies in 2045 to exceed the target estimated by the government of the Republic of Indonesia, President Joko Widodo has set a target to make Indonesia the "World Food Storage" in 2045. For this reason, the Minister of Agriculture Dr. Andi Amran Sulaiman has set a self-sufficiency target for several commodities, including rice plants. Towards Indonesia as the World Food Storage, rice production in 2045 is targeted at 100.03 million tons or equivalent to 61.06 million tons of rice with a planting area of 17.83 million ha and a productivity of 5.90 tons ha^{-1}. The achievement of the production target is expected to make Indonesia control 20% of the world's rice market share by 2045 (Sulaiman et al., 2018).

The impact of global climate change in Indonesia, especially on rice production, has been felt and has become a reality. The phenomenon of climate change has triggered an increase in the intensity of extreme events, such as floods and droughts, which cause crop failure and even puso, resulting in a decrease in crop production and productivity, which has the potential to threaten food security (Keputusan Menteri Pertanian Republik Indonesia, 2021). Climate change causes changes in the natural hydrological cycle, which results in natural disasters such as La Nina or an increase in the intensity of rainfall and flooding, and El Nino which can trigger prolonged droughts, causing drought. In the agricultural sector, the impact of climate change can shift planting patterns and times and cause pest and disease outbreaks (Sujarwo, 2023).

Mitigation and adaptation strategies in the agricultural sector related to climate change, especially the variability of rainfall that occurs, are needed to maintain agricultural productivity. Given the uncertain climate conditions, adaptation patterns can no longer be carried out by relying on seasonal patterns as before (Yulianto and Sudibyakto, 2012). Mitigation and adaptation to climate change contained in the Regulation of the Minister of Agriculture of the Republic of Indonesia in 2018 concerning the Early Warning System and Handling of the Impact of Climate Change on the Agricultural Sector Article 10, such as can apply water harvesting technology, such as utilizing reservoirs and long storage to collect rainwater that can be used in the dry season and implementing Integrated Pest Control to minimize rice plants being attacked by pests and diseases in the rainy season.

IV. CONCLUSION

1. Rainfall projections until 2045 in the two study areas of Malang and Banyuwangi regencies, in the RCP 2.6 scenario, show an increase in rainfall in several months but still maintain a relatively stable rainfall pattern and intensity, with peak rainfall in the early months of the rainy season and decreased rainfall during the dry season. Meanwhile, the RCP 8.5 scenario shows more extreme rainfall variations and greater fluctuations between wet and dry months, indicating a drier dry season and a wetter rainy season in the future.
2. Projections of rice productivity until 2045, in the RCP 2.6 scenario, show an increase in rice crop productivity in 2045, while the RCP 8.5 scenario shows a decrease in rice crop productivity in 2045 in Malang and Banyuwangi regencies. Despite the decline, the projected results of rice crop productivity obtained in Malang and Banyuwangi regencies, namely 7.83 tons ha^{-1} and 6.85 tons ha^{-1} or still exceeding the target estimated by the Republic of Indonesia government of 5.90 tons ha^{-1}

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Effect of Organic Manures and Inorganic Sources of Phosphorus on Soil Properties and Productivity of Black Gram (*Vigna mungo* L.)

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***Abstract*— *The present investigation entitled "Effect of Organic Manures and Inorganic Sources of Phosphorus on Soil Properties and Productivity of Black Gram (Vigna mungo L.)" was conducted at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, during the Kharif season of 2024. The study aimed to evaluate the effect of different organic manures and phosphorus sources on the growth, yield, and soil properties of black gram. The experiment comprised 16 treatment combinations with four levels of organic manures (FYM @ 5 t ha^{-1}, vermicompost @ 2.5 t ha^{-1}, FYM 5 t ha^{-1} + vermicompost 2.5 t ha^{-1}, and control) and four levels of phosphorus sources (100% RDP through SSP, 50% RDP through rock phosphate, 50% RDP through SSP + 50% RDP through rock phosphate, and control), arranged in a factorial randomized block design with three replications. Results revealed that the combined application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly enhanced growth and yield attributes, seed, haulm, and biological yield as well as soil organic carbon, water-holding capacity, available macronutrients, compared to other treatments. Soil pH and bulk density were significantly reduced under this treatment. Among phosphorus treatments, the application of 50% RDP through SSP + 50% RDP through rock phosphate recorded significantly higher yield attributes, yield, nutrient uptake, and soil biological activities.*

Keywords*— Black gram, FYM, Vermicompost, Rock phosphate, Single super phosphate, Soil properties, Yield

I. INTRODUCTION

The term "pulse" originates from the Latin word *puls* or *pultis*, meaning "thick soup." Belonging to the legume family (*Fabaceae*), pulses comprise more than 1,800 distinct species and form an integral part of sustainable agriculture due to their ability to fix atmospheric nitrogen and enrich soil fertility. India occupies a leading position globally in both the area and production of pulses, particularly during the Kharif and summer seasons. Pulses are cultivated on about 30.37 million hectares with an average productivity of 888 kg ha^{-1} (Annual Report, 2020-21, Department of Agriculture & Farmers' Welfare). Black gram (*Vigna mungo* L.), commonly known as urdbean, is one of the most important pulse crops grown throughout India. It is valued for its high nutritional content and ability to improve soil health through biological nitrogen fixation. It is a rich source of easily digestible protein (25-28%), oil (1.0-1.5%), fiber (3.5-4.5%), ash (4.5-5.5%), and carbohydrates (62-65%) on a dry-weight basis. Its high lysine content makes it a perfect complement to rice-based diets for balanced human nutrition (Sharma *et al.,* 2011).

In India, black gram is cultivated on about 41.4 lakh hectares with a total production of 22.3 lakh tonnes and productivity of 538 kg ha^{-1} (IIPR, 2020-21). In Rajasthan, it ranks third after chickpea and mung bean, occupying 4.11 lakh hectares with production of 160.37 thousand tonnes and productivity of 390 kg ha^{-1} (IIPR, 2020-21). The major black gram-producing districts in Rajasthan include Ajmer, Tonk, Jhalawar, Banswara, Kota, and Udaipur. Despite its importance, the productivity of black gram remains low, primarily because it is grown under rainfed conditions with limited use of fertilizers and improved technologies. Low fertilizer use offers an opportunity to promote organic manures for better yield and soil health improvement (Singh *et al.,* 2015).

Organic agriculture is globally recognized for improving crop productivity and quality while maintaining environmental sustainability. It emphasizes the use of renewable organic resources such as farmyard manure (FYM), compost, and vermicompost. Presently, organic farming is practiced in over 190 countries, covering 74.9 million hectares with a market value exceeding US$120 billion. In India, about 4.33 million hectares are under organic cultivation, producing 3.49 million metric tonnes of certified organic produce (APEDA, 2021).

Among various organic amendments, vermicompost has emerged as an efficient nutrient source for sustainable crop production. It enhances soil structure, nutrient availability, microbial activity, and enzymatic functions (Das *et al.,* 2019). The bio-oxidative process of vermicomposting involves earthworms and microorganisms that accelerate organic matter decomposition, improving humus formation and nutrient solubility (Thakur *et al.,* 2021).

Phosphorus (P) is one of the major macronutrients essential for plant growth and metabolic functions such as energy transfer, root development, and photosynthesis. Its deficiency results in stunted growth and dark green leaves (Ghosh *et al.,* 2022). However, the availability of P in Indian soils is often limited due to fixation, especially in calcareous soils. Combining organic manures with inorganic phosphorus sources like single super phosphate (SSP) and rock phosphate enhances phosphorus use efficiency, soil microbial activity, and overall productivity.

II. MATERIALS AND METHODS

The present investigation was carried out during *Kharif*, 2024 at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The experimental site is located in the south-eastern region of Rajasthan, at an elevation of 581.13 meters above mean sea level, situated at latitude 24° 34′ 52.93″ N and longitude 73° 42′ 14.4″ E. The area falls within Agro-Climatic Zone IVA, classified as the Sub-Humid Southern Plain and Aravalli Hills of Rajasthan. The region experiences typical subtropical weather with moderate summer temperature and mild winters. The rainfall occurs with south-west monsoon with 698.3 mm mm of yearly average annual precipitation. The experimental soil was clay loam in texture. The 16 treatments combination which was carried out in factorial randomized block design are existing in table 1. The variety MU-2 was used for the experiment. The crop was sown on 7th July, 2024 with seed rate of 20kg and harvested on September 25, 2024. The critical difference for the comparison of treatments was worked out, wherever, the 'F' test was found significant at 5 per cent level of significance.

Table 1: Treatment details

Treatment	**:**	**Description**
Organic Manure		
O_0	:	Control
O_1	:	FYM @ 5 t ha^{-1}
O_2	:	Vermicompost @ 2.5 t ha^{-1}
O_3	:	FYM @ 5 t ha^{-1}+ vermicompost @ 2.5 t ha^{-1}
Inorganic sources of Phosphorus		
I_o	:	Control
I_1	:	100% RDP through SSP
I_2	:	100% RDP through Rock Phosphate
I_3	:	50% RDP through SSP + 50% RDP through Rock Phosphate

III. RESULTS

Plant height at 45 DAS and harvest

A perusal of data in (Table 2) showed that application of organic manures significantly increased the plant height at 45 DAS and harvest of black gram during experimentation. Maximum plant height at 45 DAS and harvest (21.36 cm and 35.31 cm, respectively) of black gram was recorded with application of treatment O_3 (FYM @ 5 t ha^{-1}+ vermicompost @ 2.5 t ha^{-1}). It was found significantly superior over FYM @ 5 t ha^{-1} (O_1), Vermicompost @ 2.5 t ha^{-1} (O_2) and control (O_0). Further showed that application of vermicompost 2.5 t ha^{-1} and FYM @ 5 t ha^{-1} observed significantly higher plant height over control.

Table 2: Effect of organic manures and phosphorus level on plant height at 45 DAS and harvest and no. of nodules at 40 DAS of black gram

Treatments	Plant height 45 (cm)	Plant height harvest (cm)	No. of nodules at 40 DAS
O_0	16.20	24.57	17.10
O_1	17.14	28.31	19.70
O_2	18.12	31.21	20.69
O_3	21.36	35.31	25.71
SEm±	0.34	0.60	0.46
CD (0.05)	0.98	1.72	1.33
I_0	14.81	24.27	16.89
I_1	19.28	31.60	22.01
I_2	18.20	29.85	20.79
I_3	20.53	33.68	23.50
SEm±	0.34	0.60	0.46
CD (0.05)	0.98	1.72	1.33

A critical examination of data in (Table 2) revealed that different source of phosphorus fertilizers significantly varied the plant height of black gram during investigation. Plant height (20.53 and 33.68 cm at 45 DAS and harvest, respectively) was significantly higher with application of 100% RDF.

Number of nodules at 40 DAS

A perusal of data in (Table 2) showed that application of organic manures significantly increased the number of nodules at 40 DAS of black gram during experimentation. Highest number of nodules at 40 DAS (25.71) of black gram was recorded with application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1}. It was found significantly superior over control. Further showed that application of vermicompost 2.5 t ha^{-1} (O_2) and FYM @ 5 t ha^{-1} (O_1) observed significantly higher number of nodules at 40 DAS (20.69 and 19.70, respectively) over control. The increase in number of nodules at 40 DAS due to application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} was to the magnitude of 50.35 per cent over control.

A critical examination of data in (Table 2) revealed that different source of phosphorus fertilizers significantly varied the number of nodules at 40 DAS of black gram during investigation. Number of nodules at 40 DAS of black gram (23.50) was significantly higher with application of 50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate. The per cent improvement in number of nodules at 40 DAS due to application of 50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate was 39.13 % compared to application of 100 % RDP through Single Super Phosphate, 100 % RDP through Rock Phosphate and control.

Seed yield (kg ha^{-1})

An examination of data in (Table 3) indicated that application of organic manures was significant influenced on seed yield of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly increased the seed yield (1035.1 kg ha^{-1}) of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) and vermicompost 2.5 t ha^{-1} (O_2) during the experimental years reported 768.3 kg ha^{-1} and 849.9 kg ha^{-1}, respectively both the treatments.

Table 3: Effect of organic manures and phosphorus level on seed yield (kg ha^{-1}), haulm yield (kg ha^{-1}) and Harvest index (%) of black gram

Treatments	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	HI (%)
O_0	666.98	1027.12	39.57
O_1	768.36	1250.90	38.12
O_2	849.96	1368.56	38.31
O_3	1035.10	1528.69	40.50
SEm±	16.19	19.62	0.44
CD (0.05)	46.76	56.66	NS
I_0	695.34	1047.33	40.00
I_1	889.21	1383.58	39.08
I_2	830.44	1288.48	39.16
I_3	905.40	1455.88	38.27
SEm±	16.19	19.62	0.44
CD (0.05)	46.76	56.66	NS

Among sources of phosphorus, source O_3 that was 50% RDP through SSP + 50% RDP through RP produced significantly highest seed yield (905.4 kg ha^{-1}) over the other sources. While minimum seed yield was reported in control (695.3 kg ha^{-1}). Remaining source (I_1) 100% RDP through Single Super Phosphate and (T_2) 100% RDP through Rock Phosphate produced 889.2 kg ha^{-1} and 830.4 kg ha^{-1} respectively.

Haulm yield (kg ha^{-1})

An examination of data in (Table 3) indicated that application of vermicompost and FYM in different combinations was significant influenced on haulm yield of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly increased the haulm yield (1528.6 kg ha^{-1}) of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) and vermicompost 2.5 t ha^{-1} (O_2) during the experimental years reported 1250.9 kg ha^{-1} and 1368.6 kg ha^{-1}, respectively in both the treatments.

Among different sources of phosphorus, 50% RDP through SSP + 50% RDP through RP (1455.8 kg ha^{-1}) produced significantly highest haulm yield over the other sources. While minimum haulm yield was reported in control (1047.3 kg ha^{-1}). Remaining source (I_1) 100% RDP through Single Super Phosphate and (I_2) 100% RDP through Rock Phosphate produced 1383.5 and 1288.4 kg ha^{-1} respectively.

Harvest Index (%)

The data regarding harvest index presented in (Table 3) that application of different organic manures have non significantly effect on harvest index of black gram. The range for harvest index with respect organic manure treatments were 38.12 to 40.50 %.

The data regarding harvest index presented in Table 3. Among different sources of phosphorus, treatment I_0 (control) recorded highest harvest index (40.00 %) which was non significantly higher than other treatments. The range for harvest index with respect inorganic phosphorus source was 38.27 to 40.0 %.

Interactive effect of organic manures and phosphorus sources on seed yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) of black gram

An appraisal of data in (Table 4) showed that seed yield and haulm of black gram was influenced due to interactive effect of organic manures and phosphorus sources (% RDP). The significantly maximum seed yield (1198.6 kg ha^{-1}) and haulm yield (1849.8 kg ha^{-1}) of black gram was recorded in application of FYM @ 5 t ha^{-1}+ vermicompost @ 2.5 t ha^{-1} with 50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate as compared to rest of treatments.

Table 4: Interaction effect of organic manures and phosphorus sources on seed yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) of black gram

Treatments	Seed yield (kg ha^{-1})				Haulm yield (kg ha^{-1})			
	I_0	I_1	I_2	I_3	I_0	I_1	I_2	I_3
O_0	573.6	748.7	667.18	678.3	829.6	1182.7	1012.6	1083.3
O_1	662.8	810.5	762.0	837.9	1046.0	1303.2	1240.0	1414.2
O_2	732.2	907.2	853.8	906.6	1170.3	1449.2	1378.6	1475.9
O_3	812.6	1090.3	1038.6	1198.6	1143.2	1599.1	1522.4	1849.8
SEm±	32.38				39.24			
CD (0.05)	93.51				113.33			

Bulk density (Mg m^{-3})

An examination of data in (Table 5) indicated that application of vermicompost and FYM in different combinations was significant influenced on bulk density of soil after harvesting of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly reduce the bulk density of soil (1.27 Mg m^{-3}) after harvesting of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) during the experimental years reported 1.30 Mg m^{-3}, while treatment vermicompost 2.5 t ha^{-1} (O_2) was reported 1.34 Mg m^{-3}. Data further, showed that the range for bulk density with respect organic manure treatments were 1.27 to 1.36 Mg m^{-3}. Maximum bulk density was reported in Control (1.36 Mg m^{-3}).

The data regarding bulk density presented in (Table 5) Among different phosphorus source combination reported that effect of phosphorus sources on bulk density of soil after harvesting of black gram having non significant effect. The range for bulk density with respect inorganic fertilizer treatments were 1.31 to 1.32 Mg m^{-3}.

Particle density (Mg m^{-3})

The data regarding particle density presented in (Table 5) Among different organic manures combination reported that effect of organic manures on particle density of soil after harvesting of black gram having non significant effect. The range for particle density with respect organic manures treatments were 2.63 to 2.64 Mg m^{-3}.

The data regarding particle density presented in (Table 5) Among different phosphorus source combination reported that effect of phosphorus sources on particle density of soil after harvesting of black gram having non significant effect. The range for particle density with respect inorganic fertilizer treatments were 2.63 to 2.64 Mg m^{-3}.

Water holding capacity (%)

An examination of data in (Table 5) indicated that application of organic manures have significant influenced on WHC of soil after harvesting of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly increase the WHC of soil (44.85 %) after harvesting of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) during the experimental years reported 44.14%, while treatment vermicompost 2.5 t ha^{-1} (O_2) was reported 42.78%. Minimum WHC was reported in Control (42.15%).

The data regarding WHC presented in (Table 5) Among different source of phosphorus, treatment I_3 (50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate) recorded highest WHC (43.68%) which was non significantly higher than other treatments. The range for WHC with respect inorganic fertilizer treatments were 43.34 to 43.68 %.

Soil pH

An examination of data in (Table 5) indicated that application of organic manures have significant influenced on pH of soil after harvesting of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly reduce the pH of soil (7.46) after harvesting of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) during the experimental years reported 7.59 while treatment vermicompost 2.5 t ha^{-1} (O_2) was reported 7.84. Maximum pH was reported in Control (7.97).

The data regarding soil pH presented in (Table 5) among different source of phosphorus, treatment I_3 (50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate) recorded lowest pH value of soil (7.67). Phosphorus source having non significantly effect on soil pH value. The range for pH of soil with respect inorganic fertilizer treatments were 7.67 to 7.75.

EC (dS m^{-1})

The data regarding EC presented in (Table 5) Among different organic manures combination, treatment O_3 (FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1}) recorded highest EC (0.67 dS m^{-1}) which was non significantly higher than other treatments. The range for EC with respect organic manure treatments were 0.61 to 0.67 dS m^{-1}.

An examination of data in (Table 5) indicated that application of phosphorus through different source have significant influenced on EC of soil after harvesting of black gram. Application of I_3 (50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate) significantly increase the EC of soil (0.71 dS m^{-1}) after harvesting of black gram over remaining treatment. Application of 100% RDP through Single Super Phosphate (I_1) during the experimental years reported 0.61 dS m^{-1}, while treatment 100% RDP through Rock Phosphate (I_2) was reported 0.67 dS m^{-1} which was at par with treatment I_3.

Organic carbon (%)

An examination of data in (Table 5) indicated that application of organic manures have significant influenced on OC of soil after harvesting of black gram. Application of FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} significantly increase the OC of soil (0.55 %) after harvesting of black gram over remaining treatment. Application of FYM @ 5 t ha^{-1} (O_1) during the experimental years reported 0.62%, while treatment vermicompost 2.5 t ha^{-1} (O_2) was reported 0.65% which was at par with treatment O_3.

The data regarding soil organic carbon presented in (Table 5) among different source of phosphorus, treatment I_3 (50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate) recorded highest organic carbon of soil (0.54%). Phosphorus source having non significantly effect on soil organic carbon.

Available N, P, K (kg ha^{-1})

A perusal of data in (Table 6) showed that application of organic manures significantly increased the available nitrogen, phosphorus and potassium content of soil after harvesting of black gram during experimentation. Maximum available nitrogen, phosphorus and potassium content of soil (215.8 kg ha^{-1}, 22.16 kg ha^{-1} and 335.7 kg ha^{-1}, respectively) after harvesting of black gram was recorded with application of treatment O_3 (FYM @ 5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1}). It was found at par with Vermicompost @ 2.5 t ha^{-1} (O_2). The increase in available nitrogen, phosphorus and potassium content of soil due to application of FYM @ 5 t ha^{-1}+ vermicompost @ 2.5 t ha^{-1} was to the magnitude of 21.64, 20.89 and 15.60 per cent over control, respectively. Minimum available nitrogen, phosphorus and potassium content of soil (177.4, 18.23 and

286.1 kg ha^{-1}, respectively) after harvesting of black gram was recorded in control.

Table 5: Effect of organic manures and phosphorus level on bulk density, particle density, WHC, OC, soil pH and EC of soil after harvesting of black gram.

Treatments	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	WHC (%)	O.C. (%)	Soil pH	EC (dSm^{-1})
O_0	1.36	2.64	42.15	0.51	7.97	0.61
O_1	1.30	2.63	44.14	0.54	7.59	0.62
O_2	1.34	2.63	42.78	0.52	7.84	0.65
O_3	1.27	2.63	44.85	0.55	7.46	0.67
SEm±	0.003	0.004	0.13	0.006	0.02	0.02
CD (0.05)	0.01	NS	0.38	0.01	0.06	NS
I_0	1.32	2.64	43.34	0.53	7.75	0.56
I_1	1.32	2.63	43.41	0.53	7.73	0.61
I_2	1.32	2.63	43.48	0.53	7.71	0.67
I_3	1.31	2.63	43.68	0.53	7.67	0.71
SEm±	0.00	0.00	0.13	0.006	0.02	0.02
CD (0.05)	NS	NS	NS	NS	NS	0.05

Table 6: Effect of organic manures and phosphorus level on available nitrogen, phosphorus and potassium.

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
O_0	177.41	18.23	276.12
O_1	196.67	20.21	306.18
O_2	203.00	20.86	315.90
O_3	215.80	22.16	335.74
SEm±	3.44	0.35	5.28
CD (0.05)	9.94	1.00	15.25
I_0	178.60	18.36	278.12
I_1	207.20	21.28	322.41
I_2	195.64	20.09	304.41
I_3	211.44	21.72	329.00
SEm±	3.44	0.35	5.28
CD (0.05)	9.94	1.00	15.25

A critical examination of data in (Table 6) revealed that different source of phosphorus fertilizers significantly varied the available nitrogen, phosphorus and potassium content of soil after harvesting of black gram during investigation. Available nitrogen, phosphorus and potassium content of soil (211.4, 21.7 and 329 kg ha^{-1}, respectively) were significantly increased with application of 50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate. Minimum available nitrogen, phosphorus and potassium content of soil (178.6, 18.36 and 278.1kg ha^{-1}, respectively) after harvesting of black gram was recorded in control.

IV. DISCUSSION

The results of the present study revealed that the combined application of FYM (5 t ha^{-1}) and vermicompost (2.5 t ha^{-1}) significantly enhanced growth and yield attributes of black gram, including plant height, number of nodules, pods per plant, and test weight. The improvement in growth parameters may be attributed to the balanced and continuous supply of essential nutrients, which promoted vigorous vegetative growth and efficient nutrient uptake. Similar findings were reported by Prajapati *et al.* (2018), Kumar and Yadav (2018) and Soni *et al.* (2024).

The increased yield under organic manure treatments was likely due to enhanced availability of macro- and micronutrients throughout the growing period, corroborating the observations of Verma *et al.* (2017) and Tomar *et al.* (2021). Application of SSP and rock phosphate further improved phosphorus availability, root growth and water absorption, as supported by Deshpande *et al.* (2015) and Meena *et al.* (2016).

Organic manures also significantly improved soil physical and chemical properties. The FYM and vermicompost combination reduced soil pH and bulk density while increasing organic carbon, porosity, and water-holding capacity. These results align with those of Tyagi and Singh (2019) and Rajkhowa *et al.* (2017). The mineralization of organic matter further enhanced nutrient availability, consistent with Lal *et al.* (2022) and Patel *et al.* (2016). Overall, the integrated use of organic manures and phosphorus fertilizers improved growth, yield and soil fertility, offering a sustainable and eco-friendly approach to black gram cultivation.

V. CONCLUSION

On the basis of one year experiment results have clearly showed an increasing response to organic manure and inorganic phosphorus sources (% RDP) in terms of increase yield, quality, nutrient content and uptake by black gram crop. The application of (O_3) FYM 5 t ha^{-1} + vermicompost 2.5 t ha^{-1} and (I_3) 50% RDP through Single Super Phosphate + 50% RDP through Rock Phosphate (Treatment- O_3I_3) improved overall picture of efficient nutrient utilization.

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Plastic Waste and Pollution: An Evidence-Based review to Support WUP Policy Formation

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***Abstract*— *Plastic pollution is a real issue that damages the environment, animals, and humans. This research synthesizes literature from around the world to identify plastic waste issues and solutions that can help Wesleyan University Philippines (WUP) develop more effective plastic policies. The review examined over 30 studies and concluded that plastic waste increases due to inefficient waste management, the use of single-use plastics, and a lack of awareness. The Philippines is among the leading nations that contribute to plastic waste in the ocean. Effective solutions involve prohibiting single-use plastics, recycling, substituting with biodegradable products, and raising awareness to break people's habits. From the study, it is evident that plastic pollution requires collaboration between governments, businesses, communities, and schools. For WUP, this involves measures such as eliminating single-use plastics on campus, promoting reusable products, segregating waste, and educating students on plastic pollution. Through these actions, WUP can assist in safeguarding the environment and emerging as a model in combating plastic waste.*

***Keywords*— Evidence-based review, plastic waste, plastic pollution, policy formation, Wesleyan University-Philippines**

I. INTRODUCTION

Plastic waste is perhaps one of the largest issues today (Kibria et al.,2023). Plastic by the tons is disposed of every year in oceans, rivers, landfills, and streets. Plastic, since it takes hundreds of years to degrade, does damage to the environment over such a long period of time and harms both human beings and animals (Ormsby, Woodford & Quilliam, 2024).

This issue keeps increasing because of ignorance and poor waste management. Plastics are discarded irresponsibly in most areas, burnt openly, or used once and subsequently discarded. This results in pollution, flooding due to blocked drainage, and health issues for communities (South, 2014; Mohd Rosman et al., 2020).

To assist in addressing this problem, researchers at Wesleyan University Philippines conducted an extensive review of literature and data on plastic and waste pollution (Walker & Fequet, 2023; Kumar et al., 2021). They wished to know the severity of the issue and propose how it could be addressed better in schools, communities, and government.

The review established that plastic waste management is not simply a matter of cleaning up, but also requires clear regulations, improved systems, and the participation of all schools, such as Wesleyan University Philippines. Individuals, particularly students, must be informed, and policymakers must develop and implement policies to decrease plastic consumption and enhance waste management. Despite individuals' knowledge that plastic waste is bad for them, action is still none. This research was done to summarize previous studies and make specific recommendations to assist in policy-making and solutions to minimize plastic and waste issues in our society.

II. METHODOLOGY

This research used a Literature Review research design. A literature review is a qualitative research method that involves collecting, analyzing, summarizing, and synthesizing existing studies related to a specific topic. It helps researchers identify patterns, trends, contradictions, and gaps in current knowledge, guiding future research directions and policy recommendations. According to Snyder (2019), literature reviews are crucial for building theoretical frameworks and supporting evidence-based decision-making in both academic and applied fields. In this research, the authors review over 30 existing studies from different countries to identify patterns and trends in plastic problems and solutions to guide WUP policy makers in crafting a better plastic pollution control policy. This study covers the Academic Year 2024-2025.

III. RESULTS AND DISCUSSION

The researchers behind these studies examined different aspects of the plastic pollution problem. Chen and his team (2021) focused on Malaysia, explaining how the country struggles with growing plastic waste, particularly due to its extensive imports of plastic from other regions. Heidbreder and colleagues (2019) studied people's behavior and found that even when people know plastic is harmful, they often still use it out of habit or convenience. Situmorang and team (2020) showed that students who study environmental science tend to have better habits when it comes to using less plastic, which shows how important education is.

Other researchers looked at the effects of plastic pollution on nature and health. Muñoz-Pérez and team (2023) studied the Galápagos Islands and found that many animals were getting hurt or dying from plastic waste. Kurtela and Antolović (2019) also warned about tiny plastic pieces, called microplastics, getting into fish and possibly into our food. On the science side, Millican & Agarwal (2021) and Narancic & O'Connor (2019) talked about better ways to make and break down plastics, like using biodegradable materials. Finally, Leal Filho and his team (2019) suggested that companies should take more responsibility for the plastic waste they create. All these researchers agree that solving plastic pollution will take action from governments, businesses, and everyday people.

Part 1: The Existence and Utilization of Plastics

Over the past 100 years, the development of plastics has changed modern life. Because they are strong, durable, flexible, and cheap, plastics are used in many industries like packaging, construction, farming, medicine, electronics, and transportation (Millican & Agarwal, 2021). For example, during the COVID-19 pandemic, plastics were essential in making protective gear and medical tools (de Sousa, 2021). However, the same features that make plastics useful, like being long-lasting and lightweight, also make them hard to break down in the environment.

As the world's population and consumption increase, the use of plastics, especially single-use plastics, has also grown. In Malaysia, plastic waste has risen alongside economic growth and changes in consumer habits. Since 2017, Malaysia has become the largest importer of plastic waste, putting more pressure on its waste management system (Chen et al., 2021). Even though the country uses landfills, recycling, and incineration, it still faces problems such as limited facilities, weak policies, and low public participation in recycling.

Cutting down the use of plastic isn't merely about new materials and technologies. Human behavior, social practices, and convenience are also very much part of the reasons why plastic continues to be used. Heidbreder et al. (2019) discovered that even if individuals are aware that plastic is bad, they will still use it out of convenience or habit. Therefore, cutting down on plastic use takes both government regulations and modifications in human behavior.

Education and awareness can help. Situmorang et al. (2020) found that students studying environmental science were more likely to reuse bags and avoid plastic packaging than others. This shows that better environmental education can change behavior, but it needs to be widespread and supported by proper systems and incentives. Also, while biodegradable plastics are promising, they need the right recycling or composting facilities to truly reduce pollution (Narancic & O'Connor, 2019). Overall, solving the plastic problem needs a complete approach involving smart product design, responsible consumer behavior, strong waste systems, and teamwork among different sectors.

Part 2: The Problems Due to Plastic Pollution

Even though plastics are useful, they also cause serious problems for nature, human health, and waste systems. One major issue is how plastic ends up in the oceans. Rivers carry about 1.25 to 2.41 million tons of plastic into the sea each year (Kurtela & Antolović, 2019). This harms marine animals through entanglement, eating plastic, and damaging their habitats. Small plastic pieces, called microplastics, are especially dangerous because tiny sea creatures eat them, and they move up the food chain, possibly affecting humans too.

Even remote and protected areas like the Galápagos Islands are now affected by plastic pollution. Researchers found plastic waste in all coastal areas and in 52 species, including rare reptiles, mammals, and sea animals (Muñoz-Pérez et al., 2023). Some species like sea turtles, iguanas, and whale sharks are most at risk from getting tangled in plastic, while others are harmed by eating it. This shows that plastic pollution is a global problem that reaches even the most untouched places.

Plastic pollution is also a danger to human health and society. Microplastics in seafood might expose people to harmful chemicals, although scientists are still studying the full effects (Kurtela & Antolović, 2019). In poorer countries, plastic waste clogs drainage systems, causes floods, and worsens living conditions. The problem is made worse by weak waste systems, low recycling rates, and poor planning. In Malaysia, for example, imported plastic waste and poor local systems make it even harder to manage (Chen et al., 2021).

One possible solution is a policy called Extended Producer Responsibility (EPR), which makes companies responsible for the waste from their products. Leal Filho et al. (2019) believe EPR can lead to better product design and more recycling. However, for EPR to work, it needs strong laws, support from industries, and public involvement. Without big changes, the environmental, health, and social problems caused by plastic will keep getting worse.

Part 3. Plastic Pollution in the Philippines

The Philippines has a serious plastic pollution problem, especially in its oceans. It is one of the top countries contributing to both large and small plastic waste in the sea, releasing about 0.75 million metric tons of unmanaged plastic each year (World Bank Group, 2021). Although the government has made some rules to control this, there isn't enough research to fully understand where the plastic comes from and how it affects the environment (Galarpe, Jaraula, & Paler, 2021; Abueg, 2019). This lack of data makes it hard to create strong and effective solutions.

The issue is made worse by poverty and poor waste systems. Many people use cheap plastic sachets because they are affordable, which adds to the waste problem (Ramos, 2023). About 70% of Filipinos don't have access to proper waste disposal, so a lot of plastic ends up in rivers and then the ocean. In fact, 7 of the world's 10 most plastic-polluted rivers are in the Philippines (Ramos, 2023). This shows the problem starts on land, with bad waste management.

Plastic pollution harms the country's marine life, including coral reefs that support fish and local livelihoods (Ramos, 2023). It also increases coral disease and puts microplastics into the food chain, affecting fish and possibly human health (Ramos, 2023; Omeyer et al., 2022). This is not just a problem in the Philippines. Many Southeast Asian countries face similar issues due to weak laws and poor coordination (Garcia, Fang, & Lin, 2019). While there are some local efforts, most are not enough to solve the problem at a national level.

Overall, plastic pollution in the Philippines is caused by a mix of poverty, poor waste systems, limited research, and weak enforcement of laws. To fix it, the country needs better cooperation among the government, scientists, communities, and industries, plus stronger policies based on good data (Garcia, Fang, & Lin, 2019; Omeyer et al., 2022). Without these changes, the Philippines will remain one of the top contributors to ocean plastic waste.

Part 4. Solutions to Plastic Problems: Policies and the Role of Wesleyan University Philippines

Many countries have made laws to fight plastic pollution. These include banning single-use plastics, adding taxes on plastic bags, and making companies responsible for their waste (Nikiema & Asiedu, 2022). The European Union encourages better recycling, while China has banned plastic waste imports to reduce pollution (Palm et al., 2022; Miao et al., 2021). These actions show that strong laws and major changes in plastic use are needed to solve the problem.

Technology also helps reduce plastic waste. Some new materials, like biodegradable plastics, can break down naturally, but they are not yet widely used (Filiciotto & Rothenberg, 2021). Recycling and turning plastic into fuel are also helpful solutions (Miao et al., 2021). However, these methods only work well if governments provide funding, create good policies, and build the needed facilities (Nikiema & Asiedu, 2022).

Communities are also instrumental. In Uganda, Indonesia, and the United States, residents collect plastic litter and trace it back to where it originates (Owens et al., 2023). In the Philippines, most of the plastic in mangroves originates from surrounding communities (Paler et al., 2022). This indicates that education at the community level and improved local waste management play an important role in preventing plastic pollution.

These beneficial practices could be implemented at Wesleyan University Philippines (WUP). WUP may install waste separation bins, promote the use of reusable items, forbid single-use plastics, and work with recyclers. These efforts can be led by departments and organizations. Additionally, WUP can run awareness campaigns and provide incentives for eco-friendly behavior (Borongan & Naranong, 2022). WUP can thus serve as a model for reducing plastic waste and protecting the environment for future generations (Paler et al., 2022).

IV. CONCLUSION

Plastics are helpful in many aspects of our existence, including packaging, health care, and technology. Yet, their longevity and strength also cause dire problems for the environment and people's health. In Malaysia and the Philippines, among others, plastic trash is growing exponentially because of poor waste facilities and poorly enforced laws. Plastics find their way into rivers and oceans, poisoning animals and humans. This issue is too large for technology by itself to address. It requires assistance from the government, companies, schools, and communities.

Wesleyan University Philippines (WUP) can be a part of the solution. By prohibiting single-use plastics, encouraging recycling, and educating students about the issue, WUP can contribute to plastic waste reduction on campus and in the community. Other nations and cities have demonstrated that success is based on firm regulations, collaboration, and sound planning. If WUP takes action now, it can be an example for other schools in the Philippines and can save the planet for generations to come.

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Influence of Species, Stand Age and Seasonal Dynamics on Soil Microbial Biomass Carbon in Restoring Limestone Mine

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Abstract*— This study evaluates the impacts of plantation species, stand age, and seasonal variation on soil microbial biomass carbon (MBC) in the restoration of degraded limestone mine soils at the Nandini Limestone Mines, Chhattisgarh, India. Four plantation species namely Dalbergia sissoo, Azadirachta indica, Tectona grandis, and Albizia procera were analyzed across three chronosequence ages (5, 15, and 25 years) and three seasonal periods (pre-monsoon, monsoon, and post-monsoon) at 15–30 cm soil depth. Soil microbial biomass carbon increased significantly with plantation age across all species, with Dalbergia sissoo demonstrating superior recovery from 62.85 ± 3.71 µg C g^{-1} at 5 years to 99.34 ± 8.03 µg C g^{-1} at 25 years (pre-monsoon), while monsoon peaks reached 117.64 ± 4.99 µg C g^{-1}. Seasonal patterns revealed dramatic moisture-driven increases, with monsoon MBC values (70–130 µg C g^{-1}) approximately two-fold higher than pre-monsoon values (40–110 µg C g^{-1}). Three-way ANOVA analysis revealed that plantation age ($F_{2,72} = 137.87$, $p < 0.001$), season ($F_{2,72} = 57.67$, $p < 0.001$), and species identity ($F_{3,72} = 33.75$, $p < 0.001$) all exerted significant main effects on MBC, with plantation age accounting for 47.4% of total variance, season explaining 19.8%, and species identity explaining 17.4%. All two-way and three-way interaction terms were non-significant ($p > 0.36$), indicating additive rather than synergistic effects. Despite substantial improvement, MBC values in 25-year plantations (mean 100 µg C g^{-1}) remained 40% depleted relative to undisturbed reference soils (157.59–170.56 µg C g^{-1}). The model explained 84.7% of total variance with minimal residual error (12.4%), demonstrating robust predictive capacity for restoration trajectories. Results demonstrate that integrating fast-growing, high-quality litter species like Dalbergia sissoo and Azadirachta indica with moisture-conserving amendments offers a promising strategy for accelerating microbial and ecosystem recovery in degraded limestone mine landscapes.

***Keywords*— Soil microbes, soil carbon, biomass carbon, limestone mine, restoration.**

I. INTRODUCTION

Mining activities constitute one of the most significant anthropogenic disturbances to terrestrial ecosystems globally, with limestone quarrying representing a particularly intensive form of extraction that severely compromises soil structure, biological processes, and ecological functionality (Parthiban et al., 2023). India, being the world's second-largest producer of limestone with reserves exceeding 118 billion tonnes, faces substantial environmental challenges from extensive mining operations that extract approximately 350 million tonnes annually (Prathibam et al., 2023; Halder et al., 2024). These operations invariably result in topsoil removal, vegetation clearance, habitat fragmentation, and fundamental alterations to biogeochemical cycles (Sharma et al., 2000). The ecological restoration of post-mining landscapes has emerged as a global imperative, with forest-based rehabilitation strategies gaining recognition as the most effective approach for re-establishing ecosystem services and soil functionality recovery (König et al., 2023; Le et al., 2021). Forest restoration in degraded mining areas involves complex interactions between above-ground vegetation establishment, soil development, and the recovery of critical soil biological communities that drive nutrient cycling and ecosystem functioning (Witt et al., 2000; Zhang et al., 2019).

Soil microbial biomass carbon (MBC) has been established as one of the most sensitive and reliable indicators of soil health and ecosystem restoration success, representing the living component of soil organic matter that responds rapidly to environmental changes (Sharma et al., 2000; Vance et al., 1987). This parameter encompasses the total mass of living microorganisms that constitute approximately 1-4% of total soil organic carbon but exert disproportionate influence on soil processes through their roles in organic matter decomposition, nutrient release, and soil aggregation (Mummey et al., 2002; Barbhuiya et al., 2004). Unlike total organic carbon, MBC exhibits rapid responses to alterations in soil conditions, making it an invaluable early indicator for assessing restoration progress in post-mining environments (Ashraf et al., 2022). The restoration of limestone mine sites through forest plantations involves complex temporal dynamics where microbial biomass recovery is influenced by plantation age, species composition, seasonal variations, and site-specific soil conditions (Luo et al., 2020; Ngugi et al., 2020). Age-related changes in forest plantations fundamentally alter soil microbial communities through progressive organic matter accumulation, evolving root architecture, and changing litter inputs that collectively influence microbial habitat quality (Adeli et al., 2019; Pandey et al., 2007). Research has demonstrated that microbial biomass typically follows predictable successional patterns during forest development, with younger plantations exhibiting lower microbial biomass that gradually increases with stand maturity (Lladó et al., 2017).

Seasonal variations represent another critical dimension influencing soil microbial dynamics in tropical forest ecosystems, where monsoon-dominated climate patterns create distinct wet and dry periods that profoundly affect soil moisture, temperature, and microbial activity levels (Tomar & Baishya, 2020; Sarkar et al., 2024). The monsoon season typically triggers dramatic increases in microbial biomass due to enhanced soil moisture that alleviates water stress and promotes optimal conditions for microbial growth (Tomar & Baishya, 2020). Conversely, dry seasons often result in reduced microbial biomass as water limitations constrain metabolic activities (Tomar & Baishya, 2020). Tree species selection plays a pivotal role in determining restoration success, with different species exhibiting varying capacities to enhance soil microbial communities through their distinct litter quality, root exudate composition, and rhizosphere modification abilities (Shi et al., 2011; Allek et al., 2023). Fast-growing species commonly employed in tropical restoration programs, such as Dalbergia sissoo, Azadirachta indica, Tectona grandis, and Albizia procera, demonstrate markedly different influences on soil microbial development due to variations in their litter decomposition characteristics and root architecture (Li et al., 2022; Wang et al., 2011).

Despite the recognized importance of soil microbial biomass in ecosystem restoration, there remains a significant knowledge gap regarding the interactive effects of plantation age, species composition, and seasonal variations on microbial community recovery in post-mining environments, particularly in tropical regions where monsoon climates create unique restoration challenges (Thoms & Gleixner, 2013; Allek et al., 2023). The present investigation addresses this critical gap by examining the effects of different aged forest tree plantations (5, 15 and 25 years) comprising four important species on soil microbial biomass carbon dynamics across three seasonal periods in restoring Nandini limestone mine sites. This comprehensive approach enables the elucidation of temporal patterns in microbial recovery, species-specific restoration effectiveness, and seasonal modulation of soil biological processes that determine the success of forest-based restoration strategies in degraded lands.

II. MATERIALS AND METHOD

2.1 Study site

The study was carried out in Nandini Limestone Mine located in Dhamdha, District- Durg of Chhattisgarh State. The total area of mine is distributed in 1528 hectares located between Latitude N 21° 22’ 25.56’’ to N 21° 25’ 04.1” and Longitude E 81° 22’ 01.2’’ to E 81° 23’ 01.88’’ in which about 549 hectares are covered by core mining lease area and about 978 hectares are covered by outer buffer zone (Fig 1). The maximum elevation of the site is about 284 meters from mean sea level. The general ground slope is towards N, with gradient about 5°. The district receives an annual rainfall of 1130 mm in which 80% of rainfall was during the month of June-September. The study site exhibited mean annual temperature and humidity around 28.67°C and 56% respectively (Maitry et al., 2025a).

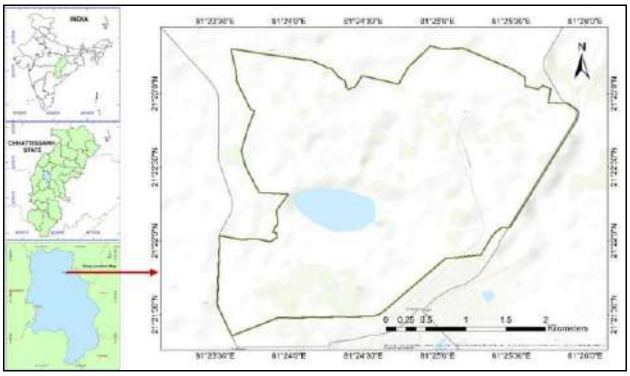

Fig 1. Geographical location of Nandini Limestone Mines (distributed over a total area of 970 hectares) in Durg, Chhattisgarh.

2.2 Selection of Sampling Plots

To assess how plantation age and species identity influence soil microbial biomass carbon during restoration of the Nandini Limestone Mine, sampling plots were established across four dominant tree species, *Dalbergia sissoo* (S1), *Azadirachta indica* (S2), *Tectona grandis* (S3) and *Albizia procera* (S4) at three stand ages (A: 5 years, B: 15 years, C: 25 years) and three seasons (Pre Monsoon, Monsoon and Post Monsoon). Each plantation type, age combination and season defined one segment, yielding thirty-six segments in total. Within each segment, rhizosphere soils were collected to capture species-, age- and season-specific microbial responses. In addition, soil from an adjacent undisturbed soil served as a reference for natural microbial biomass carbon levels.

2.3 Soil Sampling Method

Soil sampling followed a standardized chronosequence and seasonal protocol. In each of the twelve plantation segments and the reference forest, three randomly located points were marked during pre-monsoon, monsoon, and post-monsoon seasons. At each point, three blocks were established, and soil was excavated from 15–30 cm depth within a 30 cm × 30 cm × 30 cm pit. Sub-samples from each block were homogenized into a composite sample, debris and coarse fragments were removed, and the composite was divided into three replicates (Maitry et al., 2025b). All samples were passed through a 0.2 mm sieve, stored at 4 °C, and processed for microbial biomass carbon analysis within 48 hours of collection.

2.4 Analysis of Soil Microbial Biomass Carbon

Collected mine spoil samples were stored at (28 ± 2)°C for one week to stabilize respiration before estimating microbial biomass. Microbial biomass carbon (MB-C) was determined using the fumigation-extraction method (Vance et al., 1987). Two portions of moist spoil sample, each equivalent to 25 grams on an oven-dry weight basis, were prepared. One portion was fumigated with ethanol-free chloroform for 24 hours at 25°C. After fumigation, the mine spoil was extracted with 100 ml of 0.5M K_2SO_4 by horizontal shaking at 200 rpm for 30 minutes and then filtered through Whatman No. 42 filter paper. The unfumigated portion was extracted simultaneously at the start of the fumigation process. The filtered extracts were preserved at -20°C for further analysis. Organic carbon content in the filtrate was determined by wet oxidation, where 2 ml of 0.4N $K_2Cr_2O_7$ was added to 8 ml of the extract in the presence of 15 ml of an acid mixture (H_2SO_4/H_3PO_4). The mixture was placed in a 250 ml round-bottom flask fitted with a Leidig condenser and gently refluxed for 30 minutes. After cooling, the solution was diluted with 25 ml of water. The residual dichromate was measured through back titration against 0.04N $(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$ using ferroin as an indicator and was calculated using the following formulas:

$$Extracted\ organic\ C\ (\mu g/ml-1) = \frac{(H - S) \times M \times D \times E \times 1000}{C \times A}$$

Where, H = titration solution consumed by hot (refluxed) blank (in ml); S = titration solution consumed by sample (in ml); C = titration solution consumed by cold (unrefluxed) blank (in ml); M = normality of $K_2Cr_20_7$; D = volume of $K_2Cr_20_7$ (in ml); A = aliquots; E = 3 (conversion of Cr VI to Cr III).

$$Extracted\ organic\ C\ (\mu g/g-1\ dry\ sample) = \frac{C\ (\mu g\ ml-1) \times K}{25 \times dwt}$$

Where, K = volume of the extractant (in ml), dwt = oven dry weight of 1g of mine spoil sample (in g); 25 = weight of the sample (in g).

$$Microbial\ biomass\ C\ (\mu g/g-1\ dry\ sample) = \frac{Ec}{Kec} = \frac{Ec}{0.38}$$

Where, Ec = Organic C extracted from fumigated sample - Organic C extracted from unfumigated sample, Kec = the calibration factor, which is equal to 0.38.

2.5 Statistical Analysis

In the present study, statistical analyses (like Mean and Standard Deviation) have been calculated using Microsoft Excel 2021.

The Duncan's multiple range test was performed using SPSS V25 software whereas Three-way ANOVA, box plot analysis and heatmap hierarchical clustering between different studied criteria were performed using Origin 2025b software.

III. RESULTS AND DISCUSSION

3.1 Species-Specific Microbial Biomass Carbon Recovery

Microbial biomass carbon (MBC) at 15–30 cm depth exhibited pronounced age-dependent increases across all plantation species (Table 1). *Dalbergia sissoo* (S1) demonstrated superior recovery, with pre-monsoon MBC rising from 62.85 ± 3.71 to 99.34 ± 6.56 µg C g^{-1} across 5–25 year plantations, and monsoon peaks reaching 117.64 ± 4.99 µg C g^{-1} (Hao et al., 2025). This superiority reflects *D. sissoo*'s robust root exudate composition rich in organic acids and amino acids (Wu et al., 2024; Srivastava et al., 2022), enabling sustained organic carbon inputs through deep rhizodeposition crucial for restoration success (Singh et al., 2025). Recent research confirms *D. sissoo* harbours specialized rhizosphere bacteria capable of producing siderophores and antagonistic compounds against soil pathogens (Srivastava et al., 2022).

Table 1. Comparative analysis of change in Soil Microbial Biomass Carbon (µgC g^{-1}) under different aged plantations at Nandani Limestone Mines and Reference Normal Soil (RNS) in different seasons at 15-30cm depth.

Age	*Species*	*Seasons*		
		Pre-Monsoon	***Monsoon***	***Post-Monsoon***
5 Years	**S1**	62.85 ± 4.539d	86.13 ± 12.004cd	77.21 ± 15.772c
	S2	58.96 ± 12.256d	82.59 ± 5.239cd	64.01 ± 6.391cd
	S3	62.41 ± 10.522c	72.06 ± 6.528c	66.79 ± 5.038d
	S4	43.53 ± 5.752c	66.50 ± 7.844c	61.25 ± 6.544c
15 Years	**S1**	81.69 ± 10.280c	101.32 ± 6.695bc	89.40 ± 6.695c
	S2	77.09 ± 7.490c	96.40 ± 6.752c	81.14 ± 12.521c
	S3	73.11 ± 10.789bc	97.75 ± 6.403b	87.16 ± 5.884c
	S4	57.48 ± 16.380bc	80.45 ± 6.806bc	68.53 ± 4.932bc
25 Years	**S1**	99.34 ± 8.027b	117.64 ± 6.114b	115.72 ± 4.979b
	S2	93.94 ± 6.302b	120.91 ± 8.455b	108.99 ± 10.354b
	S3	86.96 ± 9.510b	116.60 ± 11.161b	101.34 ± 5.392b
	S4	72.02 ± 5.810b	94.66 ±6.756b	83.41 ± 7.910b
RNS		157.59 ± 10.109a	170.56 ± 14.838a	166.31 ± 11.144a

(n=3, Average ± Standard deviation) Different letters in a row indicate the significant difference among different plantation years and RNS at $p<0.05$ according to Duncan's Multiple Range Test. Code: S1= *Dalbergia sissoo*, S2= *Azadirachta indica*, S3= *Tectona grandis*, S4= *Albizia procera*. Abbreviation: RNS= Reference Normal Soil, MB-C= Microbial Biomass Carbon.

Azadirachta indica (S2) exhibited similarly impressive patterns, with pre-monsoon MBC increasing from 58.96 ± 10.01 to 93.94 ± 5.15 µg C g^{-1} and monsoon peaks of 120.91 ± 8.46 µg C g^{-1} (Mummey et al, 2002). Its exceptional performance relates to allelopathic compounds including nimbolide B, azadirachtin, and phenolic substances that create unique rhizosphere conditions favouring beneficial microorganisms (Kato-Noguchi & Ino, 2014; Mweetwa et al., 2016). The species maintained notably higher MBC during dry pre-monsoon periods, suggesting effective buffering of microbial communities against moisture stress through diverse root exudate profiles containing alkaloids, flavonoids, and terpenoids (Wu et al., 2024; Mweetwa et al., 2016).

Tectona grandis (S3) showed moderate enhancement with pre-monsoon MBC increasing from 62.41 ± 8.59 to 86.96 ± 7.77 µg C g^{-1} and monsoon peaks of 116.60 ± 9.11 µg C g^{-1} (Mummey et al, 2002), indicating $p<0.05$ according to DMRT. However, smaller seasonal increases reflect elevated lignin content (35.7–48.0 g kg^{-1}) and high polyphenolic compounds that slow microbial decomposition (Cavalcante et al., 2020). The species' half-life decomposition time of 0.74 years and high lignin-to-nitrogen ratios constrain readily decomposable substrates and nutrient mineralization (Giweta, 2020; Xu et al., 2024).

Albizia procera (S4) recorded the lowest MBC values across all periods (pre-monsoon: 43.53 ± 4.70 to 72.02 ± 4.74 µg C g^{-1}; monsoon: 66.50 ± 6.41 to 94.66 ± 5.52 µg C g^{-1}) (Zhao et al., 2020), indicating $p<0.05$. The inferior performance reflects poor litter quality, limited root exudate diversity, and reduced rhizosphere priming effects (Rakotonindrina et al., 2025). The species exhibited pronounced post-monsoon declines (61.25 ± 5.34 to 83.41 ± 6.46 µg C g^{-1}), demonstrating insufficient substrate availability during moisture-stressed conditions (Singh et al., 2025). Shallow-rooted species produce fewer diverse root exudates and maintain lower belowground carbon allocation (Mori et al., 2016).

However, these values still lag behind the Natural Soil value of 157.59 ± 8.26 to 170.56 ± 12.12 µg C/g in all three seasons, indicating that while soil function is improving, full recovery may require more time or additional interventions. Species-wise, S1 consistently showed higher MBC than other species, suggesting species differences in litter quality, root exudation, or canopy cover that influence microbial habitat and carbon availability (Fig. 2).

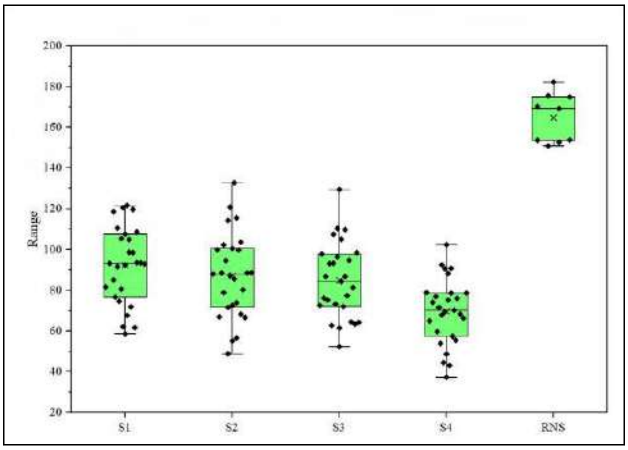

Fig 2. Species-specific variation in soil microbial biomass carbon (MB-C, µg C g^{-1}) across four plantation tree species and comparison with reference normal soil (RNS) at 15–30 cm depth. Code: S1= Dalbergia sissoo, S2= Azadirachta indica, S3= Tectona grandis, S4= Albizia procera. Abbreviation: RNS= Reference Normal Soil.

3.2 Seasonal Dominance and Environmental Controls

MBC values ranged 70–130 µg C g^{-1} during monsoon (median ~95 µg C g^{-1}) versus 40–110 µg C g^{-1} pre-monsoon, reflecting moisture availability as the primary environmental driver creating two-fold increases during optimal conditions (Barbhuiya et al., 2004; Hao et al, 2025) (Fig. 3). Pre-monsoon depression (40–110 µg C g^{-1}) reflects combined stress from reduced soil moisture, elevated temperatures, and substrate limitation (Lyngdoh & Karmakar, 2018). Intermediate post-monsoon values (60–110 µg C g^{-1}) indicate gradual biomass decline during seasonal transition (Sarkar et al., 2024). Greater pre-monsoon variability suggests substantial heterogeneity in soil microhabitats across plantation sites, while condensed monsoon distributions indicate homogenizing effects of abundant moisture (Bolat et al., 2022; Mori et al., 2016). Moisture-induced community shifts from drought-tolerant taxa to metabolically active populations during moist conditions have implications for nutrient cycling efficiency (Singh et al., 2025; Rakotonindrina et al., 2025).

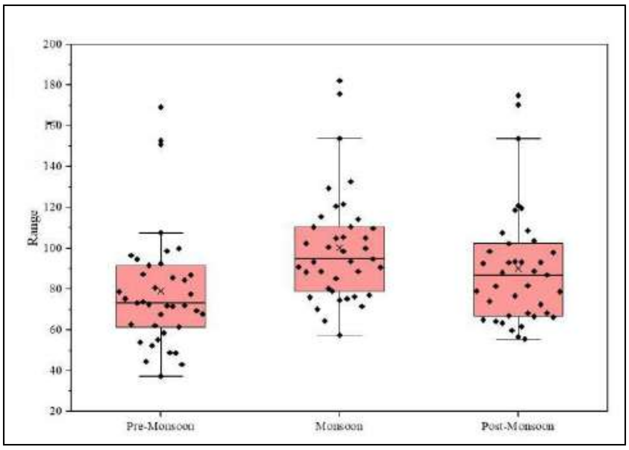

Fig 3. Seasonal variation in soil microbial biomass carbon (MB-C, µg C g^{-1}) at 15–30 cm depth across pre-monsoon, monsoon, and post-monsoon periods at Nandani Limestone Mines.

3.3 Chronosequence Analysis: Plantation Age Gradient and Soil Microbial Biomass Recovery

Five-year-old plantations showed lowest MBC (mean ~68 µg C g^{-1}) with extensive variability indicating species-based heterogeneity during early establishment. Mean MBC approximately doubled from 5-year (68 µg C g^{-1}) to 15-year plantations (85 µg C g^{-1}), demonstrating substantial microbial recruitment during early-to-middle development stages (Fig. 4). Twenty-five-year plantations approached 60% recovery toward reference soil (171 µg C g^{-1}) with mean ~100 µg C g^{-1}, yet remained ~40% depleted relative to natural soils, indicating restoration timelines may exceed standard rotation periods in severely disturbed environments (He et al., 2024; Xu et al., 2018). RNS values (170–180 µg C g^{-1}) represent the recovery target and emphasize mining-induced degradation extent. Tighter value distributions in mature plantations suggest greater microbial community stability and resistance with ecosystem maturation.

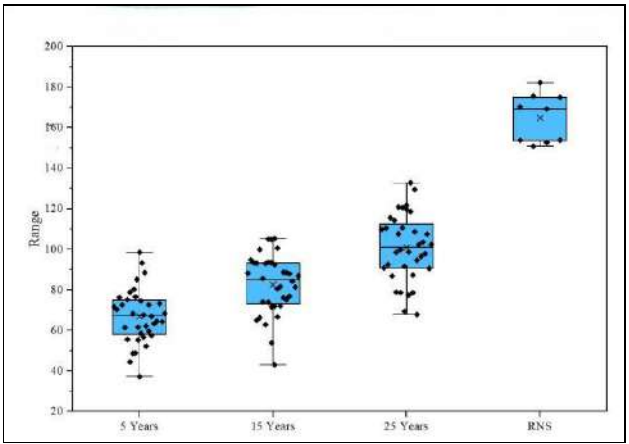

Fig 4. Chronosequence analysis of soil microbial biomass carbon (MB-C, µg C g^{-1}) recovery across plantation age classes and comparison with reference normal soil (RNS) at 15–30 cm depth. Abbreviation: RNS= Reference Normal Soil.

3.4 Multivariate Integration: Three-Way Interactions Among Age, Species, and Seasonality

Quantitative MBC data (Table 1) remained substantially below natural soil levels (157.59–170.56 µg C g^{-1}) across all seasons, indicating incomplete restoration requiring extended timelines or supplementary interventions. The overwhelming influence of seasonal moisture dynamics emerged as the primary environmental driver, with species-wise differences in litter quality and root exudation significantly modulating age-related recovery patterns. Complex interactions between seasonal moisture availability, species-specific litter chemistry, root architecture, and rhizosphere exudate composition collectively determine restoration success (Rakotonindrina et al., 2025).

Three-way analysis of variance (ANOVA) revealed that plantation age, tree species, and season were all significant main effects on soil microbial biomass carbon ($F[2,72]=137.87$, $F[3,72]=33.75$, and $F[2,72]=57.67$, respectively; all $p<0.001$). Plantation age emerged as the dominant factor, explaining 47.4% of total variance in MB-C concentrations, reflecting the strong recovery trajectory across the chronosequence (Table 2). Season explained 19.8% of variance, demonstrating that seasonal moisture availability substantially constrains microbial biomass dynamics. Species identity explained 17.4% of variance, indicating significant but subordinate effects relative to age and season. Notably, all two-way and three-way interaction terms were non-significant ($p>0.36$), suggesting that age, species, and seasonal effects operate independently without complex interactive effects. These additive relationships indicate that soil microbial biomass recovery follows predictable, generalizable patterns determined primarily by chronological age progression, with secondary modulation by seasonal environmental constraints and species-specific characteristics. The model explained 84.7% of total variance with only 12.4% residual error, demonstrating robust factorial design and strong predictive capacity for ecosystem recovery trajectories.

Table 2. Three-way ANOVA summary table showing the main and interaction effects of tree species, plantation age, and season on soil microbial biomass carbon at 15–30 cm depth.

	df	***Sum of Squares***	***Mean Square***	***F Value***	***P Value***
Spp	3	7627.831	2542.61	33.74765	<0.001***
Age	2	20775.09	10387.54	137.8721	<0.001***
Season	2	8689.73	4344.865	57.66867	<0.001***
Spp * Age	6	496.7257	82.78762	1.09883	0.37154*ns*
Spp * Season	6	164.4743	27.41239	0.36384	0.89944*ns*
Age * Season	4	117.0085	29.25211	0.38826	0.81638*ns*
Spp * Age * Season	12	501.9442	41.82869	0.55519	0.87027*ns*
Error	72	5424.614	75.34186		
Corrected Total	107	43797.41			

Hierarchical clustering dendrogram analysis revealed pronounced primary separation with reference soil (RNS) clustering distinctly at the upper range (180–183 µg C g^{-1}) in intense red coloration, emphasizing the substantial ecological distinction between natural and reclaimed soils (He et al., 2024; Ogola et al., 2021). Early treatments (5-year plantations) occupied the left region with dark blue coloration (~37–40 µg C g⁻¹), indicating heterogeneous recovery trajectories across species (Fig. 5). Progressive colour gradients from blue (young) through intermediate colours (middle-aged) to red tones (mature) indicate smooth chronological progression in microbial biomass accumulation (He et al., 2024). Monsoon samples clustered more closely regardless of species identity, demonstrating that optimal moisture creates convergent environmental selection pressures overriding species-specific differences (He et al., 2024; Ogola et al., 2021). This pattern indicates that plantation age and seasonality represent dominant organizing principles for microbial composition, while species identity exerts subordinate but significant modulatory effects.

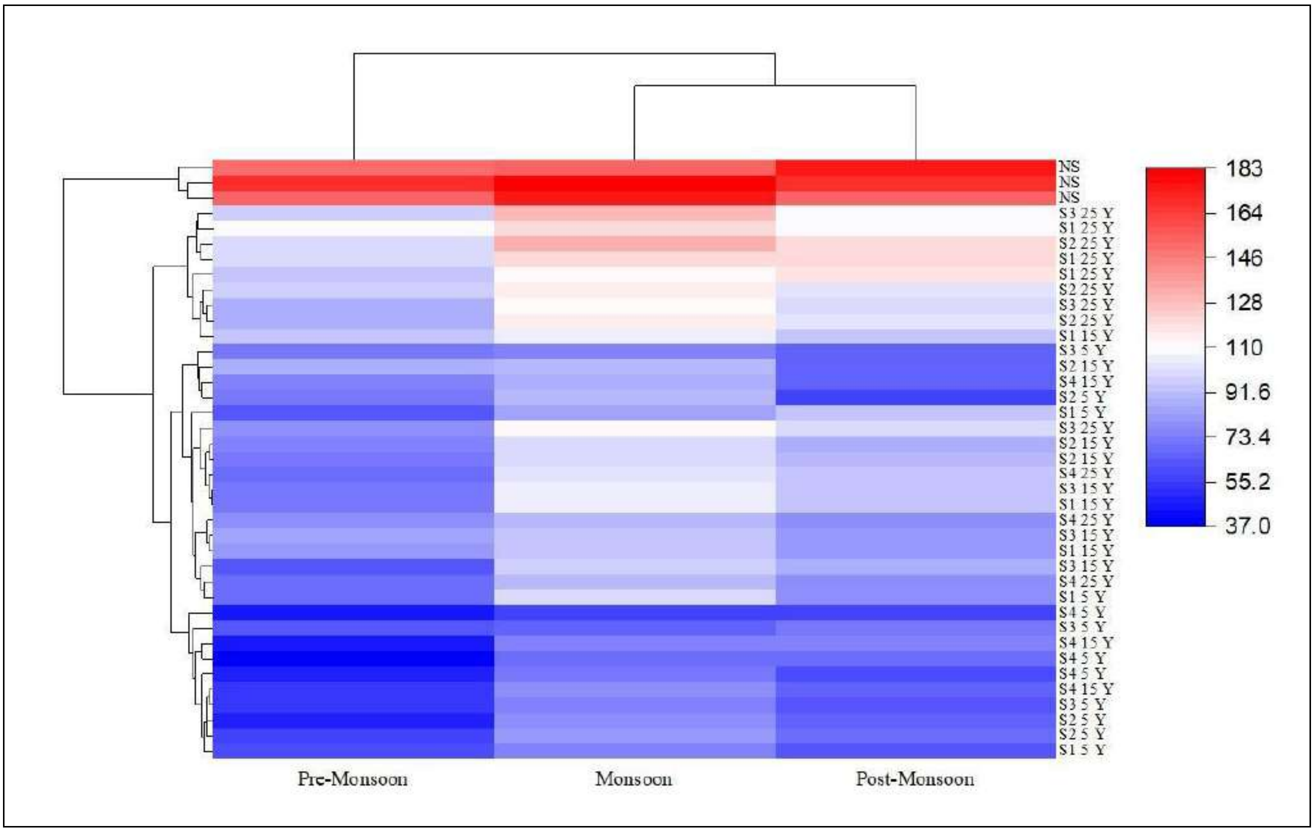

Fig 5. Hierarchical clustering dendrogram with color-coded heatmap of soil microbial biomass carbon (MB-C, µg C g⁻¹) across all treatment combinations at Nandani Limestone Mines. Code: S1= Dalbergia sissoo, S2= Azadirachta indica, S3= Tectona grandis, S4= Albizia procera. Abbreviation: NS= Normal Soil.

The complex interplay of factors reveals that species effects are conditional on seasonal context and plantation age. Legume-dominated plantations (*D. sissoo*, *A. indica*) outperform under both optimal and stress conditions, while timber species show greater seasonal dependency. Advanced molecular techniques reveal moisture-induced shifts from drought-tolerant to metabolically active taxa with implications for nutrient cycling (Singh et al., 2025; Rakotonindrina et al., 2025).

IV. CONCLUSION

This study demonstrates that forest plantations markedly enhance soil microbial biomass carbon in reclaimed limestone mine spoils, with both species identity and stand age exerting significant influence. *Dalbergia sissoo* and *Azadirachta indica* consistently supported higher microbial biomass across all seasons and ages, reflecting their labile litter inputs, diverse root exudates, and deep rooting systems that sustain subsurface carbon supply. *Tectona grandis* showed moderate improvement, constrained by recalcitrant litter chemistry, whereas *Albizia procera's* shallow roots and poorer litter quality yielded the lowest microbial recovery. Seasonal dynamics further modulated these trends, with monsoon moisture driving peak microbial activity and biomass, underscoring the critical role of soil water availability in post-mining restoration. The natural soil control highlighted that, although plantation-driven recovery significantly improves microbial biomass, it remains below undisturbed forest levels. Integrating fast-growing, high-quality litter species like *D. sissoo* and *A. indica*, coupled with moisture-conserving amendments or mixed-species plantings, offers a promising strategy for accelerating microbial and overall ecosystem recovery in degraded limestone mine landscapes.

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Analysis of Yield and Quality of Rice Varieties in Chau Phu, An Giang, Vietnam

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***Abstract*— *Yield and yield components of the varieties differed statistically. 17 high-yield rice varieties were recorded (4.03-8.90 tons ha) higher than the control variety. The total number of grains showed that HATRI 04 had the highest, with values of 122 and 127.3 grains/panicle, respectively. The weight of 1000 grains: of the lines/varieties had an average weight of 24.8-28.2 gr. For short-grain high-yield rice, the softness and fluffiness of the rice depends mainly on the amylose/amylopectin content in the starch component of the rice grain. The determination of amylose content in the endosperm of rice fluctuates from 18-24 %, in which varieties such as HATRI 722, HATRI 10, Nang Hoa, SR 24 has low amylose content. In addition, gel strength is related to the softness of sticky rice. The aroma of level 2 varieties such as HATRI 10, HATRI 722 and HATRI 25, level 1 varieties for AG1, HATRI 22, SR 24, . The high head rice ratio fluctuates from 41.5-53.40%. The HATRI 62 variety has the highest ratio and the lowest is OM8. The HATRI 10 and HATRI 190 varieties have good resistance to brown planthopper and blast disease. Analysis of 4 molecular markers recorded with RM223, RG 28 and Wx and RM42: the results recorded the assessment of the genetic purity of aroma achieved varieties such as: Nang Hoa 9, Dai Thom 8, HATRI 10, OM4900, HATRI 62, HATRI 22. Seven varieties have low amylose content is Nang Hoa 9, OM18, ST24, HATRI 10, OM4900, HATRI 25, HATRI 22.*

Keywords*— Amylose, gel consistency, Gelatinization temperature-GT yield, Milling quality, Molecular makers.

I. INTRODUCTION

Rice (Oryza sativa L.) is one of the most widely grown cereals worldwide and provides staple food for more than half of the world's population (Mbanjo et al., 2020). With the rapid development of the economy and improvement of living standards, the demand for high-quality rice is increasing in Vietnam. Yield and quality of grain are influenced by many factors such as differences in varieties, cultivation methods, and climatic conditions (Guerrini, et al., 2020). Most studies have determined that the quality of rice grown in the field depends greatly on many factors (Zhang et al., 2019). With the advancement of modern technology and the improvement of quality of life, people are looking for food with high nutritional quality and appearance in specialty varieties. Improving the quality of major crops through breeding superior rice varieties with higher yield, nutrition and resistance is essential for providing adequate, reliable and sustainable food supply in the world (Godfray et al., 2014). Identifying genes related to grain shape and chalkiness is important for breeding modern rice varieties with excellent rice quality. With the rapid development of the economy and improvement of living standards, rice quality has become a major concern for many rice producers (Godfray et al., 2014). Rice grain quality includes appearance, cooking, eating, nutritional quality and milling, among which appearance quality is the main factor affecting market acceptability (Zheng et al., 2007). Appearance quality is mainly reflected by grain shape and chalkiness. Rice grain shape is often described by grain length (GL), grain width (GW), and is closely related to grain weight (Qiu et al., 2015). Rice grain size and chalkiness are determined by the interaction of genetic and environmental factors (Zhao et al., 2015). Simple Sequence Repeat (SSR) markers are available and easily analyzed for any rice variety in any region of the genome, and candidate gene markers are being rapidly developed for glutinous rice breeding (N.T.Lang et al. 2008, N.T Lang et al., 2021). Therefore, in this paper, it is necessary to study the comparative yield and yield components, milling response and quality of 17 high-yielding rice varieties grown on Chau Phu land, An Giang.

II. MATERIALS AND METHODS

The materials used included 17 accessions from the Mekong Delta High-Tech Agricultural Research Institute.

The experiment was carried out at the Mekong Delta High-Tech Agricultural Research Institute (HATRI) and at Chau Phu An Giang

+Yield and composition traits Yield: was evaluated (Table 1,2,) the following quantitative traits were considered: panicle length (cm), which is the length of the mature panicle measured from the base of the plant to the panicle tip (taken from 10 randomly selected main panicles for each treatment). Number of panicles per bush, total number of panicles per plant (from 10 randomly selected main panicles for each treatment). 1000-grain weight (g), the weight of 1000 well-developed grains with 14% moisture (from 5 main panicles for each treatment). Number of grains/panicles obtained from the total number of filled grains per panicle (5 main panicles for each treatment). % empty grains, obtained from the number of total empty grains (5 main panicles for each treatment). Yield was determined by threshing, cleaning, drying and weighing the harvested grain mass from each replicate of each treatment. Moisture content in each plot was determined immediately after weighing with a moisture meter. Yield = weight of harvested grain (g)/number of harvested dust x number of dusts that can be obtained x MF (of harvested grain).

Quality analysis: according to (Lang et al., 2016).

+ **Amylose content** (AC): 40 grams of grain were dehulled and milled. The grain was ground through a 100 mesh sieve. Weigh 25 mg of rice flour and 2 ml of 1.0 N NaOH in a conical flask, leave overnight or place in a water bath at 500C. If in aqueous solution, leave in a water bath for 10 minutes and cool. The cooled solution is added with 5ml of butanl: pertroleum (1:3) to remove lipid. Then add 1.5ml of 0.4N KI and mix well. The AC solution is tested according to the following standards (5%, 10%, 15%, 20%, 25% and 30%) with standard amylose.

+ Gel consistency (GC): Weigh 100mg of rice flour in a test tube measuring 10mm x 110mm and add 0.2ml of 95% alcohol and containing 0.025% thymol blue. Add 0.2N KOH to the test tube. The test tube is closed and boiled in a water bath for 8 minutes. Remove from room temperature and leave for 5 minutes, put the test tubes on ice for 20 minutes and let them lie along the surface of the gel. The length of the gel is measured with a ruler. Evaluate the length of the gel.

+GT was determined using the alkali digestion test (Little et al.1958). A duplicate set of six whole-milled kernels without cracks was selected and placed in a plastic box (5×5×2.5 cm). Ten mL of 1.7% (0.3035 M) KOH solution was added. The samples were arranged to provide enough space between kernels to allow for spreading. The boxes were covered and incubated for 23 h in a 30°C oven. The starchy endosperm was rated visually based on a seven-point numerical spreading scale as a standard evaluation system for rice (IRRI .1913). According to the ASV score, GT of rice grains can be classified into four groups: high (1–2), high-intermediate (3), intermediate (4–5) and low (6–7) (Juliano et al.,1985)

+ Assess protein content according to the Yoshida method 1976. **Measure total nitrogen according to the Kjeldahl method**: Procedure:Organic matter is mineralized with concentrated H2SO4 at high temperature. Organic molecules will be decomposed into CO2, H2O and NH3. NH3 reacts with H2SO4 to form salt (NH4)2SO4. The salt (NH4)2SO4 is decomposed with NaOH solution to release NH3 gas again. The released NH3 is allowed to react with H3BO3 to form salt (NH4)2B4O7. This salt is titrated with H2SO4 or 0.05N HCl. Determine the total amount of nitrogen based on the amount of acid used for titration.

+DNA extraction:

DNA extraction by Miniscale method (Nguyen Thi Lang, 2002). Fresh, young rice leaf samples (2 cm) were ground in a mortar and pestle after adding 400 µl of buffer solution (50 mM Tris-HCl pH 8.0, 25mM EDTA, 300mM NaCl and 1% SDS). Grind the sample until the buffer solution turns green. Add 400 µl of buffer solution and mix well. Transfer 400 µl of lysate to the test tube containing the original leaf sample. The lysate was activated by adding 400 µl of chloroform. The supernatant was transferred to a new test tube (1.5 ml) and the DNA was precipitated using ethanol. The DNA sample was dried and suspended in 50 µl of TE buffer (10mM Tris-HCl pH 8.0, 1mM EDTA pH 8.0). The DNA sample was stored at -20oC.

+PCR reaction:

PCR amplification was performed in 10mM Tris-HCl (pH 8), 50mM KCl, 1.5mM MgCl2, one unit of TAKARA Taq, 4 nmol dNTP, 10 pmol primer, using microsatellite (SSR) marker and 50ng genomic DNA. PCR cycle: strand separation at 950C for 5 min, followed by 35 cycles of 940C for 60 sec, 550C for 30 sec and 720C for 60 sec. The final strand extension was at 720C for 5 min. 13 µl l of buffer solution (98% formamide, 10mM EDTA, 0.025% bromophenol blue, 0.025% xylene cyanol) was added after PCR. Polymorphisms in the PCR products were detected by ethidium bromide staining after electrophoresis on 3% agarose gel.

+**Data analysis**: Analysis of variance. The agronomic morphological data collected were initially analyzed through analysis of variance to verify genetic variation in the measured traits. Some traits with insignificant genetic variation, based on Ftest, were not considered for further analysis.

III. RESULTS AND DISCUSSION

Analysis of yield and yield components of the lines/varieties recorded statistically significant differences.Through analysis, the lines/varieties were recorded to have very good yields during cultivation. Plant height: average of lines/varieties 94-127 cm; The tallest variety is ST 24 (127 cm) so this variety is prone to lodging.

The growth period of the varieties is mostly lower than that of the control variety, most of the varieties have a growth period in the crop season from 95-120 days, there are two varieties with the longest growth period: Nang Hoa 9 and ST24. All varieties show some resistance to brown planthoppers. Except for AG 1, OM8, ST 24, Nang Hoa 9, OM 18, Jasmi85 and OM5451, which are susceptible to level 7. Some blast resistant varieties such as OM4900, HATRI 10 and HATRI 190 are very resistant, the remaining varieties are resistant to levels 3 and 5. Leaf blight is recorded as resistant to level 3 and slightly susceptible to level 5.

Table 1. Growth characteristics of the first-generation rice varieties in the Winter-Spring 2023-2024.

No.	**Lines/** varieties	**days**	**Hight plant**	**Brown plant hopper (score)**	**Bacteria leaf blight Score)**	**Blast (score)**
1	AG1	95.27 f	94.00 d	7	5	7
2	Nàng Hoa 9	115.73 b	115.00 b	7	5	5
3	Jasmine 85Checked)	108.53 c	111.65 c	7	5	5
4	OM18	107.87 c	99.98d	7	5	3
5	DaiThơm 8	107.33 c	110.31 c	7	3	5
6	ST24	120.07 a	127.00 a	7	7	5
7	HATRI 10	98.00 e	110.85 c	1	3	1
8	OM4900	100.27 d	109.17 c	1	3	1
9	OM5451 (Checked)	95.73 f	110.5c	7	5	5
10	Lộc Trời 28	98.00 e	124.4a	5	5	5
11	OM8	100.07d	110.00 c	7	5	5
12	HATRI 190	101.80 d	118.45b	3	3	1
13	HATRI 475	95.00f	107.14c	3	3	5
14	HATRI 722	98.00e	118.24b	5	3	5
15	HATRI 62	96.00f	105.35c	1	5	3
16	HATRI 25	100.00d	118.55b	3	3	3
17	HATRI 22	99.00e	114.66c	3	3	3
	LSD (%) CV (%)	2.5 4.25	1 1.02			

Notes: Characters followed by the same letter in the same column are not significantly different at the 5% level by Duncan test

Analysis of yield and yield components of lines/varieties recorded statistically significant differences. High yielding varieties such as HATRI 10, HATRI 190, HATRI 62 and HATRI 25. Filling of grains/ panicle : HATRI 25 variety has the highest number of filling of grains/ panicle followed by HATRI 62.

The weight of 1000 grains in the Winter-Spring crop is relatively high, from 24.1-28.2 grams, most of them have an average weight of (25-26 grams). Some varieties have large grains such as Nang Hoa 9, OM4900, HATR 62, HATRI 25 (27-28.2 grams). Long and slender like ST24, OM8.

The survey results show that the following traits are not statistically significant: Filling of grains/ panicle, weight of 1000 grains. This proves that the population has high genetic purity values on the variety. In particular, the yield and grain filling traits of the individuals are statistically significant. The results show that cultivation conditions, care conditions, and fertilizers for the full development of the variety are very important.

Table 2. Yield and yield components of the Winter-Spring 2023-2024

No	**Line/** varieties	**Yield (T/ha)**	**Filling/ panicle**	**% unfilling**	weight of 1000 grains	**Spikelet /m^2**
1	AG1	5.66d	113.8f	19.1g	24.0e	304.7g
2	Nàng Hoa 9	4.30e	107.9f	32.8a	28.2a	363.2e
3	Jasmine 85 (Đối chứng)	5.30d	122.5e	29.8b	26.2c	338.5f
4	OM18	4.10e	110.8f	21.8f	27.7b	357.9e
5	Đài Thơm 8	4.03e	113.3f	26.0e	26.5c	401.9d
6	ST24	3.93f	98.9h	28.0c	27.9b	298.8h
7	HATRI 10	8.90a	73.3i	19.4g	27.5b	460.8b
8	OM4900	7.76b	108.2g	27.0d	25.8d	417.9d
9	OM5451 (Đối Chứng)	6.66c	122.5e	18.8g	25.6d	374.6e
10	Lộc Trời 28	6.63b	104.5g	26.6e	26.2c	357.5e
11	OM8	5.60d	112.3f	23.0f	24.1e	360.4
12	HATRI 190	8.46a	122.3e	14.4	26.4c	490.7a
13	HATRI 475	7.50b	130.5c	18.0g	25.5d	438.9d
14	HATRI 722	8.16a	127.8d	19.1g	26.5d	485.7a
15	HATRI 62	8.40a	136.9c	10.6h	26.5d	417.4d
16	HATRI 25	8.06a	195.2a	12.1h	27.6b	460.3b
17	HATRI 22	7.26b	141.6b	18.1g	26.7d	454.4c
	LSD 5%	0.94	12.16	8.59	2.8	7.9
	CV%	6.8	15.6	26.5	1.2	13.7

Notes: Characters followed by the same letter in the same column are not significantly different at the 5% level by Duncan test

• Analysis of some quality indicators of high-yield rice

Rice quality assessment:

In addition to the appearance quality, the Ngu glutinous rice lines also have rice quality. In 17 high-yield rice varieties, through analysis of amylose content, it was noted that the amylose content of most lines was low. Amylose content (AC) is a major factor determining the quality of rice when cooked and eaten. Amylose molecules have a straight chain structure containing about 500 dextrose units. The amylose-amylopectin ratio is the main factor to classify rice into waxy (glutinous) and non-glutinous rice. The lowest amylose content was recorded in HATRI 722, HATR 10, HATRI 190, OM4900, Nang Hoa 9, ST 24…

Gel consistency (GC) is a good measure of the stickiness of milled rice and determines the softness after cooking. a simple and sensitive test to quickly determine the quality of rice when eating as a supplement to AC. It is measured by the length of cold rice pasta in a test tube in a horizontal direction and classified into: varieties of the medium group GC 41-68mm and soft GC 68-100mm (such as ST24, Jasmine 85, HATRI 722) . Gel consistency directly affects the texture of rice, so cooked rice has a gel strength that hardens faster than soft Gel consistency . The longer the Gel consistency , the softer the rice, and the lower the amylose content, which is also consistent with the rule of gelatinization temperature. The lines recorded good Gel consistency soft rice (100mm). Gelatinization temperature (GT): determines the water absorption and cooking time. GT is the temperature at which starch granules absorb water and begin to swell irreversibly. Most lines have a gelatinization resistance of level 3-5.

Evaluation of milling quality:

Milling analysis: The process of removing the germ and outer bran layer from brown rice is called "whitening" or "milling". Polishing is the process of removing the "subaleurone" layer after whitening the rice grain. Friction and abrasion are the two main processes used to remove the bran layers from brown rice: friction breaks the kernel and hull from the bran, while abrasion separates the raw rice surface from the bran. The degree of milling can be varied to suit consumer taste or to comply with general regulations, it is also estimated on the basis of the color of the milled grain and the percentage of broken rice. Milled rice has whole and broken grains of different sizes. Rice bran and germ account for 8-10% of the total grain mass. Evaluation of head rice percentage shows that varieties with good head rice percentage above 50% such as HATRI 10, HATRI 62, HATRI 190, HATRI 722. These varieties will increase the high head rice recovery(table 3). Chalkiness in rice refers to the opaque areas in the grain.C halkiness, a major determinant of rice quality, reduces the appearance of rice and affects milling and cooking qualities, thereby reducing the commercial value of rice(Zhao et al 2022). Recent studies have also identified WBR7 and LCG1 as regulators of chalkiness in rice through their effects on the accumulation of grain reserve components(Tu et la .2025). Despite these advances, the underlying genetic and molecular mechanisms causing chalkiness in rice remain unclear. E3 ligase is a key component of the ubiquitin-proteasome system, which determines substrate specificity in the cascade of reactions by covalently linking ubiquitin to target proteins (Shi et al .2024).Most of the 17 varieties give grain not chalkiness table 3 . Evaluation of nutritional quality:Protein analysis: The amount and type of protein are important factors in rice nutrition. Different factors affect the protein content of rice: climate and environment, and the amount of fertilizer applied, maturity time, degree of milling, and the characteristics of the variety. The protein content of rice varieties ranges from 7.5 to 8.9%. The variety with the highest protein content (HATRI 10, HATRI 22).The aroma of the high-aromatic variety is the variety with 3 high-aromatic varieties HATRI 10, HATRI 722 and HATRI 25.(Table 3).

Table 3. Milling quality and rice quality of 17 lines / varieties rice.

No.	**Line/ Varieties**	**Brown rice(%)**	**White rice (%)**	head rice(%)	**Length (cm)**	**Wide (cm)**	**Amylose(%)**	**gel consistency (GC) (mm)**	Gelatinization temperature	chalkiness	Protein(%)	**Aroma**
1	AG1	81.7d	74.0b	45.0d	7.14b	3.2a	21.2e	78a	5	0	7.5e	1
2	NangHoa 9	80.8d	74.0b	48.0c	8.12a	3.0a	19.9e	79a	5	0	8.6a	1
3	Jasmine 85 (Checked)	84.3b	71.0c	47.3d	7.14b	2.9b	19.0cd	76a	5	0	8.0b	1
4	OM18	82.3b	72.0c	40.1d	7.23b	3.0a	19.5d	77a	5	0	8.4b	1
5	DaiThơm 8	83.4b	75.0a	46.3e	7.10b	3.0a	20.1f	78a	5	0	8.3b	1
6	ST24	80.6d	73.0c	42.0f	8.25a	2.9b	17.0c	77a	5	0	8.4b	1
7	HATRI 10	80.6d	70.6e	51.2b	7.10b	3.1a	19.5.	77a	5	0	8.9a	2
8	OM4900	80.9d	71.2d	53.6a	7.08c	3.0a	18.7c	77a	5	0	7.6e	1
9	OM5451	80.6d	74.0b	49.4b	7.12b	3.0a	24.0ab	64b	0	0	8.7a	0

	(Checked)											
10	Lộc Trời 28	80.2d	72.2d	46.8b	7.10b	2.8c	22.0b	64b	3	0	8.6a	0
11	OM8	80.3d	72.0d	41.5f	7.05c	2.6d	22.5a	62b	3	0	8.5a	0
12	HATRI 190	82.0c	76.8a	50.7a	7.25b	3.1a	21.5	68b	3	0	8.7a	1
13	HATRI 475	82.7c	78.5a	51.2a	7.02c	2.9b	22.4	68b	3	1	8.4b	1
14	HATRI 722	82.4c	76.4a	51.4a	7.15b	3.2a	180.14	78a	5	1	8.5b	2
15	HATRI 62	82.6c	76.8a	53.4a	7.05c	3.1a	22.4	64c	3	1	8.7a	0
16	HATRI 25	86.7a	74.5b	50.5a	7.69b	3.2a	18.4	70a	5	0	8.6a	2
17	HATRI 22	84.7b	74.5b	52.7a	7.56b	3.2a	19.45	77a	5	0	8.9a	1
	CV (%)	***1.11***	***1.16***	***1.50***	***0.21***	***0.60***	***4.28***	***2.73***	-	-	***1.09***	-
	F	**	**	**	**	**	**	**	-	-	**	-

Notes: Characters followed by the same letter in the same column are not significantly different at the 5% level by Duncan test

PCR products with SSR molecular markers

In this study, 4 SSR molecular markers were used to amplify DNA for 17 experimental rice lines/varieties. The results showed that all SSR products showed polymorphism on 17 rice varieties (P=100%). The presentation of the results of the products of the experimental SSR primers only presented some products of typical primers while the products of the remaining primers are presented in the appendix.

The study applied microsatellite to design the aroma on the chromosome 8 and concluded that RM223 was quite tightly linked to fgr, with a genetic distance value of 1.6 cm (N.T.Lang et al.,2002) . From the results obtained, it was shown that the number of samples creating different bands with two alleles was often clear at the position of the molecular marker size. The difference in the number and position of the bands can indicate the difference in DNA sequence between varieties. Based on the band image, both alleles are recorded, allele A (220bp) and allele B (210bp).

Observe the image bands with a size of 210bp compared to the standard scale corresponding to allele B carrying the aromatic gene. For the image bands with a size of 220bp compared to the standard scale corresponding to allele A not carrying the aromatic gene. PCR product for primer pair RM223 on chromosome 8: electrophoresis results show that DNA amplification for the product reaches 100% and 2 alleles with amplification sizes from 220 bp to 210 bp. The aromatic varieties Nang Hoa 9, Dai Thom 8, HATRI 10, OM4900, HATRI 22

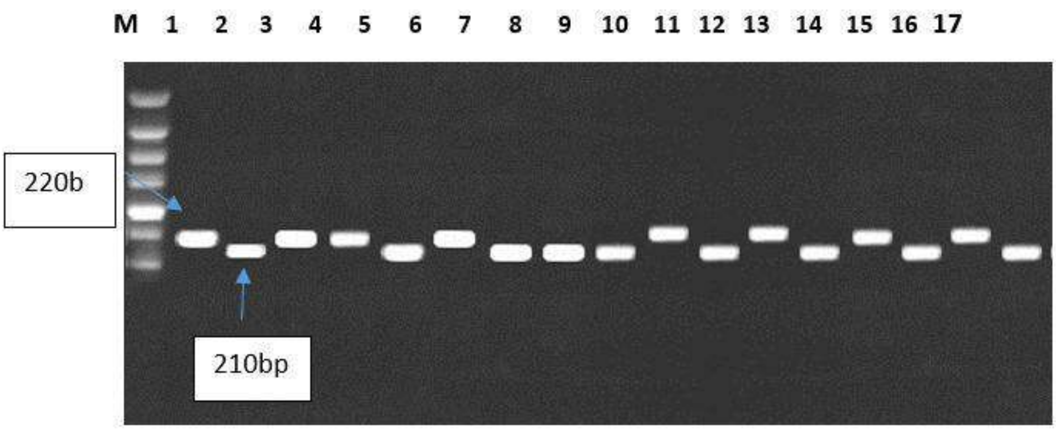

Fig.1. The segregation prediction of the aroma of determined by PCR analysis . PCR products of the detected by DNA amplification with primers for RM223 on 17 rice lines/varieties

Notes:

1: AG1; 2: Nang Hoa 9; 3: Jasmine 85; 4: OM18, 5: Dai Thom 8; 6: ST24; 7: HATRI 10; 8: OM4900; 9: OM5451; 10: Loc Troi 28; 11: OM8; 12: HATRI 190; 13: HATRI 475; 14: HATRI722; 15: HATRI 62; 16: HATRI 25; 17: HATRI 22.

For the RG28 marker, Aromatic genotype evaluation with the RG28FL-RB marker on 17 lines/varieties. The results recorded aromatic band with molecular size of 1800bp, non-aromatic band with molecular size of 1600bp. The aromatic homozygous or non-aromatic homozygous individuals correspond to the presence of 1 band on the electrophoretic spectrum, the heterozygous individuals show 2 bands on the electrophoretic spectrum as shown in Figure 2.

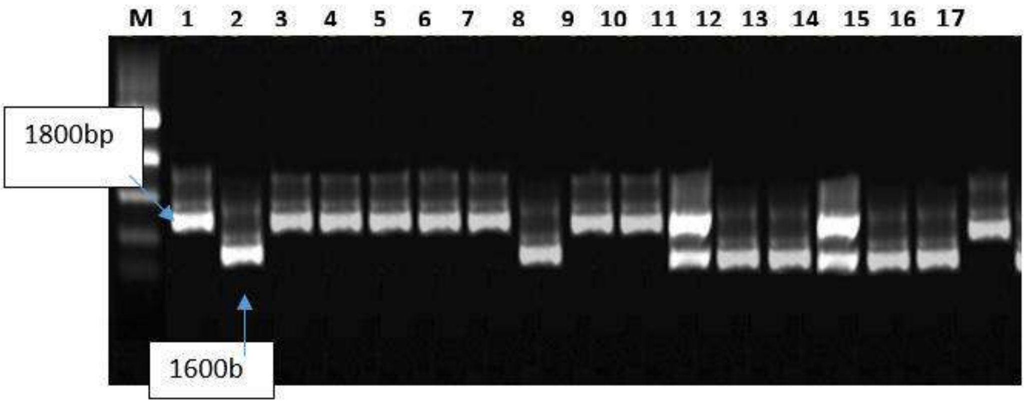

Fig.2. The segregation prediction of the aroma of determined by PCR analysis . PCR products of the detected by DNA amplification with primers for RG28F-R .

Notes : 1: AG1; 2: Nàng Hoa 9; 3: Jasmine 85; 4: OM18, 5: Đài Thơm 8; 6: ST24; 7: HATRI 10; 8: OM4900; 9: OM5451; 10: Lộc Trời 28; 11: OM8; 12: HATRI 190; 13: HATRI 475; 14: HATRI 722; 15: HATRI 62; 16: HATRI 25; 17: HATRI 22.

Analysis of amylose content : The banding patterns on the gel are the maker genotypes from wich we can predict the genotypes of markers linked locus and the phenotype of the individual plants. The Band pattern identifical to amylose contents were selected with maker Wx , RM42 . For marker Wx :The results recorded low amylose band with molecular size of 210bp, hight amylose band with molecular size of 220 bp. Nang Hoa, Jasmine 85, OM4900, HATRI 475, HATRI 62, HATRI 25 give for low amylose .

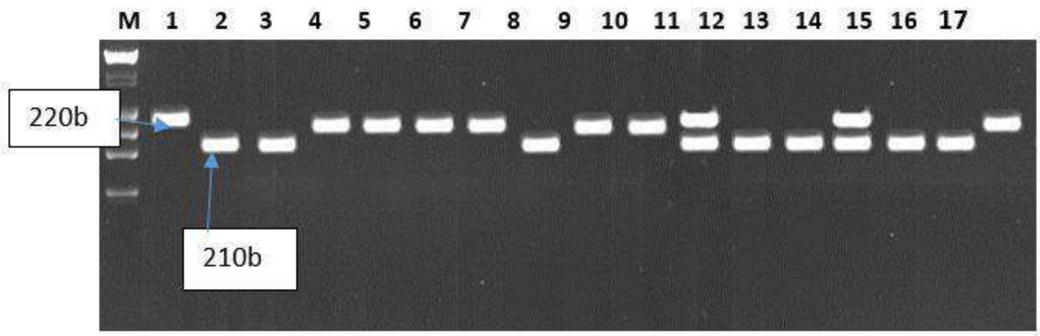

Fig.3. The segregation prediction of the amylose of determined by PCR analysis . PCR products of the detected by DNA amplification with primers for Wx.

Notes : 1: AG1; 2: Nang Hoa 9; 3: Jasmine 85; 4: OM18, 5: DaiThơm 8; 6: ST24; 7: HATRI 10; 8: OM4900; 9: OM5451; 10: Lộc Trời 28; 11: OM8; 12: HATRI 190; 13: HATRI 475; 14: HATRI 722; 15: HATRI 62; 16: HATRI 25; 17: HATRI 22.

For marker RM 42 .The results recorded low amylose band with molecular size of 220bp, hight amylose band with molecular size of 250 bp.

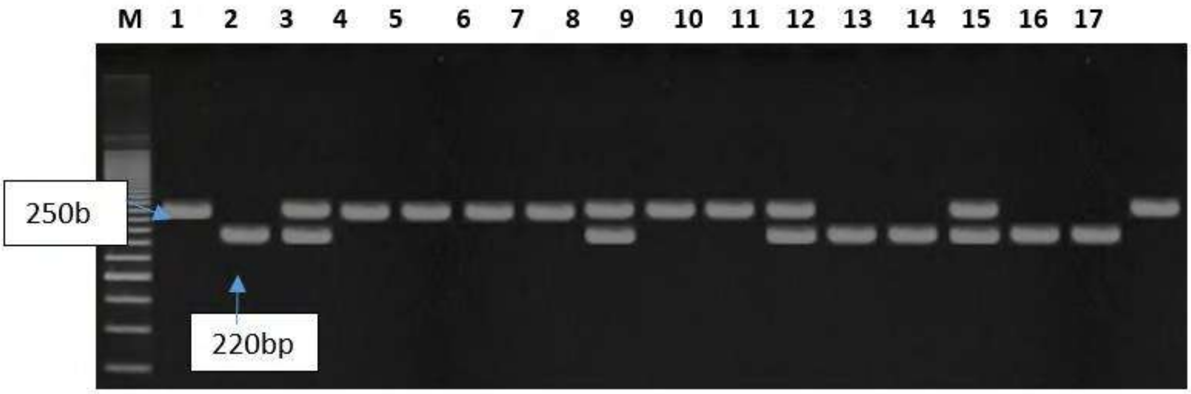

Fig.4. The segregation prediction of the amylose of determined by PCR analysis . PCR products of the detected by DNA amplification with primers forRM 42 .

Notes : 1: AG1; 2: Nàng Hoa 9; 3: Jasmine 85; 4: OM18, 5: Đài Thơm 8; 6: ST24; 7: HATRI 10; 8: OM4900; 9: OM5451; 10: Lộc Trời 28; 11: OM8; 12: HATRI 190; 13: HATRI 475; 14: HATRI 722; 15: HATRI 62; 16: HATRI 25; 17: HATRI 22.

In summary, the analysis of 4 indicators recorded the assessment of the genetic purity of aroma in varieties such as: Nang Hoa 9, Dai Thom 8, HATRI 10, OM4900, HATRI 62, HATRI 22. Seven varieties with low amylose content are Nang Hoa 9, Jasmine 85 , OM 4900, HATRI 190, HATRI 475, HATRI 25.

IV. DISCUSSION

Analysis of variance. For each of the 14 quantitative traits, the mean, range (maximum and minimum), standard deviation, coefficient of variation (CV), mean standard error, and F value were calculated (Table 1and 2). Results show that most of the quantitative traits are highly variable. With respect to maturity, the earliest maturing genotype matured in 95 days while the maximum number of days to maturity was 120 days. Maximum values were obtained in yield (8.9 tons/ha) on the variety HATRI 10, and number of filled grains (195.2 grain/ panicle) on HATRI 25 . Both showed high fertility which indicate that these are good materials that could potentially be used by plant breeders for varietal development in the future.

Highly significant differences among the various traits in the 17 improves varieties were obtained for grain length, grain width, number of unfilled grains, 1000-grain weight. Differences were not significant for panicles per plant.

Paddy rice is obtained through the process of growing rice, which undergoes sequential mechanical processes in rice hullers, hullers, millers, polishers, graders and packaging before being stored in warehouses for distribution and marketing. Typically, when processing 100 kg of paddy, about 20% is separated into husks, leaving the remaining 80% as brown rice. Further milling of brown rice produces about 10% bran and polish and 70% milled rice. This milled rice consists of a mixture of head rice and broken grains, where high quality milled rice allows a maximum of 4% broken grains in the head rice. Therefore, after milling, about 66% of the original rough rice remains, which is considered suitable for consumption. The size and chalkiness of the rice grain are determined by the interaction of genetic and environmental factors (Zhao et al., 2015). Most of the 17 varieties give grain not chalkiness table 3.

Eating and cooking quality and protein content in the grain (are the main factors that determine the quality of rice grains. Quality can be further analyzed into amylose content (AC), Gel consistency (GC) and gelatinization temperature (GT). AC can be divided into five groups, namely waxy (0–2%), very low (3–9%), low (10–19%), medium (20–25%) and high (>25%). Rice grains with AC of 16–20% are the most common in the market and meet the demand for non-glutinous rice (Lang et al., 2002). GT is usually measured on glutinous rice varieties, which record gel strength (100mm) and gelatinization resistance of level 9. However, amylose content clearly shows that the variety has a lower amylose content than other varieties (Table 3).

Milling quality and appearance are the most important indicators to evaluate rice quality as in this article, the glutinous rice variety has the highest head rice ratio is the HATRI 62 variety to 53.4% (Table 3). Milling form is an essential parameter of the final quality of rice, wheat and other cereal products, because the milling process can create the largest and most profound changes in the final products (Cappelli et al., 2020).Aroma is ranked among the main indicators. And this is the typical variety HATRI 10, HATRI 722 has long grains, grade 2 aroma.

V. CONCLUSION

Rice variety, growth period (95-120 days, strong plant, medium tillering, high yield (4.30-8.9 tons/ha). Maximum values were obtained in yield (8.9 tons/ha) on the variety HATRI 10, and number of filled grains (195.2 grain/ panicle) on HATRI 25 . Almost 17 lines with amylose contents (18-24%), delicious rice, fragrant (grade 2). High whole grain rate. The variety is resistant to brown planthopper and blast disease. In general, the rice variety's shape is completely different from the rice varieties in comparison with checked . When analyzing 4 molecular markers recorded with RM223, RG 28 , Wx , RM 42 makers , the analysis of 4 markers recorded the assessment of genetic purity of aroma in varieties such as: Nang Hoa 9, Dai Thom 8, HATRI 10, OM4900, HATRI 62, HATRI 22 when PCR products of the detected by DNA amplification with primers for RG 28 and RM 223 . Seven varieties with low amylose content are Nang Hoa 9, OM18, ST24, HATRI 10, OM4900, HATRI 25, HATRI 22 when PCR products of the detected by DNA amplification with primers for RM 42 and Wx . These varieties continue to be widely propagated in the province.

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Evaluation of the shelf-life of biocontrol agents enhanced with additives for use in tomato cultivation

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Abstract*— This study investigated the shelf life of biocontrol agents amended with additives and their efficacy were evaluated on growth parameters and wilt incidence in tomato. Under in vitro conditions 13 biocontrol agents were evaluated for their efficacy against Ralstonia solanacearum using the agar well diffusion technique and it was observed that Pseudomonas fluorescens (Pf 3) and T. koningii (DMA -8) were most effective in inhibiting the growth of R. solanacearum. Talc based formulations were prepared for biocontrol agents and it was observed that treatments with 2 per cent tryptone and 2 per cent peptone supplemented with 2 per cent glycerol enhanced the shelf life of Pf 3 and treatments with 2 per cent yeast extract and tryptone supplemented with 2 per cent glycerol increased the shelf life of Bacillus spp. (Bc) in the formulation. Biocontrol formulations were also evaluated in the greenhouse and their effect was studied on the wilt incidence and growth parameters. It was revealed that the combined application of Bc1+Pf 3 enriched with 2 kg FYM significantly reduced the wilt incidence and R. solanacearum population density and also increased the shoot length, number of branches/plants, number of fruits/plant and yield of tomato.

***Keywords*— Biocontrol agents, shelf life, Tomato and talc based formulations**

HIGHLIGHTS

Nutrient-amended talc formulations extend the shelf-life and efficacy of biocontrol agents, making biological disease management practical for field use.

Integrating bioagent-enriched FYM in tomato cultivation represents a sustainable alternative to chemical bactericides, reducing chemical input, environmental residue, and enhancing crop health.

I. INTRODUCTION

Bacterial wilt disease caused by *Ralstonia solanacearum* have been reported to affect more than 200 plant species of more than 53 botanical families (Denny 2006). Tomato a very important vegetable crop grown in the hill state of Himachal Pradesh in 13,185 ha area with production of 5,39,540 tonnes (Anonymous 2021). Tomato grown in the sub-tropical and sub temperate hills of Solan, Sirmaur, Palampur and Mandi Districts of Himachal Pradesh is very susceptible to the bacterial wilt caused by *R. solanacearum*. In the absence of host plants, *R. solanacearum* can survive in soil or water for a long time. Continuous cultivation of tomato on the same piece of land over the years has also aggravated the disease associated with the crop especially soil borne diseases like Bacterial wilt. Farmers are advised to practice field sanitation, crop rotation, and the use of bactericides but these methods have only given a moderate level of success in managing the disease and the use of chemicals also pose significant issues, such as environmental pollution and the generation of pesticide residues. These concerns have raised doubts about the safety of agricultural products. Biological control using bacterial antagonists has emerged as an essential method for plant disease management (Kumar 2017). This makes the management of diseases less dependent on the use of hazardous chemicals and has a strong effect on the management of soil-borne phytopathogens. Therefore, biological control methods that use antagonistic fungal and bacterial agents is an attractive approach (Mandal et al. 2017).

There are some inconsistencies associated with biocontrol agents like they exhibit variability and limited effectiveness, primarily because their lifespan is shorter than that of chemical pesticides. The effectiveness of biological control largely relies on the method employed to deliver biocontrol agents to the plants. A formulated product, therefore, should be easy to prepare and stable during transportation and storage. In addition, it should have abundant viable propagules with good shelf life. Talc is used as a raw material in the soapstone industry, is inert in nature and is readily available at low cost. Therefore, it is used as a carrier for formulation development. The present study investigated the effect of using talc-based formulation on the shelf life of two bioagents (*Bacillus subtilis* and *Pseudomonas fluorescens)* up to 150 days of storage. These bioagents formulations were then evaluated to check their efficacy on wilt incidence.

II. MATERIALS AND METHODS

1. Isolation, identification, purification and maintenance of *R. solanacearum*

The plants showing typical symptoms of vascular discoloration caused by *R. solanacearum* were collected and brought to bacteriological research laboratory. A confirmatory test was conducted by aseptically cutting the wilted plants showing discolored vascular tissues into small pieces of 3-4 mm size using a sterilized scalpel blade and suspending them in a test tube containing clean water. After 5-10 minutes it was observed that clean water turns turbid due to oozing of the bacterial cells and hence, confirmed the presence of the bacteria. After preliminary diagnosis again 3-4 mm small bits were cut and surface sterilized in 1.0 per cent sodium hypochlorite for 30 seconds followed by three subsequent washings of sterile water to remove traces of sodium hypochlorite. The infected bits were then suspended in a test tube containing sterilized distilled water for 10 minutes. The oozing of the bacterial cells from the tissue took place, turning the water in the test tube milky. Then a loopful of bacterial cell suspension was streaked onto three petri plates containing Kelman's 2, 3, 5 triphenyl tetrazolium chloride agar (TZC) medium under aseptic conditions. The inoculated plates were incubated at 28 ± 1^0C and after 24-36 hrs. the plates were examined for the development of well separated irregularly shaped, fluidal, dull white colonies with slight red or pink center. It was purified by picking the highly virulent colonies producing extracellular polysaccharide (EPS) and having a pink center and streaked on the surface of TZC medium contained in Petri plates.

2. Preparation of Talc based formulation

i) Culturing of bacteria

Mass multiplication of *P. fluorescens* was done by inoculating King's B broth with 0.1 per cent of bacterial culture (from late log phase) in 250 ml medium in 500 ml flasks and incubated for 48 hrs. on a rotary shaker at 200 rpm (28ºC). *B. subtilis* was grown in nutrient broth under similar condition for mass multiplication.

ii) Formulation of treatments

The formulation was initially prepared as described by Vidhyasekaran *et al.* (1997) using a mixture of 10 g of carboxymethylcellulose (CMC) in 1 kg of talc powder. The pH was adjusted to 7.0 by adding calcium carbonate and modified with nutrients. Nutrients includes 1 or 2 per cent bacteriological peptone or yeast extract or tryptone. Nutrients fortified with 1 or 2 per cent glycerol were also evaluated. The talc powder ($3MgO\ 4SiO_2.\ H_2O$) was incurred from Loba Chemie Pvt. Ltd. Mumbai and then autoclaved at 121^0C for 30 min on two successive days and was mixed with 0.2 per cent CMC prior to soil application. The formulations were prepared by mixing 200 ml culture broth of different isolates of *P. fluorescens*, containing a minimum population of 9 x 10^8cfu/ml with 500g of sterile talc powder (pre-mixed with 15 g calcium carbonate + 10 g of carboxymethylcellulose (CMC) + nutrient). Calcium carbonate was used to adjust the pH to 7.0. The control treatments were talc + calcium carbonate + CMC + culture broth and talc + culture broth. The resulting mixture was thinly spread over sterilized aluminium trays and dried overnight under sterile conditions. The mixture was packed in polypropylene bags, sealed and stored at room temperature (25 ± 2°C).

iii.) Preparing talc-based formulation of *Trichoderma* spp -

Mass multiplication of *Trichoderma* spp was done by inoculating PDA broth with bits from fully grown culture *Trichoderma* spp. and incubated at 25 ± 2°C for 7 days. of in 250 ml medium in 500 ml flasks and incubated for 48 hrs. on a rotary shaker at 200 rpm (28ºC). After 7 days of incubation 400 ml of broth was mixed with 1 kg of earlier sterilized talc powder. The soil was mixed with the *Trichoderma* spp. formulation at 5, 10, 15 g/kg of soil.

iv.) Population count

To estimate the viable population in the talc-based formulations, 1.0 g of the talc mixture was ground in a mortar and pestle. The resulting solution was mixed with 10 ml of sterile water and stirred for 20 minutes. Serial dilutions up to 10^8 cfu were prepared. From each dilution, 0.1 ml aliquots were spread on King's B agar (for *P. fluorescens*) and nutrient agar (for *Bacillus* spp.). Plates were incubated for 24 hours, and observations on survival were recorded. Subsequent observations were made every 30 days, up to 150 days.

v.) Survival of *P. fluorescens* and *Bacillus* spp. in talc based powder formulation amended with additives

The talc-based formulation of *P. fluorescens* and *Bacillus* spp. were taken and amended with following ingredients

T_1	Talc + 1% peptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_2	Talc + 2% peptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_3	Talc + 1% peptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_4	Talc + 2% peptone + 1% $CaCO_3$ + 0.1% carboxy methylcellulose
T_5	Talc + 1% tryptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_6	Talc + 2% tryptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_7	Talc + 1% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_8	Talc + 2% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_9	Talc + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_{10}	Talc + 1% yeast extract + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_{11}	Talc + 2% yeast extract + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_{12}	Talc + 1% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_{13}	Talc + 2% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose
T_{14}	Talc + calcium carbonate + CMC + culture broth
T_{15}	Talc + culture broth
T_{16}	Talc alone

vi.) Enrichment of organic manure

Two gram of talc formulation of bioagents *viz. Bacillus* spp.and *P. fluorescens* were mixed with 2 kg of farm yard manure (FYM) and kept for 15 days maintained optimum moisture conditions and once in every two days the manure was thoroughly mixed. The pot experiment was conducted in Department of Plant Pathology, CSKHPKV, Palampur to evaluate the bio-efficacy of various talc based formulations against *R. solanacearum* by adopting a complete randomized design which comprised of twelve treatments including an untreated control which was replicated thrice.

vii.) Development of bioformulations and their mode of application

The sick soil was taken from the farm of Department of Plant Pathology; subsequently the bioformulations were developed and then applied in the manner as specified below.

T_1	Sick soil
T_2	T_1+ application of 1kg enriched farm yard manure with *Bacillus* spp.
T_3	T_1+ application of 1kg enriched farm yard manure with *Pseudomonas fluorescens*
T_4	T_1+ application of 1kg enriched farm yard manure with *Bacillus* spp. + *Pseudomonas fluorescens*
T_5	T_1+ application of 2kg enriched farm yard manure with *Bacillus* spp.
T_6	T_1+ application of 2kg enriched farm yard manure with *Pseudomonas fluorescens*
T_7	T_1+ application of 2kg enriched farm yard manure with *Bacillus* spp. + *Pseudomonas fluorescens*
T_8	T_1+ application of 1kg farm yard manure
T_9	T_1+ application of 2kg farm yard manure
T_{10}	T_1+ Streptocyclin @ 0.1g in 1 litre of water and used for drenching
T_{11}	T_1+ application of 1kg enriched farm yard manure with *Trichoderma* spp.

The inoculation was done as per rapid method of screening given by Kishun and Chand (1988) in which the seedlings were pricked using a sterilized needle and a drop of bacterial inoculum (10^8cfu/ml) was kept at the leaf axil of third or fourth expanded leaf from the top of seedling and pricked with the help of a sharp sterilized dissecting needle. The seedlings inoculated with sterilized distilled water in a similar manner was served as control.

viii.) Treatment of tomato seedlings

Five gram of talc formulation of bioagents *viz*., *Bacillus* spp., *P. fluorescens*, was added to 1 liter of water. The seedlings were treated by dipping in these suspensions for 30 minutes before transplanting.

ix.) Estimation of *R. solanacearum* population density

The rhizosphere soil after 45 days of termination of the experiment was enumerated by serial dilution technique and spread plate method on triphenyl tetrazolium chloride (TTC) agar. Three replicates were maintained for each dilution. The cfu from each plate were counted and population density of *R. solanacearum* per g of soil was calculated as follows:

$$No.\,of\,Colonies/g\ soil = \frac{\text{Average No. of colonies in a dilution}}{\text{Dry weight of soil (g)}} X\ Dilution\ factor$$

Wilt incidence

After termination of the experiment, the wilt incidence was recorded using the following formula:

$$\text{Wilt incidence (\%)} = \frac{\text{Number of wilted plants}}{Total\ number\ of\ plants\ observed} X\ 100$$

x.) Analysis of yield attributes

Data on average fruit weight (g)/plant, No. of branches/plant at 50 per cent flowering, shoot length (cm)/plant at 50 per cent flowering, No. of fruits/plant, yield (kg)/plant and dry plant weight (g)/plant of the treated tomato plants were recorded to evaluate the efficacy of bioagents.

III. RESULTS AND DISCUSSION

Survival of potential *P. fluorescens* (Pf 3) isolated from talc-based powder formulations amended with additives

The data pertaining to viable populations of *P. fluorescens* in talc-based powder formulations amended with additives are presented in Table 2. The changes in population were monitored over a 150-day period. In almost all the treatments in which the plants were amended with nutrients, there was a gradual increase in the *P. fluorescens* (Pf 3) population for up to 90 days, which ranged from 0.00 to 10.94 × 10^6 cfu/g, 0.00 to 11.22 × 10^6 cfu/g, 0.00 to 11.74 × 10^6 cfu/g, and 0.00 to 11.80 × 10^6 cfu/g on the 1st, 30th, 60th and 90th days, respectively. At 90 days, the highest population of 11.80 x 10^6 cfu/g was observed in talc amended with 1% tryptone and glycerol. A decrease in the population was observed from 90 days onward in all treatments, ranging between 0.00 and 11.32 x 10^6 cfu/g and between 0.00 and 10.97 x 10^6 cfu/g on the 120th and 150th days, respectively. With respect to the nonamended talc formulations, a decrease in the population was observed after 30 days, and a population of 0.00 cfu/g was observed on the 30th day in the talc alone group, followed by an increase of 8.54 x 10^6 cfu/g in the talc + broth group. Similarly, a decrease in the population density of 0.00 to 9.16 x 10^6 cfu/g, 0.00 to 8.74 x 10^6 cfu/g, 0.00 to 8.12 x 10^6 cfu/g, and 0.00 to 7.44 x 10^6 cfu/g were detected on the 60th, 90th, 120th and 150th days, respectively.

The results of the present study revealed that treatment with 1 per cent tryptone, 2 per cent yeast extract and 2 per cent peptone supplemented with 2 per cent glycerol improved the survival of Pf 3. These results are in agreement with the findings of Kumaresan *et al*. (2005), who also developed talc-based formulations of several isolates of PGPR belonging to the species *Bacillus subtilis* and *Pseudomonas* spp. and reported that these formulations had a shelf life of more than 4 months.

Survival of potential *Bacillus* spp. (Bc 1) isolated from talc-based powder formulations amended with additives

The data with respect to viable populations of *Bacillus* spp. in talc-based powder formulations amended with additives are presented in Table 3. The changes in population were monitored over a 150-day period. In almost all the treatments in which the plants were amended with nutrients, *Bacillus* spp. (Bc 1) increased for up to 90 days, ranging between 0.00 and 9.54 × 10^6 cfu/g, 0.00 and 9.90 × 10^6 cfu/g, 0.00 and 9.92 × 10^6 cfu/g, and 0.00 and 9.90 × 10^6 cfu/g on the 1st, 30th, 60th and 90th days, respectively. On the 90th day, the highest population of 9.90 x 10^6 cfu/g was observed in talc amended with 2% yeast extract and glycerol. A decrease in the population was observed from 90 days onward in all treatments, ranging between 0.00 and 9.86 x 10^6 cfu/g and between 0.00 and 9.82 x 10^6 cfu/g on the 120th and 150th days, respectively. For the nonamended talc formulations, a decrease in the population was observed after 30 days, and a population of 0.00 cfu/g was observed on the 30th day for talc alone, followed by a decrease of 7.56 x 10^6 cfu/g in talc + broth. Similarly, a decrease in the population was observed, ranging between 0.00 and 7.82 x 10^6 cfu/g, 0.00 to 7.80 x 10^6 cfu/g, 0.00 to 7.55 x 10^6 cfu/g, and 0.00 to 7.44 x 10^6 cfu/g on the 60th, 90th, 120th and 150th days, respectively.

The perusal study (Table 3) revealed that all the talc formulations amended with nutrient sources for 150 days had a population of 8.80 x 10^6 cfu/g or more. The population declined to below 7.50 x 10^6 cfu/g only in the nonamended treatments. Treatment with 2 per cent yeast extract or tryptone supplemented with glycerol increased the shelf life of the Bc 1 isolate. Schmidt *et al*. (2001) reported that the biological control activity of *B. subtilis* increased by adding peptone (0.25%) to the medium and that of *Erwinia herbicola* increased by adding glucose (0.5%) or high concentrations of peptone (1-2%).

Table 2: Survival of potential Pseudomonas sp. (Pf 3) in talc-based formulations amended with additives

Treatment	**Days (cfu × 10^6 per g of talc)**					
	1*	**30***	**60***	**90***	**120***	**150***
T_1 - Talc + 1% peptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.60 (3.25)	9.84 (3.29)	9.93 (3.30)	9.98 (3.31)	9.34 (3.21)	8.93 (3.15)
T_2 - Talc + 2% peptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	10.83 (3.43)	10.86 (3.44)	10.90 (3.45)	10.94 (3.45)	10.69 (3.42)	9.87 (3.29)
T_3 - Talc + 1% peptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.40 (3.22)	9.44 (3.23)	9.47 (3.23)	9.48 (3.23)	8.97 (3.15)	8.03 (3.00)
T_4 - Talc + 2% peptone + 1% $CaCO_3$ + 0.1% carboxy methylcellulose	8.76 (3.12)	8.92 (3.15)	9.49 (3.23)	9.53 (3.24)	8.77 (3.12)	8.35 (3.05)
T_5 - Talc + 1% yeast extract + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.93 (3.30)	10.24 (3.35)	10.36 (3.37)	10.38 (3.37)	9.62 (3.25)	9.40 (3.22)
T_6 - Talc + 2% yeast extract + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	10.27 (3.35)	11.04 (3.47)	11.65 (3.55)	11.66 (3.55)	11.30 (3.50)	10.89 (3.44)
T_7 -Talc + 1% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.02 (3.16)	9.39 (3.22)	9.68 (3.26)	9.80 (3.28)	9.24 (3.20)	8.22 (3.03)
T_8 - Talc + 2% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.33 (3.05)	8.46 (3.07)	8.67 (3.11)	8.82 (3.13)	8.25 (3.04)	8.03 (3.00)
T_9 - Talc + 1% tryptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	10.42 (3.37)	10.51 (3.39)	10.76 (3.42)	10.80 (3.43)	10.09 (3.33)	9.33 (3.21)
T_{10} - Talc + 2% tryptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	10.94 (3.45)	11.22 (3.49)	11.74 (3.56)	11.80 (3.57)	11.32 (3.51)	10.97 (3.46)
T_{11} - Talc + 1% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.20 (3.19)	9.69 (3.27)	10.26 (3.35)	10.19 (3.34)	9.45 (3.23)	8.56 (3.09)
T_{12} - Talc + 2% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.67 (3.26)	9.82 (3.28)	9.87 (3.29)	9.80 (3.28)	9.44 (3.23)	8.24 (3.04)
T_{13}- Talc + 2% $CaCO_3$ + 0.1% carboxymethylcellulose	8.77 (3.12)	8.80 (3.13)	9.16 (3.18)	8.74 (3.12)	8.12 (3.02)	7.44 (2.90)
T_{14} -Talc + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.75 (3.12)	8.91 (3.14)	8.20 (3.03)	7.85 (2.97)	7.60 (2.93)	7.22 (2.86)
T_{15} -Talc + culture broth	8.69 (3.11)	8.54 (3.09)	7.86 (2.97)	7.44 (2.90)	6.75 (2.78)	3.76 (2.18)
T_{16} -Talc alone	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
C.D.	0.06	0.06	0.05	0.06	0.05	0.05
SE(m)	0.02	0.02	0.01	0.02	0.02	0.02

* = mean of three replications

cfu – Colony forming unit

The values in parentheses are square root-transformed value

Combined effect of different talc-based formulations and seedling treatments on yield

It is evident from the table 4 that all the treatments showed significantly better results than the control. All the antagonistic treatments, consisting of either single or combined application of *Bacillus* spp. and *Pseudomonas fluorescens* to seedling roots and soil, resulted in significantly greater tomato fruit yields than the uninoculated control. Among all the treatments, the highest average number of fruits per plant was recorded in the T_7 treatment, which was enriched with Bc 1+Pf 3 isolates along with 2 kg FYM with 8.7 fruits per plant, followed by treatment $T_{7,}$ which was enriched with Bc 1+Pf 2 along with 2 kg FYM with 7.7 fruits per plant, and the minimum average number of fruits per plant was recorded in the T_1-Sick soil, i.e., 1.3. The maximum average yield was also recorded in the T_7 treatment, which was enriched with Bc 1+Pf 3 along with 2 kg FYM with a yield of 296 g per plant, followed by treatment $T_{7,}$ which was enriched with Bc 1+Pf 2 along with 2 kg FYM with a yield of 238 g per plant. Thus, these two treatments were found to be significantly superior to the other treatments in terms of the yield of tomato fruits. The lowest average yield (32.30) was obtained in the T_1-Sick soil. It is apparent from the above results that the combined application of *Bacillus* spp. and *Pseudomonas fluorescens* with 2 kg of FYM explicitly substantiated the yield-promoting effects. The results of the present investigation are also in agreement with those of Wydra and Semrau (2005).

Table 3: Survival of potential Bacillus sp. (Bc 1) in talc-based formulations amended with additives

Treatment	Days (cfu × 10^6 per g of talc)					
	1*	30*	60*	90*	120*	150*
T_1 - Talc + 1% peptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.40 (3.06)	8.50 (3.08)	9.02 (3.16)	9.10 (3.17)	8.99 (3.16)	8.80 (3.13)
T_2 - Talc + 2% peptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.99 (3.16)	9.48 (3.23)	9.65 (3.26)	9.66 (3.26)	9.60 (3.25)	9.20 (3.19)
T_3 - Talc + 1% peptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.48 (3.07)	8.68 (3.11)	9.14 (3.18)	9.16 (3.18)	9.12 (3.18)	9.00 (3.16)
T_4 - Talc + 2% peptone + 1% $CaCO_3$ + 0.1% carboxy methylcellulose	9.29 (3.20)	9.62 (3.25)	9.82 (3.28)	9.84 (3.29)	9.80 (3.28)	9.65 (3.26)
T_5 - Talc + 1% tryptone + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.58 (3.09)	8.80 (3.13)	9.78 (3.28)	9.79 (3.28)	9.78 (3.28)	9.76 (3.28)
T_6 -Talc + 2% tryptone + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.54 (3.08)	8.61 (3.10)	9.79 (3.28)	9.78 (3.28)	9.72 (3.27)	9.70 (3.27)
T_7 -Talc + 1% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.51 (3.08)	8.65 (3.10)	9.20 (3.19)	9.18 (3.19)	9.15 (3.18)	9.10 (3.17)
T_8 - Talc + 2% tryptone + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.50 (3.08)	8.72 (3.11)	9.20 (3.19)	9.14 (3.18)	9.11 (3.18)	9.00 (3.16)
T_9 - Talc + 1% yeast extract + 1% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.52 (3.24)	9.79 (3.28)	9.90 (3.30)	9.88 (3.29)	9.69 (3.26)	9.46 (3.23)
T_{10} - Talc + 2% yeast extract + 2% glycerol + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.54 (3.24)	9.90 (3.30)	9.92 (3.30)	9.90 (3.30)	9.86 (3.29)	9.82 (3.29)
T_{11} - Talc + 1% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.48 (3.23)	9.82 (3.28)	9.84 (3.29)	9.80 (3.28)	9.75 (3.27)	9.50 (3.24)
T_{12} - Talc + 2% yeast extract + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	9.49 (3.24)	9.84 (3.29)	9.85 (3.29)	9.84 (3.29)	9.70 (3.27)	9.58 (3.25)
T_{13}- Talc + 2% $CaCO_3$ + 0.1% carboxymethylcellulose	8.40 (3.06)	7.84 (2.97)	7.82 (2.97)	7.80 (2.96)	7.55 (2.92)	7.44 (2.90)

T_{14} -Talc + 1% $CaCO_3$ + 0.1% carboxymethylcellulose	8.40 (3.06)	7.73 (2.95)	7.66 (2.94)	7.58 (2.92)	7.29 (2.88)	7.22 (2.86)
T_{15} -Talc + culture broth	8.38 (3.06)	7.56 (2.92)	7.52 (2.91)	7.46 (2.90)	7.25 (2.87)	7.00 (2.82)
T_{16} -Talc alone	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
C.D.	0.05	0.07	0.06	0.05	0.05	0.06
SE(m)	0.01	0.02	0.01	0.01	0.01	0.02

* = mean of three replications. Values in parentheses are square root-transformed values.

cfu – Colony forming unit

Table 4 Effect of potential microbe-based formulations on yield

Treatment	**Avg. no. of fruits/plant***	**Yield(g)/plant***
T_1 - Sick soil	1.3	32.3
T_2 - T_1+ 1 kg FYM with Bc 1	5.7	140.0
T_2 - T_1+ 1 kg FYM with Bc 2	5.3	140.4
T_2 - T_1+ 1 kg FYM with Bc 3	5.0	138.6
T_3 - T_1+1 kg FYM with Pf 1	5.3	140.0
T_3 - T_1+ 1 kg FYM with Pf 2	5.7	140.7
T_3 - T_1+ 1 kg FYM with Pf 3	6.0	140.7
T_4 - T_1+ 1 kg FYM with Bc 1+Pf 1	6.7	159.6
T_4 - T_1+ 1 kg FYM with Bc 1+Pf 2	6.7	159.6
T_4 - T_1+ 1 kg FYM with Bc 1+Pf 3	7.0	224.8
T_4 - T_1+ 1 kg FYM with Bc 2+Pf 1	6.3	140.0
T_4 - T_1+ 1 kg FYM with Bc 2+Pf 2	6.3	140.4
T_4 - T_1+ 1 kg FYM with Bc 2+Pf 3	6.7	159.6
T_4 - T_1+ 1 kg FYM with Bc 3+Pf 1	7.0	224.8
T_4 - T_1+ 1 kg FYM with Bc 3+Pf 2	7.0	224.8
T_4 - T_1+ 1 kg FYM with Bc 3+Pf 3	7.7	234.4
T_5 - T_1+ 2 kg FYM with Bc 1	6.0	140.0
T_5 - T_1+ 2 kg FYM with Bc 2	6.3	140.4
T_5 - T_1+ 2 kg FYM with Bc 3	6.3	140.0
T_6 - T_1+ 2 kg FYM with Pf 1	6.3	140.7
T_6 - T_1+ 2 kg FYM with Pf 2	6.7	159.6
T_6 - T_1+ 2 kg FYM with Pf 3	6.7	159.6
T_7 - T_1+ 2 kg FYM with Bc 1+Pf 1	7.0	224.8
T_7 - T_1+ 2 kg FYM with Bc 1+Pf 2	7.7	238.0
T_7 - T_1+ 2 kg FYM with Bc 1+Pf 3	8.7	296.0
T_7 - T_1+ 2 kg FYM with Bc 2+Pf 1	5.3	140.4
T_7 - T_1+ 2 kg FYM with Bc 2+Pf 2	5.7	140.7
T_7 - T_1+ 2 kg FYM with Bc 2+Pf 3	6.7	159.6
T_7 - T_1+ 2 kg FYM with Bc 3+Pf 1	5.7	140.7
T_7 - T_1+ 2 kg FYM with Bc 3+Pf 2	5.3	140.0
T_7 - T_1+ 2 kg FYM with Bc 3+Pf 3	5.3	140.0

T_8 - T_1+ 1 kg FYM	5.0	138.6
T_9 - T_1+ 2 kg FYM	5.3	140.0
T_{10} - T_1+ Streptocyclin @ 0.1 g/liter of water	7.0	224.8
CD (P=0.05)	0.33	2.60
SE(m)	0.63	0.02

* = mean of three replications, Pf - *Pseudomonas fluorescence*, Bc – *Bacillus* spp.

Combined effect of different talc-based formulations and seedling treatments on wilt incidence

The data depicting the combined effect of different talc-based formulations and seedling treatments on wilt incidence are presented in Table 5. All the treatments of bioagents consisting of either single or integrated application of *Bacillus* spp. and *P. fluorescens* exhibited a significantly high degree of reduction in the incidence of bacterial wilt, which ranged from 31.56 to 65.78% over that of the uninoculated control. The greatest reduction in wilt incidence was observed in treatment T_7, which was enriched with Bc1+ Pf 3 along with 2 kg FYM, which was statistically at par with treatment T_7, which was enriched with Bc1+ Pf 2 isolates along with 2 kg FYM, and the disease control was up to 65.78%. The minimum reduction in wilt incidence over the control was observed in treatment T_8, which was enriched with 1 kg FYM in comparison to the uninoculated control and the disease (20.14%). The results explicitly suggest a greater level of protection from bacterial wilt; thus, the most efficient isolates could be used for biological control. *P. fluorescens* is an effective control measure for managing bacterial diseases, and its application reduced the incidence of bacterial wilt from 85% in the untreated control group to 30% after treatment with *P. fluorescens* (Vanitha *et al*. 2009).

Table 5 Effect of different talc-based formulations and seedling treatments on wilt incidence

Treatment	**Wilt Incidence (%)**	**Disease control (%)**
T_1 - Sick soil	97.40 (81.06)	-
T_2 - T_1+ 1kg FYM with Bc 1	66.66 (54.71)	33.34 (35.25)
T_2 - T_1+ 1kg FYM with Bc 2	64.43 (53.37)	35.56 (36.59)
T_2 - T_1+ 1kg FYM with Bc 3	64.44 (53.37)	35.56 (36.59)
T_3 - T_1+1kg FYM with Pf 1	48.88 (44.34)	51.12 (45.62)
T_3 - T_1+ 1kg FYM with Pf 2	48.88 (44.34)	51.12 (45.62)
T_3 - T_1+ 1kg FYM with Pf 3	44.43 (41.78)	55.56 (48.17)
T_4 - T_1+ 1kg FYM with Bc 1+Pf 1	35.55 (36.58)	64.45 (53.38)
T_4 - T_1+ 1kg FYM with Bc 1+Pf 2	35.55 (36.58)	64.45 (53.38)
T_4 - T_1+ 1kg FYM with Bc 1+Pf 3	35.55 (36.58)	64.45 (53.38)
T_4 - T_1+ 1kg FYM with Bc 2+Pf 1	66.66 (54.71)	33.34 (35.25)
T_4 - T_1+ 1kg FYM with Bc 2+Pf 2	66.66 (54.72)	33.34 (35.25)
T_4 - T_1+ 1kg FYM with Bc 2+Pf 3	50.00 (44.98)	50.00 (44.98)
T_4 - T_1+ 1kg FYM with Bc 3+Pf 1	48.88 (44.34)	51.12 (45.62)
T_4 - T_1+ 1kg FYM with Bc 3+Pf 2	48.88 (44.34)	51.12 (45.62)
T_4 - T_1+ 1kg FYM with Bc 3+Pf 3	50.00 (44.98)	50.00 (44.98)
T_5 - T_1+ 2kg FYM with Bc 1	64.44 (53.37)	35.56 (36.59)
T_5 - T_1+ 2kg FYM with Bc 2	64.44 (53.37)	35.56 (36.59)
T_5 - T_1+ 2kg FYM with Bc 3	66.66 (54.72)	33.34 (35.25)
T_6 - T_1+ 2kg FYM with Pf 1	50.00 (44.98)	50.00 (44.98)
T_6 - T_1+ 2kg FYM with Pf 2	44.43 (41.78)	55.56 (48.17)
T_6 - T_1+ 2kg FYM with Pf 3	44.44 (41.79)	55.56 (48.17)
T_7 - T_1+ 2 kg FYM with Bc 1+Pf 1	35.55 (36.58)	64.45 (53.38)
T_7 - T_1+ 2kg FYM with Bc 1+Pf 2	33.33 (35.24)	66.70 (54.73)

T_7 - T_1+ 2kg FYM with Bc 1+Pf 3	33.33 (35.24)	66.70 (54.73)
T_7 - T_1+ 2kg FYM with Bc 2+Pf 1	73.33 (58.89)	26.67 (31.07)
T_7 - T_1+ 2kg FYM with Bc 2+Pf 2	73.33 (58.88)	26.67 (31.08)
T_7 - T_1+ 2kg FYM with Bc 2+Pf 3	73.33 (58.88)	26.67 (31.07)
T_7 - T_1+ 2kg FYM with Bc 3+Pf 1	50.00 (44.98)	50.00 (44.98)
T_7 - T_1+ 2kg FYM with Bc 3+Pf 2	44.44 (41.78)	55.56 (48.17)
T_7 - T_1+ 2kg FYM with Bc 3+Pf 3	44.44 (41.79)	55.56 (48.17)
T_8 - T_1+ 1kg FYM	77.77 (61.85)	22.23 (28.11)
T_9 - T_1+ 2kg FYM	73.33 (58.89)	26.67 (31.08)
T_{10} - T_1+ Streptocyclin @ 0.1g/ litre of water	50.00 (44.98)	50.00 (44.98)
T_{11} - T_1+ 1kg FYM with *T. koningii* (DMA -8)	64.43 (53.37)	35.56 (36.59)
T_{11} - T_1+ 1kg FYM with *T. harzianum* (TH-11)	64.44 (53.37)	35.55 (36.59)
T_{11} - T_1+ application of 1 kg FYM with *T. harzianum* (TH-5)	66.66 (54.71)	33.34 (35.25)
CD (P=0.05)	2.22 (1.57)	2.08 (1.23)
SE(m)	0.78 (0.55)	0.73 (0.43)

* = mean of three replications; Pf - *Pseudomonas fluorescence*, Bc – *Bacillus* spp.; The values in parentheses are angularly transformed values.

IV. CONCLUSION

The study concludes that nutrient-amended talc-based formulations of Bacillus subtilis and Pseudomonas fluorescens significantly enhance their shelf life and viability for up to 150 days. Application of these optimized biocontrol agents, particularly in combination with farmyard manure (FYM), resulted in a marked reduction in bacterial wilt incidence and improved tomato yield. Integrating these biocontrol agents with organic amendments offers a sustainable and effective strategy for managing soil-borne diseases in tomato, minimizing chemical input and promoting better crop health. The approach facilitates practical field use of biological products, supporting safer, residue-free agriculture and improved farmer outcomes.

COMPETING INTERESTS

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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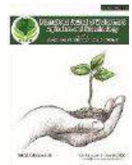

Community Analysis of Soil Nematodes from five Wildlife Sanctuaries of West Bengal (Ballavpur, Bethuadahari, Bibhutibhushan, Raiganj, Ramnabagan), India

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***Abstract*— *Soil nematode community analysis was carried out in five Wildlife sanctuaries (WLS) of West Bengal, namely, Ballavpur, Bethuadahari, Bibhutibhushan, Raiganj and Ramnabagan. The study documented a total of 53 nematode genera belonging to 11 orders and 27 families. In terms of taxonomic diversity, the order Tylenchida exhibited the greatest variety at Ballavpur, Bethuadahari and Ramnabagan WLS. In contrast, the order rhabditida was the most diverse at Bibhutibhushan and Raiganj WLS. In terms of trophic composition, bacterivores represented the highest generic diversity at Ballavpur, Bibhutibhushan, Raiganj, and Ramnabagan, except for Bethuadahari, where plant parasites represented the highest generic diversity. In terms of trophic groups, bacterivores were the most abundant at Bethuadahari, Bibhutibhushan and Raiganj WLS, whereas plant parasites were the most abundant at Ballavpur and Ramnabagan WLS. The Shannon-Weaver (H') diversity and Maturity Index (MI) were highest at Ballavpur WLS with values 1.58 ± 0.01 and 2.62 ± 0.01, respectively. The MI value indicates the study areas are less disturbed. The food web indices, Channel Index (CI), Enrichment Index (EI), and Structural Index (SI), indicate that the study area supports a resource-rich and well-organized soil ecosystem. The present study serves as a preliminary analysis of soil nematodes from these WLS, and this data will be helpful for future long-term ecological monitoring.*

***Keywords*— Abundance, diversity, enrichment, maturity index, trophic bb**

I. INTRODUCTION

Soil nematodes are among the most diverse multicellular organisms living in terrestrial habitats, found in nearly all types of soils. Their population density can be extremely high, with millions of individuals from various taxa present in just one square meter of soil [1]. Functionally, nematodes are classified according to their feeding habits, including bacterial-feeders, fungal-feeders, plant parasites, omnivores, and predators [2]. Bacterial and fungal feeders play a crucial role in breaking down organic matter and recycling nutrients in soil, releasing plant-available nutrients such as nitrogen [3]. On the other hand, plant-parasitic nematodes can negatively affect crop productivity by damaging roots and increasing plants' vulnerability to pathogens [4]. Predatory and omnivorous nematodes feed on other nematodes and small invertebrates, helping regulate nematode populations and maintain the stability of the soil food web [5].

This diversity is determined by various biotic and abiotic factors, including soil type, moisture, temperature, vegetation and land management practices [2]. As a result, they are often used as bioindicators of soil health and environmental disturbance because changes in their community structure can indicate shifts in ecosystem processes [5].

Worldwide, several researchers have conducted studies on the community analysis of soil nematodes in forests, such as [6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Recent studies from

India include [16, 17, 18, 19]. While soil nematode communities have been studied in various regions of India, there is a notable lack of data from the five wildlife sanctuaries in West Bengal. This gap motivated our research to examine the diversity and abundance of soil-inhabiting nematodes in these specific areas of West Bengal. We excluded the order Dorylaimida from the study because work has already been published on Dorylaimida in this particular region [20]. The main aim of our study was to quantify the diversity and abundance of soil nematodes in five wildlife sanctuaries located across five different districts of West Bengal, India.

II. MATERIAL AND METHODS

Soil samples were collected from the forest ecosystem of five wildlife sanctuaries of West Bengal, namely Ballavpur, Bethuadahari, Bibhutibhushan, Raiganj and Ramnabagan, located in five different districts (Birbhum, Nadia, North 24 Parganas, North Dinajpur and Bardhaman, respectively) of West Bengal (Table 1). A narrow-bladed shovel or spade was used for soil sampling. Random sampling was conducted to a depth of 20 cm or more, and a total of 60 soil samples (N=60) were collected from these areas. The collected soil samples were subsequently placed in polythene bags and properly labelled. After labelling, soil samples were brought to the laboratory for further processing**.** Nematodes were extracted from samples using Cobb's sieving and decanting method [21], followed by a modified Baermann's funnel technique [22]. After that, extracted nematodes were fixed instantly in their characteristic body posture by Seinhorst's method in hot formaldehyde acetic acid solution [23]. Later on, the specimens were kept in a cavity block containing glycerine alcohol solution and were transformed in a desiccator for at least 2-3 weeks for proper dehydration. After dehydration, permanent slides were made following the wax ring method [24]. The mounted specimens were studied under a BX-53 DIC Olympus microscope with Cellsens software. Soil nematodes were counted and identified up to the generic level and then classified into trophic groups, namely bacterivores, fungivores, plant parasites and predators [1]. The c-p groups were assigned to the genera as described by [25].

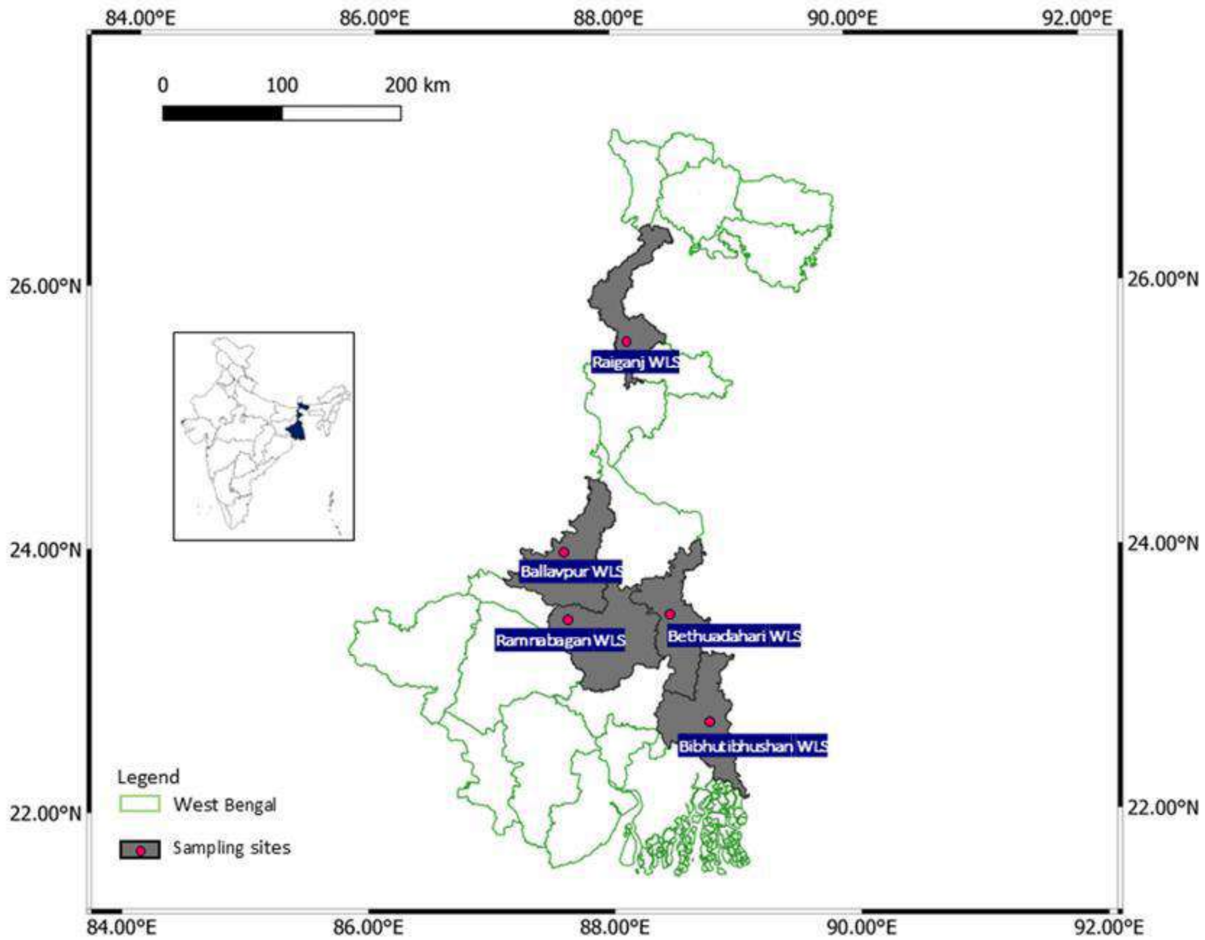

Fig. 1: Sampling locations across five districts of West Bengal

Table 1. Geographic coordinates of sampling sites at five wildlife sanctuaries in West Bengal. Abbreviations for the WLS are mentioned within parenthesis.

Sl no.	Location	Districts	Latitude (N)	Longitude (E)
1.	Ballavpur WLS (Ba)	Birbhum	23º40'936"	87º40'865"
2.	Bethuadahari WLS (Be)	Nadia	23º35'703"	88º23'781"
3.	Bibhutibhushan WLS (Bi)	North 24 Pargana	23º11'215"	88º76'552"
4.	Raiganj WLS (Rai)	North Dinajpur	25º38'246"	88º07'241"
5.	Ramnabagan WLS (Ra)	Bardhaman	23º15'094"	87º51'163"

Community analysis and diversity indices calculated

Frequency (N): the number of samples in which the genus was present.

Absolute frequency (AF %): (Frequency of the genus)/ total number of samples X 100.

Mean density (D): Total nematode specimens of the genus found in samples /total number of collected samples.

Relative density (RD %): Mean density of the genus / Sum of the mean density of all nematode genera X 100.

Shannon's diversity (H'): $-\Sigma$ pi ln pi;

Where Pi represents the proportion of individuals belonging to Taxon *i* within the total population.

Maturity indices (MI) were calculated based on c-p values assigned to different genera of soil nematodes [25].

MI= $\Sigma vi \times fi/n$,

Where vi is the c-p value of the family and frequency of family i in the sample, and n is the total number of individuals in the sample

Plant parasitic index (PPI) was used to assess the nutrient stability [26, 27].

The functional structure of the community was measured by the Wasilewska index (WI), enrichment index (EI), Channel index (CI) and structural index (SI).

Wasilewska index (WI) represents the ratio of bacterial feeders (BF) plus fungal feeders (FF) to plant parasites (PP) as WI = (BF + FF)/PP [28].

Channel index (CI): It reflects the dominance of fungal versus bacterial decomposition pathways in the soil food web.

$$CI = (Fu_2*0.8/ Ba_1*3.2 + Fu_2*0.8) * 100$$ [29].

Enrichment index (EI): The Enrichment Index (EI) reflects the overall biomass of opportunistic bacterivorous (Ba_1 and Ba_2) and fungivorous (Fu_2) nematodes that emerge as a result of organic matter decomposition [29].

$$EI= 100 * e/ (e+b), \text{ where } e = (Ba_1* 3.2) + (Fu_2* 0.8),\ b= (Ba_2+ Fu_2)* 0.8$$

Structure index (SI): The Structural Index reflects the complexity of the soil food web and the extent of interactions among its components within the ecosystem [29].

$$SI = 100* s/(s + b), \text{ Where } s = (Ba+ Pr + Fu + Om, n=3–5) \text{ and } b =Ba_2+ Fu_2$$

Ba: Bacteriovores, Pr: Predatory, Fu: fungivorous & Om: omnivorous nematodes; subscript 1 to 5 represent C-P scale; 3.2 and 0.8 are weighted faunal components [29, 30].

III. RESULT AND DISCUSSION

3.1 Taxonomic diversity

The study revealed a total of 53 nematode genera, belonging to 11 orders and 27 families, collected from soil samples of five Wildlife Sanctuaries in West Bengal. In terms of taxonomic diversity, the order Tylenchida was the most diverse, followed by Rhabditida at Ballavpur, Bethuadahari and Ramnabagan WLS. Order Rhabditida was the most varied, followed by order Tylenchida at Bibhutibhushan and Raiganj WLS (Fig. 2).

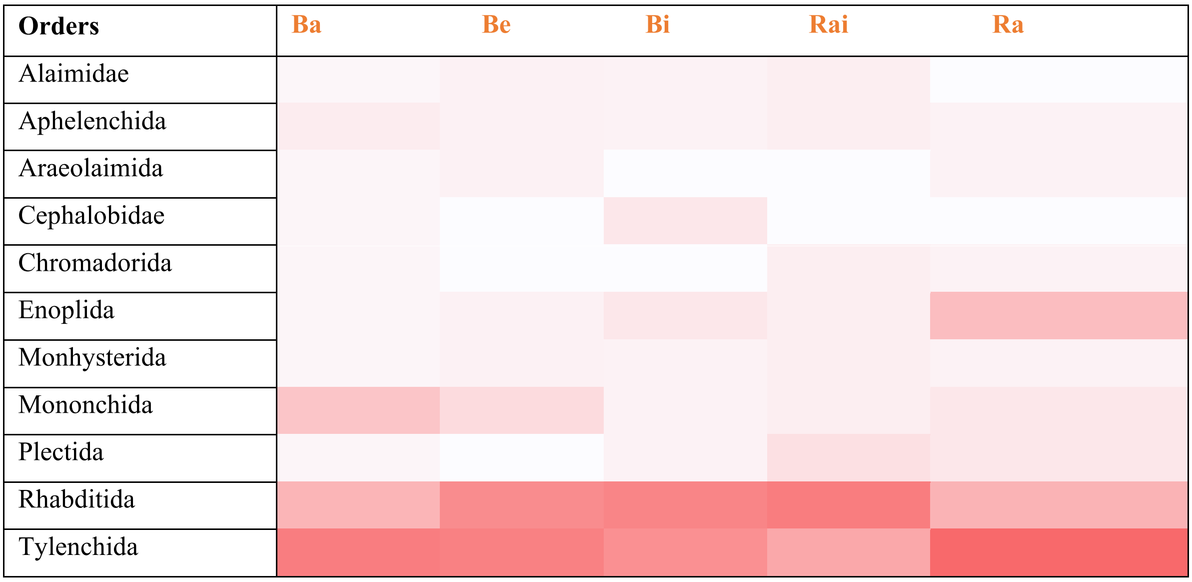

Fig. 2: Soil nematode taxonomic diversity at five WLS of West Bengal

Regarding trophic abundance, Ballavpur WLS represented the highest percentage of plant parasites (43%), followed by bacterivores (33%); Bethuadahari WLS represented the highest percentage of bacterivores (41 %) followed by plant parasites (40%); Bibhutibhushan showed the highest percentage of bacterivores (54%) followed by plant parasites (33%) and Ramnabagan WLS represented highest percentage of plant parasites (43%) followed by bacterivores (39%). The percentage of predators and fungivores was much less compared to the bacterivores and plant parasites within the five WLS. The results indicated that the highest percentage of bacterivores was from Raiganj WLS, followed by Bibhutibhusan WLS; the highest percentage of plant parasites was represented by both Ballavpur and Ramnabagan WLS (Fig. 3a). The highest generic diversity of bacterivores was represented from four WLS-Ballavpur, Bibhutibhushan, Raiganj and Ramnabagan. In contrast, the generic diversity of Plant parasites was highest only at Bethuadahari WLS (Fig. 3b).

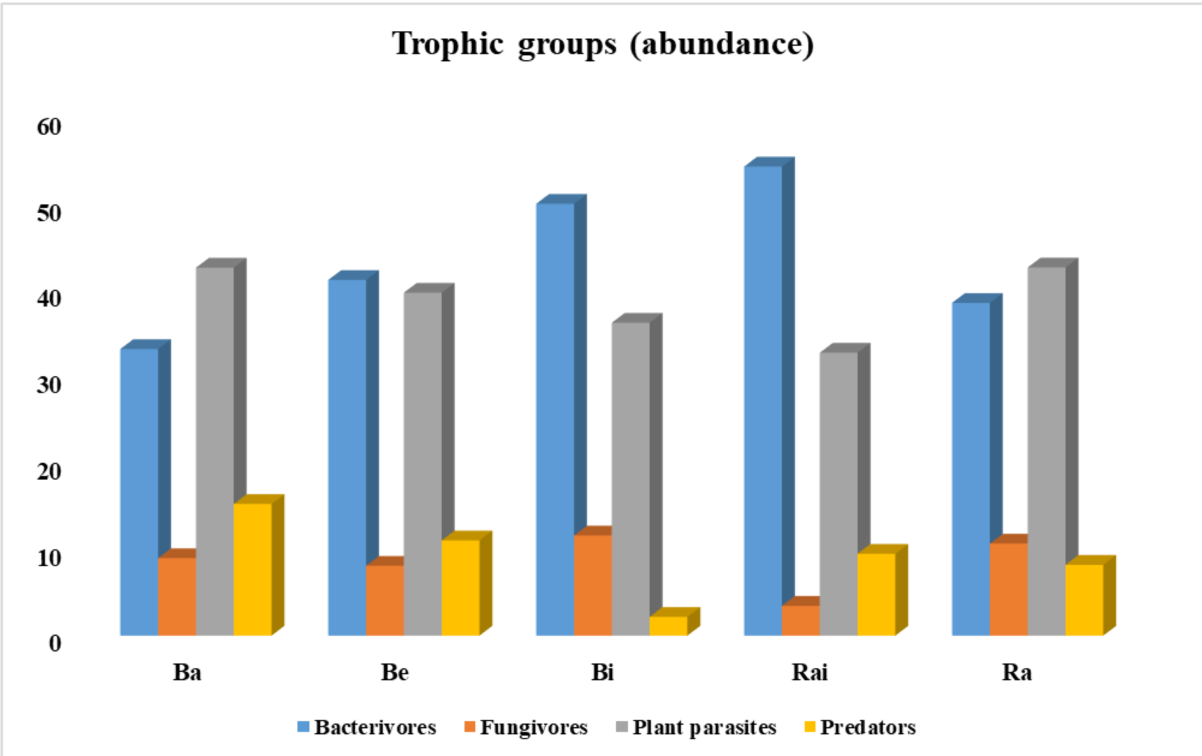

Fig. 3a: Abundance of Trophic groups of soil nematodes

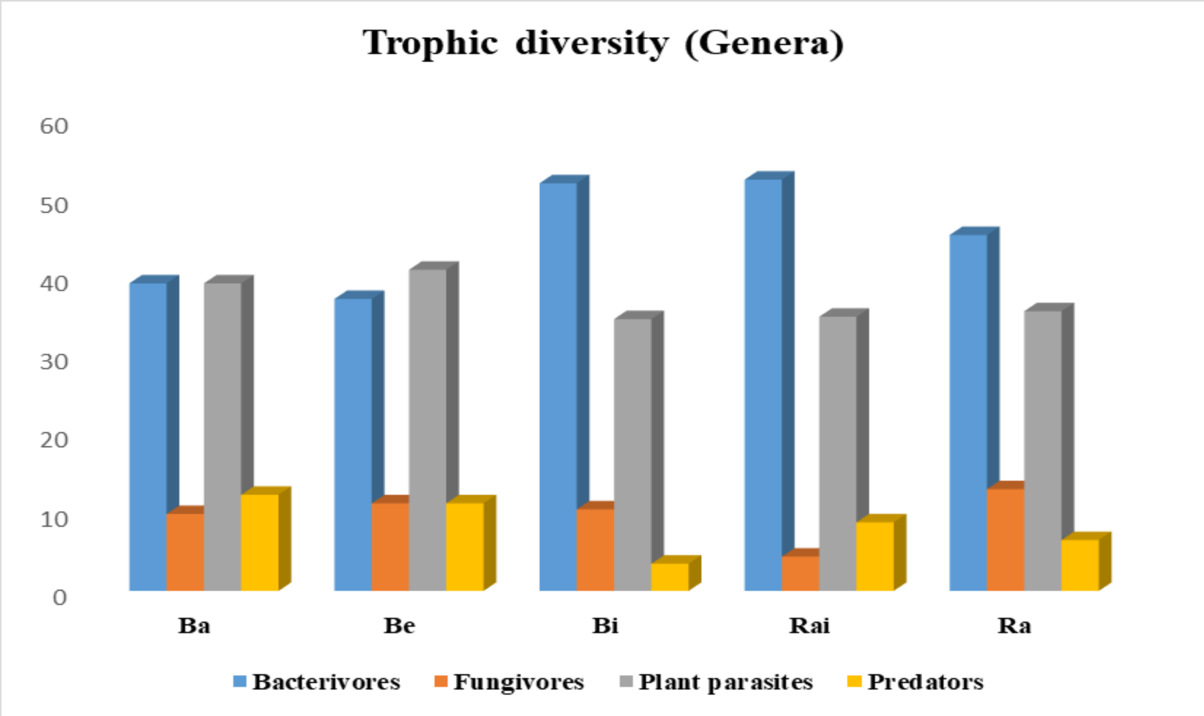

Fig. 3b: Generic diversity of trophic groups

3.2 Nematode diversity

Frequency: In the present study, Genus *Helicotylenchus, Tylenchorhynchus, Rotylenchulus,* and *Ironus* were the most dominant genera, exhibiting the highest frequency of occurrence (N=9, each) among all the nematode communities from these five wildlife sanctuaries (Ballavpur, Bethuadahari, Bibhutibhushan, Raiganj and Ramnabagan).

Among the bacterivores, the genus *Bursilla* showed the highest absolute frequency (N=26 and AF=43 %), whereas *Macrolaimellus and Panagrellus* were recorded the least among them (N=3 and AF=5%). Among fungivores, genus *Aphelenchoides* was the most frequent (N=17 and AF=28%), whereas the least frequent genus was *Aphelenchus* (N=5 and AF=8%).

Regarding plant parasites, the most frequent genus was *Helicotylenchus* (N=38 and AF=63%), whereas the least frequent genus was *Neopsilenchus* (N=4 and AF=7%). The genus *Ironus* showed the highest absolute frequency among all predatory nematodes (N=31 and AF= 52%), in contrast, the least frequent genus was *Parahadronchus* (N=3 and AF= 5%).

3.3 Trophic Relationship among Soil Nematodes

Frequency: After analysing the soil nematode community of all five wildlife sanctuaries, Plant parasites from Ballavpur WLS were found to be the most prevalent group in the entire nematode community, with N=4.62 and AF=38.54. Fungivores from Ramnabagan WLS and Raiganj WLS were the least frequent in the community, with N=2 and AF=16.66 each.

Density: Plant parasites from Ballavpur WLS were the most dominant group in the whole nematode community with D=0.93 and Relative Density (RD) = 3.04, whereas Predators from Bibhutibhushan and Ramnabagan WLS were the least dominant with D=0.34 and RD=1.75 & 1.47 respectively.

Table 2. Nematode community analysis in the five Wildlife Sanctuaries of West Bengal Park (N = 60).

Genera	Frequency					AF%					MD					RD%				
Bacteriovores	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra
Acrobeles	6	2	3	0	4	50.0	16.7	25.0	0.0	33.3	0.58	0.25	0.42	0.00	0.75	1.91	1.05	2.12	0.00	3.23
Acrobeloides	5	2	6	2	5	41.7	16.7	50.0	16.7	41.7	0.42	0.25	0.75	0.25	0.67	1.36	1.05	3.81	1.23	2.87
Alaimus	5	3	4	7	2	41.7	25.0	33.3	58.3	16.7	0.50	0.92	0.42	0.58	0.33	1.63	3.83	2.12	2.87	1.43
Bursilla	8	5	3	4	6	66.7	41.7	25.0	33.3	50.0	1.00	1.33	0.67	0.58	0.83	3.27	5.58	3.39	2.87	3.58

Cephalobus	7	5	4	4	2	58.3	41.7	33.3	33.3	16.7	1.08	0.92	0.75	0.58	0.67	3.54	3.83	3.81	2.87	2.87
Chiloplacus	1	5	6	5	4	8.3	41.7	50.0	41.7	33.3	0.17	0.42	0.75	0.67	0.42	0.54	1.74	3.81	3.28	1.79
Chronogaster	4	0	4	5	2	33.3	0.0	33.3	41.7	16.7	0.67	0.00	0.42	0.67	0.33	2.18	0.00	2.12	3.28	1.43
Cruznema	1	4	0	1	0	8.3	33.3	0.0	8.3	0.0	0.17	0.58	0.00	0.08	0.00	0.54	2.44	0.00	0.41	0.00
Eucephalobus	6	2	7	2	5	50.0	16.7	58.3	16.7	41.7	1.17	0.75	1.00	0.67	0.92	3.81	3.14	5.08	3.28	3.94
Macrolaimellus	0	2	0	1	0	0.0	16.7	0.0	8.3	0.0	0.00	0.33	0.00	0.25	0.00	0.00	1.39	0.00	1.23	0.00
Mesorhabditis	5	6	5	3	4	41.7	50.0	41.7	25.0	33.3	0.75	0.58	0.67	0.42	0.50	2.45	2.44	3.39	2.05	2.15
Panagrellus	0	0	2	0	1	0.0	0.0	16.7	0.0	8.3	0.00	0.00	0.25	0.00	0.17	0.00	0.00	1.27	0.00	0.72
Panagrolaimus	1	0	4	6	0	8.3	0.0	33.3	50.0	0.0	0.17	0.00	0.42	0.92	0.00	0.54	0.00	2.12	4.51	0.00
Paraphanolaimus	0	1	1	0	4	0.0	8.3	8.3	0.0	33.3	0.00	0.17	0.08	0.00	0.42	0.00	0.70	0.42	0.00	1.79
Plectus	1	1	0	2	1	8.3	8.3	0.0	16.7	8.3	0.17	0.08	0.00	0.33	0.08	0.54	0.35	0.00	1.64	0.36
Prismatolaimus	2	3	2	6	4	16.7	25.0	16.7	50.0	33.3	0.33	0.25	0.25	0.58	0.33	1.09	1.05	1.27	2.87	1.43
Protorhabditis	4	6	5	7	2	33.3	50.0	41.7	58.3	16.7	0.42	0.75	0.50	0.92	0.17	1.36	3.14	2.54	4.51	0.72
Pseudacrobeles	8	4	3	3	7	66.7	33.3	25.0	25.0	58.3	1.00	0.67	0.75	0.33	0.75	3.27	2.79	3.81	1.64	3.23
Rhabdolaimus	5	2	0	0	1	41.7	16.7	0.0	0.0	8.3	0.75	0.33	0.00	0.00	0.08	2.45	1.39	0.00	0.00	0.36
Zeldia	1	0	1	0	4	8.3	0.0	8.3	0.0	33.3	0.17	0.00	0.08	0.00	0.42	0.54	0.00	0.42	0.00	1.79
Fungivores																				
Aphelenchoides	6	3	2	3	3	50.0	25.0	16.7	25.0	25.0	0.75	0.42	0.50	0.42	0.58	2.45	1.74	2.54	2.05	2.51
Aphelenchus	1	3	0	1	0	8.3	25.0	0.0	8.3	0.0	0.17	0.50	0.00	0.25	0.00	0.54	2.09	0.00	1.23	0.00
Filenchus	4	2	3	2	1	33.3	16.7	25.0	16.7	8.3	0.42	0.75	0.92	0.50	0.17	1.36	3.14	4.66	2.46	0.72
Plant parasites																				
Aglenchus	3	0	0	2	4	25.0	0.0	0.0	16.7	33.3	0.42	0.00	0.00	0.25	0.42	1.36	0.00	0.00	1.23	1.79
Atetylenchus	6	2	4	2	8	50.0	16.7	33.3	16.7	66.7	0.58	0.42	0.33	0.42	0.92	1.91	1.74	1.69	2.05	3.94
Cephalenchus	0	4	0	1	0	0.0	33.3	0.0	8.3	0.0	0.00	0.33	0.00	0.17	0.00	0.00	1.39	0.00	0.82	0.00
Criconema	3	0	3	0	2	25.0	0.0	25.0	0.0	16.7	0.33	0.00	0.25	0.00	0.17	1.09	0.00	1.27	0.00	0.72
Ditylenchus	3	0	0	0	4	25.0	0.0	0.0	0.0	33.3	0.75	0.00	0.00	0.00	0.42	2.45	0.00	0.00	0.00	1.79
Helicotylenchus	6	8	9	8	7	50.0	66.7	75.0	66.7	58.3	1.92	2.08	1.75	2.75	2.33	6.27	8.71	8.90	13.52	10.04
Hemicriconemoides	3	4	0	2	1	25.0	33.3	0.0	16.7	8.3	0.42	0.58	0.00	0.25	0.33	1.36	2.44	0.00	1.23	1.43
Hemicycliophora	0	2	3	0	4	0.0	16.7	25.0	0.0	33.3	0.00	0.25	0.58	0.00	0.17	0.00	1.05	2.97	0.00	0.72
Hirschmanniella	3	2	6	0	0	25.0	16.7	50.0	0.0	0.0	0.67	0.92	0.58	0.00	0.00	2.18	3.83	2.97	0.00	0.00
Histotylenchus	2	0	3	0	2	16.7	0.0	25.0	0.0	16.7	0.67	0.00	0.33	0.00	0.50	2.18	0.00	1.69	0.00	2.15
Hoplolaimus	3	4	7	0	7	25.0	33.3	58.3	0.0	58.3	0.75	0.42	1.00	0.00	0.92	2.45	1.74	5.08	0.00	3.94
Neopsilenchus	0	0	0	0	4	0.0	0.0	0.0	0.0	33.3	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	1.43
Pratylenchus	5	4	3	2	5	41.7	33.3	25.0	16.7	41.7	0.75	0.58	0.00	0.00	0.00	2.45	2.44	0.00	0.00	0.00
Psilenchus	0	1	1	6	0	0.0	8.3	8.3	50.0	0.0	0.00	0.00	0.00	1.42	0.00	0.00	0.00	0.00	6.97	0.00
Rotylenchulus	6	9	7	4	5	50.0	75.0	58.3	33.3	41.7	1.75	0.92	0.00	0.00	1.17	5.72	3.83	0.00	0.00	5.02
Telotylenchus	5	0	3	3	1	41.7	0.0	25.0	25.0	8.3	0.75	0.00	0.33	0.42	0.17	2.45	0.00	1.69	2.05	0.72
Trichotylenchus	6	0	0	0	0	50.0	0.0	0.0	0.0	0.0	1.00	0.00	0.00	0.00	0.00	3.27	0.00	0.00	0.00	0.00
Trophurus	8	7	4	7	6	66.7	58.3	33.3	58.3	50.0	1.83	2.25	1.58	1.33	2.17	5.99	9.41	8.05	6.56	9.32

Tylenchus	5	4	3	0	3	41.7	33.3	25.0	0.0	25.0	0.67	0.50	0.33	0.00	0.33	2.18	2.09	1.69	0.00	1.43
Tylenchorhynchus	7	8	4	9	8	58.3	66.7	33.3	75.0	66.7	1.67	1.25	0.58	1.33	1.58	5.45	5.23	2.97	6.56	6.81
Predators																				
Achromadora	1	0	0	3	2	8.3	0.0	0.0	25.0	16.7	0.08	0.00	0.00	0.33	0.25	0.27	0.00	0.00	1.64	1.08
Iotonchus	5	6	3	2	4	41.7	50.0	25.0	16.7	33.3	0.67	1.00	0.42	0.67	0.83	2.18	4.18	2.12	3.28	3.58
Ironus	6	5	5	9	6	50.0	41.7	41.7	75.0	50.0	1.00	0.92	0.67	1.17	0.83	3.27	3.83	3.39	5.74	3.58
Mulveyellus	3	0	1	1	2	25.0	0.0	8.3	8.3	16.7	0.33	0.00	0.17	0.17	0.08	1.09	0.00	0.85	0.82	0.36
Mylonchulus	4	2	0	2	1	33.3	16.7	0.0	16.7	8.3	0.83	0.33	0.00	0.42	0.25	2.72	1.39	0.00	2.05	1.08
Parahadronchus	2	0	1	0	0	16.7	0.0	8.3	0.0	0.0	0.67	0.00	0.25	0.00	0.00	2.18	0.00	1.27	0.00	0.00
Paramylonchulus	4	0	1	0	1	33.3	0.0	8.3	0.0	8.3	0.67	0.00	0.17	0.00	0.25	2.18	0.00	0.85	0.00	1.08
Prionchulus	3	2	0	2	0	25.0	16.7	0.0	16.7	0.0	0.58	0.42	0.00	0.25	0.00	1.91	1.74	0.00	1.23	0.00
Sporonchulus	0	2	1	0	1	0.0	16.7	8.3	0.0	8.3	0.00	0.50	0.33	0.00	0.17	0.00	2.09	1.69	0.00	0.72
Tripylina	0	0	4	0	1	0.0	0.0	33.3	0.0	8.3	0.00	0.00	0.42	0.00	0.08	0.00	0.00	2.12	0.00	0.36

Table 3. Community relationship between different trophic groups of nematodes. (BF: Bacterivores; FF: Fungivores; PP: Plant Parasites; PR: Predators).

	BACTERIVORES					FUNGIVORES					PLANT PARASITES					PREDATORS				
	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra	Ba	Be	Bi	Rai	Ra
Frequency	4.11 ±0.16	3.31 ± 0.02	3.75 ± 0.006	3.86 ±0.04	3.41 ± 0.02	3.66 ±0.006	2.67 ± 0.5	6.5 ± 0.13	3 ± 0.03	2 ± 0.08	6.37 ± 0.12	4.53 ± 0.03	4.29 ±0.02	4 ± 0.01	4.44 ±0.02	4.37 ±0.02	3.8 ± 0.001	2.29 ±0.07	3.17 ±0.03	2.25 ±0.07
AF%	34.31 ± 0.2	27.6 ±0.03	31.25 ± 0.14	32.22 ±0.19	28.43 ±0.006	30.55 ± 0.11	22.22 ± 0.30	20.83 ±0.37	16.66 ±0.58	16.65 ±0.58	38.54 ± 0.51	37.82 ±0.47	35.71 ±0.37	34.84 ±0.32	36.97 ±0.43	29.12 ±0.04	28.33 ±0.001	19.04 ±0.46	26.32 ± 0.9	18.75 ±0.47
MD	0.58 ±0.005	0.53 ± 0.002	0.51 ± 0.003	0.52 ± 0.002	0.46 ± 0.005	0.44 ± 0.006	0.55 ±0.001	0.7 ± 0.006	0.38 ±.009	0.375± 0.009	0.93 ± 0.018	0.87 ±0.015	0.69 ± 0.06	0.75 ± 0.009	0.79 ±0.01	0.6 ± 0.06	0.63 ± 0.003	0.34 ±0.01	0.5 ± 0.003	0.34 ±0.01
RD%	1.82 ± 0.035	2.24 ±0.014	2.59 ±0.003	2.56 ±0.002	1.98 ± 0.02	1.45 ±0.05	2.32 ±0.01	3.6 ± 0.05	1.91 ±0.03	1.61 ±0.04	3.04 ±0.026	3.65± 0.056	3.54 ±0.051	4.55 ±0.101	3.41 ±0.04	1.97 ±0.02	2.64 ± 0.006	1.75 ±0.03	2.45 ±0.003	1.47 ±0.05

3.4 Nematode Community Indices

The maturity index (MI) of the soil nematodes in the five Wildlife sanctuaries ranged from (2.52±0.5) to (2.62±0.01), with the lowest value recorded at Bethuadahari WLS and the highest at Ballavpur WLS. The Shannon Diversity Index (H’) varied from (1.45± 0.29) to (1.58± 0.01), with the lowest value from Raiganj WLS and the highest value from Ballavpur WLS. The Plant Parasitic Index (PPI) Varied from (1.27± 0.25) to (1.86± 0.37) (Table 4).

Table 4. Various ecological indices of soil nematodes in five Wildlife Sanctuaries of West Bengal (Mean ± SE)

	Ba	Be	Bi	Rai	Ra
MI	2.62 ± 0.01	2.52± 0.5	2.53± 0.5	2.57± 0.5	2.55± 0.5
H’	1.58 ± 0.01	1.5 ± 0.3	1.52 ± 0.3	1.45 ± 0.29	1.55 ± 0.31
PPI	1.74 ± 0.4	1.31 ± 0.26	1.86 ± 0.37	1.27 ± 0.25	1.32 ± 0.26
PPI/MI	0.66 ± 0.01	0.52 ± 0.1	0.74 ± 0.1	0.49 ± 0.09	0.52 ± 0.1
WI	0.72 ± 0.04	0.97 ± 0.004	1.25 ± 0.06	1.08 ± 0.02	0.72 ± 0.04
EI	68.2 ± 0.05	73.88 ± 1.18	65.27 ± 0.53	74.4 ± 1.29	58 ± 1.99
CI	15.67 ± 0.24	13.13 ± 0.26	14.89 ± 0.09	10.82 ± 0.72	17.64 ± 0.65
SI	76.58 ± 0.71	74.7 ± 0.34	66 ± 1.4	78 ± 1.0	69.7 ± 0.66

The present study on the soil-inhabiting nematodes of West Bengal Protected Areas revealed a total of 53 genera belonging to 11 orders and 27 families. Both plant parasites and bacterivores exhibited the highest generic diversity, with bacterivores showing the highest abundance, followed by plant parasites. Among all the taxonomic groups, Order Tylenchida represented the highest number of genera with a total of 19 genera, followed by Order Rhabditida with a total of 17 genera. Earlier research [11, 31, 32, 33] on soil-inhabiting nematodes in forest areas also found the dominance of bacterivores.

Shannon’s diversity index (H’) of the study area varied from (1.45±0.29) to (1.58± 0.01), with the lowest value at Raiganj WLS and the highest from Ballavpur WLS. Higher values of H’ indicate the ecosystem to be more diverse, whereas lower values indicate the area to be less diverse. The results from the present study show that the areas are not highly diverse. The Maturity Index (MI) varied from (2.52± 0.5) to (2.62± 0.01). Lower value of MI denotes the area to be disturbed, whereas higher values represent the area to be less disturbed. Comparing the five WLS, it can be stated that the highest value of H’ and MI at Ballavpur suggests that this area is less disturbed in comparison to the other WLS.

The plant parasitic index denotes whether a community is disturbed or not, where higher values reflect less disturbance and lower values denote higher disturbance in the area [25]. The present study reflects a considerably higher value of PPI; thus, it can be inferred that the Wildlife sanctuaries are less disturbed.

Food web indices, including the Channel Index (CI), Enrichment Index (EI), and Structural Index (SI), evaluate the structure, function, and nutrient dynamics of the soil ecosystem based on nematode community composition [29].

The Enrichment Index (EI) indicates the dominance of opportunistic organisms, which indicates whether the soil is enriched with nutrients or not. In this study, the value of EI ranged from (58 ±1.99) to (74.4 ± 1.29), suggesting that the study areas are nutrient-rich. Similar results were found in other studies, such as [34] and [35], where higher EI values were associated with bacterial decomposition pathways in the soil.

The Channel index (CI) indicates whether the soil organic matter is enriched with bacteria or fungi. Higher values of CI suggest fungal dominance and lower values reflect bacterial dominance [29]. The present study observed that the value of CI of all five study areas was relatively low, ranging from (10.82± 0.72) to (17.64± 0.65) (Table 4). This decline in the value of CI suggests that the study areas are nitrogen-enriched, which promotes the soil food web toward bacterial-driven decomposition pathways. Some previous studies [34, 36, 37] have also observed that nitrogen-enriched soils tend to exhibit reduced CI values, indicating a shift toward bacterial-driven decomposition processes.

The Structural Index (SI) reflects the level of development and stability within a soil ecosystem, where higher values show a well-structured or mature system and lower values indicate disturbance [29]. Previous studies have shown that the value of SI was higher in forest areas due to the greater abundance of omnivorous and predatory organisms, which contribute to a more complex food web with multiple trophic interactions [38]. In the present study, the value of SI ranges from (66 ± 1.4) to (78 ± 1.0). This higher value of SI supports the earlier findings [29, 30, 39] that associate elevated SI values with relatively undisturbed ecosystems.

IV. CONCLUSION

The analysis of soil nematode communities across five Wildlife Sanctuaries in West Bengal—Ballavpur, Bethuadahari, Bibhutibhushan, Raiganj, and

Ramnabagan—showed significant taxonomic and trophic diversity. The dominance of the order Tylenchida in some sanctuaries and Rhabditida in others reflects habitat-specific ecological conditions. Bacterivores appeared as the most diverse and abundant trophic group in most of the locations, highlighting active microbial decomposition. Simultaneously, the prevalence of plant-parasitic nematodes at particular locations suggests localised plant-nematode interactions. Overall, the findings not only deepen the understanding of nematode diversity in Indian forest soils but also emphasise the utility of nematode communities as reliable bioindicators of soil health. This baseline data can serve as a valuable reference point for long-term ecological monitoring in the region.

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Advancing Sustainability in Indian Banking: A Study of Initiatives and Sectoral Impact

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Abstract— *Environmental degradation and climate change have made sustainable finance a priority across nations. A strong and dynamic sustainable banking system is vital to integrate the climate related and societal challenges in the financial system for inclusive growth of the economy. The concept of sustainability in banking involves aligning financial services with environmental protection, social equity, and responsible governance. Research on sustainability issues within the banking industry has become an increasingly important field of inquiry. Scholars and practitioners are paying closer attention to how banks integrate environmental, social, and governance (ESG) principles into their operations, recognizing that financial institutions play a pivotal role in shaping sustainable economic transitions. By examining these issues, researchers provide valuable insights for policymakers and regulators to strengthen ESG adoption and align financial systems with long-term development and climate goals. The study observes that in recent years, the research and development in this field is more planned, intensive and deliberate. A few latest research papers and studies are mentioned in the literature review. These researches highlight the importance of financial decisions in promoting sustainability. The paper outlines the regulations, guidelines given by the Reserve Bank of India (RBI), mandates from the Securities and Exchange Board of India (SEBI) and the major instruments which are being used in the banking sector to develop a roadmap for the transition towards a sustainable economic and financial model. The study focuses on the initiatives taken by leading banks to promote the sustainability in the banking system of India. The paper identifies the different types of benefits of sustainable banking in banking operations in India. Despite significant progress, Indian banks continue to face structural and operational hurdles in embedding sustainability across governance, lending, and reporting frameworks. The issue of sustainable banking is in a transitional phase. There is a need to focus on the sustainability objectives by regulators, policymakers and financial institutions, to ensure the growth of a resilient and inclusive sustainable financial ecosystem in India.*

Keywords*— *Indian Banking, Sustainability, Social Equity, Regulators, Initiatives, Capital Markets, ESG.

I. INTRODUCTION

Actually, Sustainability Banking means synchronising financial services with the principles of environmental protection, social equity and responsible governance. It goes further than the traditional profit earning model, positioning banks as active contributors to sustainable development. Transforming an economy toward sustainability requires substantial capital mobilization and in India, banks are central to this process. Unlike economies where capital markets dominate, India's financial system is bank-driven, with debt capital primarily routed through banks. This makes the banking sector indispensable in financing the transition to a low-carbon economy. As the backbone of India's industrial and employment landscape, not only the large businesses, but micro, small and medium enterprises (MSMEs) also rely heavily on bank financing for both their capital investment and operational expenditure funding requirements. By embedding sustainability into corporate and project financing, banks enable these enterprises to access funds more efficiently than through capital markets. This ensures that innovation in clean energy, resource efficiency and green infrastructure is supported while promoting inclusive growth simultaneously. Thus, sustainable banking in India is not merely about ethical responsibility; it is about leveraging the country's bank-centric financial architecture to mobilize capital for climate goals, social progress, and national resilience. By integrating ESG principles into lending, governance, and product innovation, Indian banks can act as engines of sustainable transformation, making it certain that the transition to a resilient economy is equitable and effective.

II. OBJECTIVES OF THE RESEARCH

- To examine the concept of sustainability in Indian banking.
- To analyse initiatives taken by Indian banks to promote sustainability in Indian banking.
- To assess the role of the Reserve Bank of India in supporting sustainable banking.
- To identify the benefits of sustainability in banking in India.

III. REVIEW OF LITERATURE

The development of sustainability banking in India has been gradual yet impactful, shaped by both international pressures and domestic priorities. Over time, the sector has mirrored shifts in societal expectations, regulatory frameworks, and market dynamics. Initially, sustainability practices in banks were largely charity activities or obeying minimal environmental rules. But in recent years, the development shows a more deliberate and planned transformation in approach.

> **Sharma and Singh (2018)** document the transition from Corporate Social Responsibility (CSR) as a stand-alone activity to a more inclusive model, where Environmental, Social, and Governance (ESG) principles are embedded into lending and investment decisions of banks and financial institutions.

> **Kumar and Gupta (2020)** highlight the role of government policies and regulatory framework and guidelines by the Reserve Bank of India (RBI) in accelerating this shift. Their study assessed ESG adoption across the banking sector, including regional rural banks and small finance banks, while also considering CSR practices.

> **Gidage and Bhide (2025)** extend the study to explain the approach taken by the banks to integrate sustainability initiatives with societal expectations. Their analysis of direct and indirect impacts of sustainability provides understanding for the banks and others, offering pathways to strengthen the road towards sustainability.

> **Dr. Neetu Kumari et al. (2025)** reviewed ESG adoption across Indian banks. Although there is considerable progress in incorporating ESG considerations in their operations through microfinance and community development schemes or adoption of global models and digital banking etc. by private banks, it is found that there is the absence of standard ESG reporting, inconsistencies in the regulation, excessive compliance costs. Besides, the financial incentives are scarce and there is a shortage of suitable qualified professionals and socio -cultural resistance also. So regulatory harmonization, use of advanced technology, establishing clear reporting norms to grow sustainable investments are recommended by the study.

> **Ayush Saraf (2025)** stressed the importance of sustainable banking in holistic sustainable growth. Although, the Indian banks have come a long way but still a more coordinated, structured, inclusive and policy driven approach is required. Also, banks should invest in training and development of employees on ESG risk assessment and green finance frameworks.

> A framework has been developed by IISc Bangalore (2025) that links sustainable banking practices to measurable outcomes such as resource efficiency and community impact

> The UN Principles for Responsible Banking (PRB) offer a global model for aligning banking with sustainability goals.

> A number of studies by the Bank of England and IMF underscore the financial threat caused by climate change and advocate for stress testing and scenario analysis.

> International Banks like HSBC and Citi have adopted ESG scoring systems, demonstrating improved risk-adjusted returns and capital mobilization for climate action.

This progression clearly proves the movement from compliance-driven and philanthropic efforts to a strategic, legitimacy-based integration of ESG principles, positioning Indian banks as key actors in advancing sustainable development. But still there is a long way to go as per global standards. Globally, the banks benefit from mature ESG frameworks, robust disclosure norms and advanced green finance instruments.

IV. CONCEPT OF SUSTAINABILITY IN INDIAN BANKING

In the Indian context, sustainability in banking refers to the adoption of environmentally responsible and socially conscious practices that aim to reduce the negative impact of financial operations while promoting long-term development. It involves integrating sustainability principles into the core of financial services so that economic growth is pursued in harmony with ecological preservation and social equity. At its essence, sustainable banking means embedding Environmental, Social, and Governance (ESG) principles into everyday banking operations to foster resilience, inclusivity and ecological preservation. Banks are encouraged to adopt eco-friendly policies, finance projects with positive environmental and social outcomes and promote digital and paperless transactions for resource efficiency. Some of the key dimensions include:

- **Green Finance:** Funding for renewable energy, electric mobility and sustainable agriculture.
- **ESG Risk Assessment:** Evaluating environmental and social risk into lending and investment decisions.
- **Sustainability Reporting:** ESG reporting in line with global standards.
- **Financial Inclusion:** Accessing the banking finance and services to underprivileged sections of society to encourage the policy of equitable distribution.
- **Discouraging Harmful Investments:** Avoiding financing activities that contribute to environmental degradation or social harm.

V. INITIATIVES OF SUSTAINABILITY IN INDIAN BANKING

The sustainability initiatives undertaken by Indian banks reflect the sector's growing commitment to environmental protection, social responsibility and sustainable development. These measures target to lessen the environmental footprint of banking operations, expand green finance, and encourage environmentally responsible investments. Guided by the Reserve Bank of India (RBI), the Indian Banks' Association (IBA) and other regulatory bodies, banks have introduced a range of policies, products, and programs to embed sustainability into their business models.

5.1. Regulatory Initiatives:

>**Reserve Bank of India (RBI):** The RBI has played a pivotal role in building the regulatory architecture for sustainable finance. In 2007, it issued guidelines encouraging banks to integrate environmental and social governance (ESG) practices and conduct social risk assessments in credit appraisals. In 2021, the RBI established the Sustainable Finance Group (SFG) to coordinate policies on climate-related risks and sustainability. In 2022, the RBI initiated a discussion paper urging banks to incorporate climate risk into governance and strategic planning.

In 2023, the RBI introduced the Framework for Acceptance of Green Deposits, enabling banks to mobilize funds specifically for green projects. In 2024, the draft of the guidelines on Climate Risk Management and Disclosure were released by the RBI, aligning Indian banking practices with global standards. Collectively, these initiatives have embedded sustainability into the regulatory structure of India's banking system, strengthening long-term climate resilience.

> **Indian Banks' Association (IBA):** The IBA has issued model green banking guidelines to help banks integrate sustainability across operations, from lending practices to internal resource management.

> **Securities and Exchange Board of India (SEBI):** The Business Responsibility and Sustainability Reporting (BRSR) framework of SEBI mandates ESG disclosures for the top listed companies for increasing transparency and accountability in financial markets.

> **Ministry of Finance:** The Ministry of Finance has encouraged public sector banks to promote green bonds, thereby supporting India's emissions target and mobilizing capital for climate-aligned projects.

5.2. Policy Initiatives:

Sustainable financing has become a central pillar of India's banking sector, channeling credit flows into projects that deliver long-term environmental and social benefits. It includes loans, bonds and targeted credit programs supporting renewable energy, waste management, sustainable agriculture, and clean transportation. By embedding sustainability into credit policies, banks reduce climate-related risks while advancing India's national development agenda.

> **State Bank of India (SBI):** In the year 2025, SBI continued to expand its renewable energy portfolio. For example, it extended a ₹3,200 crore loan to KPI Green Energy to scale solar and wind capacity, alongside issuing new green bonds worth ₹6.7 billion to finance clean energy projects. This builds on SBI's long-standing role as India's largest financier of renewable energy.

> **YES Bank:** YES Bank remains active in the green bond market. In April 2025, it disclosed allocations under SEBI's

updated framework for Green Debt Securities, reaffirming its role as one of the pioneers in India's sustainable finance landscape.

> **Axis Bank:** Axis Bank's Sustainable Bond Impact Report 2024-25 highlights partnerships with the International Finance Corporation (IFC), including a $500 million loan to develop India's blue (marine) finance market and scale sustainable projects. The bank also maintains outstanding sustainable notes under its financing framework, channeling funds into renewable and social infrastructure.

> **NABARD (National Bank for Agriculture and Rural Development):** NABARD has intensified its focus on climate-resilient agriculture and eco-friendly rural infrastructure. In 2025, it partnered with the Food and Agriculture Organisation (FAO) of the United Nations to advance carbon finance and sustainable agriculture initiatives, supporting smallholder farmers and rural communities in adapting to climate change.

Together, these initiatives demonstrate how Indian banks and development institutions are redirecting capital flows toward environmentally responsible sectors. By financing renewable energy, resilient agriculture, and low-carbon infrastructure, sustainable financing reduces emissions, conserves resources and positions banking as a driver of India's transition to a sustainable economy.

5.3. Green Infrastructure and Operational Sustainability Initiatives:

Indian banks have significantly expanded their green infrastructure and operational sustainability initiatives. They are performing well in solar adoption, energy efficiency and Indian Green Building Council (IGBC) certifications. Banks in India are increasingly embedding sustainability into their internal operations and infrastructure, aiming to reduce energy consumption, minimize emissions and promote resource efficiency.

> **Solar-powered Facilities:** By the year 2025, the State Bank of India (SBI) has the target to install over 800 solar rooftops and more than 3,500 solar-powered ATMs nationwide. Therefore, the bank is reducing energy dependence by integrating solar power into branch and ATM networks. It is also reinforcing its role as the largest adopter of renewable energy in banking operations.

> **Resource Management Systems:** Leading banks continue to implement rainwater harvesting, waste segregation, and energy-efficient technologies such as advanced Heating, Ventilation and Air Conditioning (HVAC) systems and LED lighting, reducing operational emissions as well as costs. Therefore, banks are lowering operational emissions through efficient resource management systems.

> **Green Building Certifications:** In December 2025, Bank of Baroda received Indian Green Building Council (IGBC) Platinum Certification for its Academy in Ahmedabad and IGBC Silver Certification for Baroda Bhawan in Vadodara, highlighting its commitment to sustainable infrastructure. Therefore, enhancing the credibility by achieving IGBC certifications, which serve as industry benchmarks for sustainable infrastructure.

> **Industry Recognition:** The Indian Green Building Council (IGBC) has expanded its certification programs, with more banks achieving recognition for environmentally sustainable premises, aligning with global benchmarks for green buildings. Therefore, supporting the national goals by synchronizing with India's bigger environment or climate commitments and the push for resource-efficient growth.

5.4. Green Products and Services:

Indian banks have diversified their offerings by introducing innovative green financial products that encourage customers to adopt sustainable choices. These initiatives not only promote environmentally responsible consumption but also strengthen customer participation in India's transition toward a low-carbon economy.

> **Green Car Loans:** Banks such as the State Bank of India (SBI) and HDFC Bank provide preferential loan schemes for electric and hybrid vehicles, incentivizing cleaner mobility solutions. Therefore, these banks are promoting the use of electric or clean technologies and expanding the access to renewable energy solutions.

> **Green Home Loans:** Several banks offer concessional interest rates for housing projects certified as energy-efficient or eco-friendly, stimulating demand for sustainable construction practices. In this way, banks are encouraging resource-efficient housing and infrastructure.

> **Green Deposits:** Customers can place funds into deposit schemes earmarked for ecologically efficient projects, including clean transportation, renewable energy and water conservation. Hence, the banks are mobilizing household savings toward climate-aligned projects.

> **Surya Shakti Solar Finance Scheme (SBI):** SBI provides affordable financing for rooftop solar installations, enabling households and businesses to adopt renewable energy solutions.

These products illustrate how banks are embedding sustainability into retail and corporate finance. By linking customer choices with green credit and investment instruments, these initiatives demonstrate how financial innovation can accelerate India's pathway to a resilient and low-carbon economy.

5.5. Green Bonds and Sustainable Investments:

Green bonds have become a cornerstone of India's sustainable finance market. India ranks among the top 10 countries globally in green bond issuance, reflecting its growing role in climate finance. The following developments show how green bonds are diversifying funding sources and attracting international investors committed to India's low-carbon transition.

> YES Bank pioneered India's first green bond in the year 2015, followed by Axis Bank, HDFC Bank, and SBI, which expanded the market.

> In the Financial Year 2025, the Government of India announced ₹20,000 crore in Sovereign Green Bonds, issued in four tranches to finance renewable energy, clean transportation and energy-efficiency projects.

> Municipal bodies such as the Nashik Municipal Corporation also entered the market, planning a ₹200 crore green bond issuance for urban sustainability projects.

5.6. Paperless and Digital Banking:

Digital transformation continues to be a critical driver of green banking in India. This transition reduces environmental impact, lowers operational costs, and enhances financial inclusion, particularly in rural and remote areas.

> Banks have scaled up mobile banking, internet banking and UPI platforms, reducing reliance on physical documents.

> Initiatives such as e-statements, e-receipts, e-KYC, and digital signatures have streamlined processes and reduced paper usage.

> In the year 2025, the Digital India Program introduced real-time digital document execution for e-bank guarantees, further advancing paperless governance.

> Flagship initiatives like DigiLocker and API Setu were showcased globally as secure, paperless solutions for banking and governance.

5.7. CSR and Community Engagement:

Corporate Social Responsibility (CSR) remains central to sustainable banking, with banks funding environmental and community projects. These initiatives highlight the social dimension of sustainable banking, fostering community engagement and environmental stewardship.

> Indian Bank reported a ₹25.56 crore CSR spend in the Financial Year 2025, focusing on biodiversity conservation, afforestation, and clean energy programs.

> ICICI Bank committed over ₹800 crore to CSR initiatives in the Financial Year 2025, supporting rural healthcare, environmental awareness campaigns and renewable energy adoption.

> Broader industry trends show banks and corporates investing in tree plantation drives, afforestation, waste reduction and environmental education, strengthening community participation in sustainability.

VI. IMPACT OF SUSTAINABLE BANKING IN INDIA

Sustainable banking provides a holistic framework that integrates financial performance with environmental stewardship and social responsibility. Its impact extends across environmental, economic, social, reputational, regulatory and developmental dimensions, positioning it as a cornerstone of India's sustainable growth agenda.

> **Environmental Impact:** Through digitalization/ paperless transactions and energy-efficient technologies, banks reduce their ecological footprint. Financing renewable energy projects such as solar, wind and bioenergy accelerates the transition to a cleaner energy mix. Support for sustainable agriculture and eco-friendly infrastructure further conserves biodiversity and natural resources. These initiatives advance environmental protection and align with UN SDG 13: Climate Action.

> **Economic and Financial Impact:** Integrating sustainability into banking operations enhances financial resilience. Digital platforms lower costs and improve efficiency while instruments like green bonds, loans and deposits create new revenue streams. Environmental risk assessments strengthen asset quality and reduce exposure to unsustainable industries. By attracting ESG-focused investors, banks secure long-term profitability and broaden capital access. Importantly, adherence to ESG principles attracts international capital, strengthening India's position in global sustainable finance markets.

> **Social Impact:** Sustainable banking promotes inclusive growth by extending services to rural and underserved communities. Community-oriented initiatives — including afforestation, clean energy adoption, and environmental education — generate local employment and encourage eco-conscious behaviour. In this way, banks act as a bridge between financial development and social welfare. These practices strengthen the social contract between banks and society, embedding sustainability into everyday financial intermediation.

> **Reputational and Strategic Impact:** Commitment to sustainability enhances institutional credibility and brand identity. Banks that adopt transparent and responsible practices gain customer loyalty and investor trust. Alignment with global frameworks like the Equator

Principles and the UNEP Finance Initiative provides global recognition and partnership opportunities, strengthening competitive advantage.

> **Regulatory Impact:** Sustainable banking aligns with evolving regulatory frameworks, including RBI's guidelines on green finance and SEBI's ESG disclosure requirements. Proactive compliance with international standards such as the Equator Principles and TCFD (Taskforce on Climate-related Financial Disclosures) strengthens transparency and risk management. Banks that proactively integrate these requirements reduce exposure to stranded assets and regulatory penalties, thereby improving resilience and compliance efficiency. By anticipating regulatory shifts, banks reduce legal exposure and ensure smoother integration into global financial systems.

> **National and Global Development Impact:** At the macro level, sustainable banking channels capital into sectors driving green growth — renewable energy, waste management, and sustainable agriculture. These efforts support India's Net-Zero 2070 target and commitments under the Paris Climate Agreement, aligning economic expansion with environmental preservation.

Table 1: Impact of Sustainable Banking with Case Studies

Dimension	Case Study Example	Impact
Environmental	SBI Green Bonds	Reduced carbon footprint, supported clean energy transition, aligned with UN SDG 13
Economic & Financial	Yes Bank Renewable Energy Financing	Diversified revenue streams, improved asset quality, attracted ESG-conscious investors
Social	SBI Financial Inclusion Programs	Expanded access to finance, generated local employment, supported community initiatives
Reputational & Strategic	Indian Banks & Global Frameworks	Enhanced brand identity, improved customer loyalty, gained international recognition
Regulatory & Risk Management	RBI & SEBI ESG Disclosure Mandates	Strengthened compliance, reduced exposure to stranded assets, safeguarded against penalties
National & Global Development	India's Net-Zero 2070 Pathway	Advanced national sustainability targets and Paris commitments

VII. CONCLUDING REMARKS

Thus, we come to point out that sustainable banking has evolved from a peripheral concept into a central pillar of India's financial ecosystem. It represents a transformative shift in the conventional banking model, redefining the functions of banks and other financial institutions from passive intermediaries to active drivers of sustainable development. By embedding environmental, social, and governance (ESG) principles into governance structures, lending practices, product innovation and operational frameworks, Indian banks are reshaping the trajectory of finance toward resilience, inclusivity and ecological responsibility.

The impact of this transformation is multidimensional. Environmentally, banks are financing renewable energy, clean transportation, and resource-efficient housing, thereby reducing emissions and supporting India's climate commitments. Economically, sustainable banking enhances efficiency by channeling credit flows into sectors that generate long-term value while mitigating climate-related risks. Socially, banks are expanding financial inclusion through digital platforms, green loans and CSR initiatives that empower communities and promote environmental stewardship. Institutionally, sustainability strengthens reputational capital, regulatory compliance, and investor confidence, positioning Indian banks as credible actors in global capital markets.

Yet, challenges persist. Regulatory fragmentation, inconsistent ESG data, limited institutional capacity and technology barriers continue to slow progress. Public sector banks, constrained by legacy systems, lag behind private institutions in adopting ESG frameworks. Globally, the banks benefit from mature ESG frameworks, robust disclosure norms and advanced green finance instruments. However, regulatory pressure from the RBI and the Securities and Exchange Board of India (SEBI), alongside global partnerships with UNEP Finance Initiative (FI) and International Finance Corporation (IFC), is gradually bridging these gaps. The circulation of the sovereign green bonds in Financial Year 2025 and the expansion of green deposits and ESG-linked loans demonstrate that sustainable finance is no longer experimental but increasingly mainstream. Looking ahead, sustainable banking will grow further in aligning the financial system of India with its

2070 net-zero target and the United Nations Sustainable Development Goals (SDGs).

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Profitability and Value Addition in Wheat Supply Chain in Kangra Valley of Himachal Pradesh, India

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***Abstract*— *Wheat is a critically important crop in the Kangra district, serving as a primary source of food security and livelihood for a large portion of the population. The need to analyze its processing costs, returns, and value addition stems from the necessity to improve farmer incomes and make the local agricultural economy more resilient. Thus, an attempt has been made in this research script toanalyse the costs and return from processing of wheat and degree of value addition at each stage of the supply chain in wheat in mid hills of Himachal Pradesh. The results revealed that processing of wheat in the study area incurred both variable and fixed costs, which influenced the overall cost structure. Study indicated that raw material (grain), energy expenses, labour and packaging costs, staff salary were the important components of variable costs which accounted to Rs. 2,619,95 per quintal while, interest on term loans and depreciation were the constituents of variable costs which amounted to Rs. 135.68 per quintal. As a result, the total processing cost was Rs. 2,755.63 per quintal. The returns from processing in the study area showed processing add value to the final product. The processing unit was functioned at a utilization capacity of 0.96, which means the unit is operated at 96 per cent of its capacity. The gross return was Rs. 3400 per quintal. After deducting processing and marketing costs from gross return, the net revenue was Rs. 494.37 per quintal. The degree of value addition in wheat differs across the different supply chains. According to the results, at processor's stage, the degree of value addition in channel III was highest which was worked out to be 23.79 per cent and lowest at trader's level which was found to be 4.9 per cent. Consequently, the highest degree of value addition was exhibited in the processing channel i.e. channel III. In channel II, the intermediaries added 5.50 per cent value at retailer level to 7.28 per cent value at secondary wholesaler level whereas in channel III, it varied from 4.90 per cent at traders stage to 23.79 per cent at flour millers stage before reaching to retailer and then to ultimate consumers. This suggested that longer marketing chain involving traders and processors exhibited higher degree of value addition in wheat in the study area. Therefore, farmers can and should be encouraged to directly link with processors or flour mills so that they can take part in value added activities that can augment their returns and revenues by effectively capturing value along the chain.*

Keywords*— *costs and returns, mapping, wheat, value chain, value addition, Kangra Valley.

HIGHLIGHTS

a) *Processing cost of wheat*
b) *Processing returns from wheat*
c) *Value chain map of wheat*
d) *Degree of value addition in wheat.*

I. INTRODUCTION

Wheat is the most important *rabi* (winter) cereal crop and a dietary staple, primarily consumed in the form of *chapatis* (flatbreads), in the region. Agriculture is the main occupation for over 90% of Himachal Pradesh's population, with Kangra being a major producer of wheat.

The crop provides direct employment and forms the backbone of the agrarian economy. The rice-wheat and maize-wheat rotations are the dominant cropping systems in the Kangra valley, encompassing vast areas of cultivated land. Wheat straw is a nutritious and important source of fodder for local livestock, creating an interdependent farming system.

Calculating processing costs, returns, and the degree of value addition is essential for the following reasons: The average income of agricultural households in the region is often low compared to their expenditure. Analyzing costs and returns helps identify inefficiencies and opportunities to enhance net returns, especially for small and marginal farmers. Accurate data on economics is crucial for formulating effective agricultural policies, selecting appropriate production and processing strategies, and identifying regional comparative advantage. Reliance solely on primary produce makes farmers vulnerable to market forces and price fluctuations. Value addition can create stable, higher-value products, such as flour, biscuits, and other bakery items, that fetch better prices. The cost of cultivation is rising due to factors like labour costs and climate change impacts. Understanding the processing economics can offset these challenges by increasing the final product's value. While the state promotes diversification into high-value cash crops, improving the profitability of traditional staples like wheat through value addition ensures food and nutritional security while providing viable alternative income streams.

Value addition at various stages transforms raw wheat into higher-value products, increasing income potential. By working out the specific costs and returns at each stage of marketing, farmers and local entrepreneurs can identify the most profitable processing avenues and attract necessary investment for local agro-industries.

Wheat value chain mapping visually charts the journey from farm to consumer, identifying actors / functionaries such as input suppliers, farmers, traders, processors, retailers and the their activities like input supply, growing, harvesting, storing, milling, selling where value is *added*, primarily through processing wheat into flour, maida and logistical functions like grading, storage, and distribution, with processors and retailers often adding significant value, though farmers add the initial fundamental value but often get a smaller profit share.

There are various stages in wheat value chain and the various functionaries that are involved in at each stage who add value when the produce goes through their hand. In case of wheat input suppliers provide seeds, fertilizers, insecticides, pesticides, herbicides, modern production technology and machinery to wheat growers who grow wheat and adding fundamental value through cultivation. Value addition at each stage is assessed through by doing basic production at farmer's level that has the potential for growing quality crops by using high yielding and good quality seeds, disease resistance varieties and better farming practices. Village traders, commission agents buy wheat produce from the farmers. Wholesalers buy wheat in bulk, sort, clean, grade to improve quality and store the grain to prevent losses and then the wholesalers sell to the processors or retailers. Processors then do value addition by way of milling wheat into flour, suji, maida, etc. Transforming raw wheat into high-demand products (flour, maida, etc.), creating the *highest* relative value addition done by the processors. Then, retailers come into picture. They buy wheat flour, suji, maida from the processors who ultimately sell it to consumers, adding value through convenience and smaller quantities. Consumers are the final destination of different stages of wheat value chain.

Value addition activities generally increase the final market price and the share of profit for those involved. With this background in view, an attempt has been made in this research script to evaluate the cost and return from processing of wheat into flour, value chain map, and the value addition at different stages of supply chain in Kangra district of Himachal Pradesh.

II. METHODOLOGY

2.1 Selection of the Study Area: The present study was purposively under taken in Kangra district of Himachal Pradesh as this district holds the first position in terms of wheat production in the state. The district produced about 1, 35,247 metric tons of wheat as per the statistical abstract of Himachal Pradesh (2021-22). As a result, this region was suitable for investigating the supply chain and value addition processes associated with wheat cultivation. This district also has an established network of agricultural markets and functionaries who are involved in transferring the produce from its production point to end consumers. This enabled the mapping of multiple marketing channels for wheat.

2.2 Sampling Plan and Sample: Multistage random sampling was adopted for the selection of the sample for this study. In order to achieve the objective of the study, list of wheat growing blocks of Kangra district was prepared first and then two blocks namely, Nurpur and Indora were selected randomly in the first stage. These two blocks have the highest potential of agricultural marketing of wheat as these two blocks are located in the adjoining area of Punjab. In the second stage, list of wheat growing villages was prepared for these two selected blocks in consultation with the official of the agricultural department. The five villages in each block were selected randomly. In the third stage, a list of wheat growing farmers in each selected village was prepared and eight farmers from each selected village were selected randomly that made it a total sample of 80 farmers which was selected for the study. For the analysis of data, farmers were classified into two categories, viz, small and large based on the size of their land holding using cumulative square root frequency method. By following this method, those farmers having land holding less than one hectare, we call it as small and their number was 43 and those farmers having land holding lies between 1-3 ha, we call it as large and their number was 37. Thus, total samples of 80 household were analyzed for this study.

2.3 Data Requirement: Both primary and secondary data were collected. Primary data were gathered from the sampled households on a well designed and pre-tested schedule by personally interviewing the cultivators for the agricultural year 2024-25. In addition, data from flour miller, traders, and commission agents, five each were also collected to understand the supply chain dynamics and value additions. Secondary data were collected from government publications, Statistical Abstracts of Himachal Pradesh.

2.4 Analytical Framework: To arrive at the results, simple averages, percentages, ratios were employed and cost concepts were applied to calculate processor's level economics. Marketing margins, price spreads and degree of value addition were calculated for different marketing channels using formulae available in the literature.

The procedure for working out the **degree of value addition** at each stage of the wheat supply chain involves calculating the margin (selling price minus all associated costs) for each actor, and then expressing this margin as a percentage of the total value added across the entire chain.

Step-by-Step Procedure for calculating the degree of value addition:

Here is the procedure for calculating the degree of value addition which was followed:

1. **Map the Supply Chain:** Identify all the key actors and stages in the specific wheat supply chain being studied. A typical chain might involve:
    a. Input Suppliers (seed, fertilizer)
    b. Farmers (production)
    c. Village Traders/Collectors (aggregation)
    d. Wholesalers (storage and distribution)
    e. Processors (milling into flour, rawa, etc.)
    f. Retailers (sale to consumers)
    g. Consumers

2. Collect Data for Each Stage: Gathered data on prices and costs for each actor or functionary involved. This typically involves surveys and interviews with the stakeholders. Key data points are:

a. Purchase Price: The price at which an actor buys the wheat or intermediate product.

b. Selling Price: The price at which the actor sells the product.

3. Marketing & Operating Costs: All costs incurred during that stage, including transportation, labor, storage, packaging, processing, and any taxes or commissions.

4. Calculate the Margin at Each Stage: For each actor, determine their gross margin by subtracting their costs from their revenue (selling price).

Example: A wholesaler buys wheat for ₹2,682.99 per quintal and sells it for ₹2,922.44 per quintal, incurring marketing costs of ₹67.09. Their margin is ₹2,922.44 - (₹2,682.99 + ₹67.09) = ₹172.36.

5. Calculate the Degree of Value Addition:

a. Per Stage (as a percentage of purchase price): Divide the margin by the initial purchase price at that stage and multiply by 100 to get a percentage value added relative to the product's value when acquired.

b. Overall Share (as a percentage of total chain value): Sum the margins of all actors to find the total value addition in the entire supply chain. Then, divide each individual actor's margin by this total sum and multiply by 100 to determine their percentage share of the total value addition.

In short, the primary formulas used for finding out the percentage share of the degree of value addition in wheat at each stage are:

- **Margin at each stage** = Selling Price - (Purchase Price + Marketing Costs + Processing Costs)
- **Value Addition at each stage (%)** = (Margin at each stage / Purchase price at that stage) * 100
    - *Alternatively, as a share of total value added:*
- **Percentage Share of Total Value Addition (%)** = (Margin at each stage / Sum of margins at all stages) * 100

III. RESULTS AND DISCUSSION

3.1 Results:

3.1.1 Processing cost and degree of value addition

3.1.1a Processing cost of wheat

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Wheat processing primarily involved flour milling (Table 3.1). The total variable cost per quintal was Rs. 2,619.95, which included raw material, energy, labour, packaging and staff salary. Fixed costs of Rs. 135.68/quintal were incurred for interest and depreciation, resulting in a total processing cost of Rs. 2,755.63/quintal.

Table 3.1: Processing cost of wheat

Particulars	**Cost (Rs./Quintal)**
1. Variable cost	
a. Raw material	2521.87
b. Energy expenses	25.02
c. Labour and packaging cost	35.00
d. Staff salary	38.06
Total Variable cost	2619.95
2. Fixed cost	
a. Interest on term loan and working capital	85.15
b. Depreciation	50.53
Total fixed cost	135.68
Total processing cost	2755.63

3.1.1b Returns from processing of wheat

The economic viability of wheat processing, as presented in Table 3.2, was examined by estimating gross returns, processing costs, marketing costs, and net returns per quintal of processed wheat. The processing unit operated at 96 per cent of its capacity, indicating efficient use of resources.

The gross returns obtained from selling processed wheat were recorded **at** Rs. 3400 per quintal**.** The marketing cost**,** including expenses for transportation, packaging, and handling was Rs. 150 per quintal**.**

The total processing cost, which includes variable costs as well as fixed costs, was found to be Rs. 2755.63 per quintal. The net return from processing wheat was Rs. 494.37 per quintal**,** indicating a reasonable profit margin for the processing unit.

These results highlight that wheat processing can provide additional value to the raw produce, improve profitability for processors, and contribute to overall efficiency in the supply chain.

Table 3.2: Returns from processing of wheat

Particulars	**Cost (Rs./Quintal)**
Capacity utilized	0.96
Gross returns	3400.00
Marketing cost	150.00
Total processing cost	2755.63
Net return	494.37

This analysis demonstrates the potential profitability of wheat processing and emphasizes the importance of optimizing both processing operations and marketing strategies to maximize net returns for stakeholders

3.1.1c Value chain map of wheat

Sequence of operations and procedures that occur from farming to their final consumption by end consumers is known as value chain. It involves various steps, each of which enhances the value of final product. Value chain mapping refers to visual representation of sequence of operations and procedures that a good or service goes through from conception through delivery to final consumer. Value chain map helps to identify each step taken in developing and providing the good, as well as the value contributed to each one. The value chain maps for wheat in the study area are showed in Figure 3.

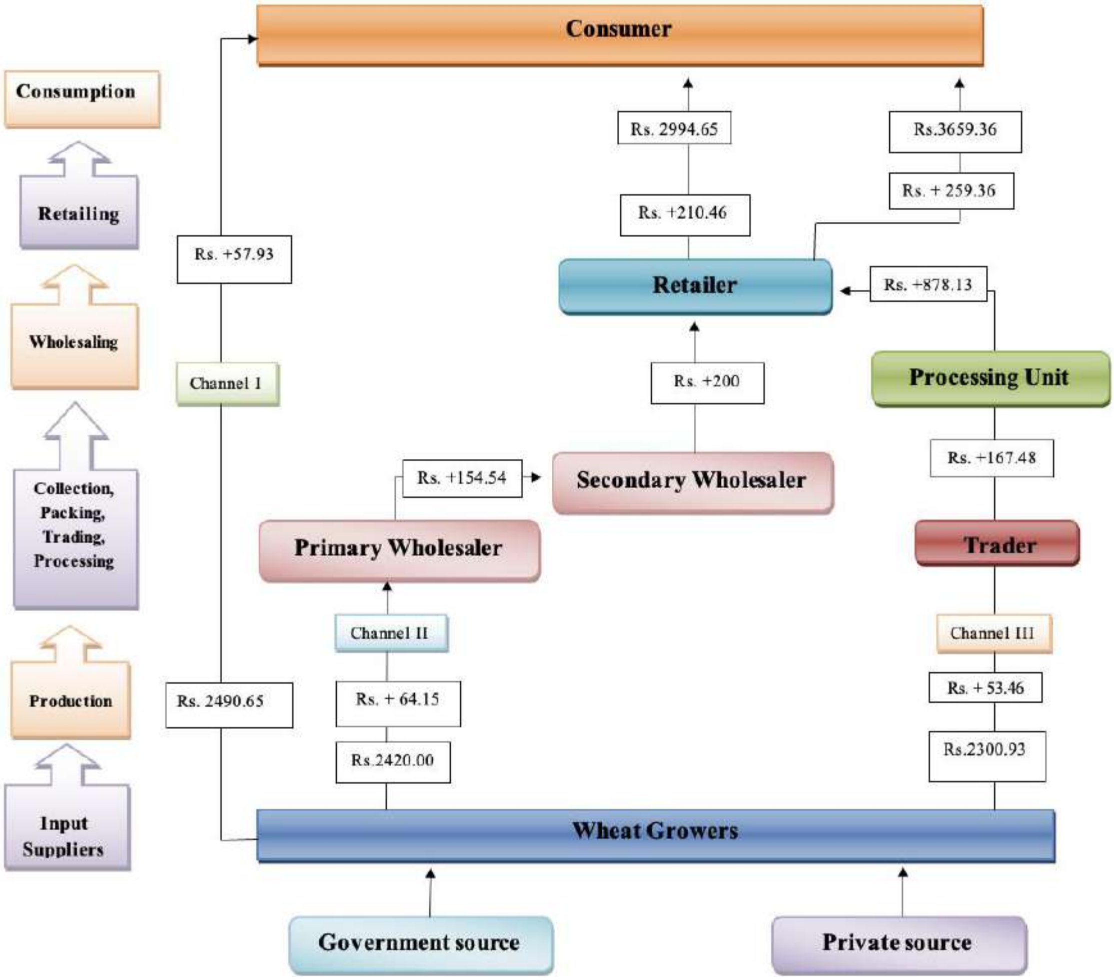

Fig.3: Value chain map of Wheat

3.1.21c Degree of value addition in wheat

As wheat move through the supply chain and change possession among various actors the value changes and this process is known as value addition. The extent of value addition is determined by the quantity or percentage increase in the product's value.

Degree of value addition in wheat is presented in Table 3.3. According to the results, the degree of value addition in channel -III was highest at the flour miller's stage (23.79%). This indicated that the processing channel exhibited the highest degree of value addition, as the transformation of raw grain into flour significantly raised both its market price and consumer demand. As a result, the processing channel exhibited the highest degree of value addition. In case of processed wheat (flour), some of the important approaches to maximize value addition include processing into refined flour or diversified products, improved packaging, better storage and preservation techniques, along with effective marketing and branding strategies that create consumer preference. At channel II, the highest degree of value addition was found to be at the retailer's stage i.e., 7.58 per cent, mainly through conducting tasks such as transportation, handling, and direct retailing of the produce to final consumers.

Table 3.3: Degree of value addition in wheat

Particulars	**Degree of Value Addition (%)**			
Channel II	**Producer → Wholesaler**	**primary wholesaler → secondary wholesaler**	**secondary Wholesaler → Retailer**	**Retailer → Consumer**
Sale price(Rs./q)	2484.15	2638.69	2783.69	2994.65
Purchase price(Rs./q)		2484.15	2638.69	2783.69

Cost(Rs./q)	64.15	98.52	75.00	90.58
Margin (Rs./q)		56.02	70.00	120.38
Degree of Value addition (%)		(6.22)	(5.50)	(7.58)
Channel III	**Producer → trader**	**Trader → Flour → Miller**	**Flour Miller→ Retailer**	**Retailer → Consumer**
Sale price (Rs./q)	2354.39	2521.87	3400.00	3659.36
Purchase price (Rs./q)		2354.39	2521.87	3400.00
Cost (Rs./q)	53.46	105.63	150.00	89.36
Margin (Rs./q)		61.85	494.27	170.00
Degree of Value addition (%)		(4.90)	(23.79)	(7.63)

3.2 Discussion:

3.2.1 Processing cost and degree of value addition

3.2.1a Processing cost of wheat

The processing of wheat in study area incurred both variable and fixed costs, which significantly influenced the overall cost structure. Study revealed that variable costs were raw material cost, energy expenses, labour and packaging costs, staff salary, accounted to ₹2,619.95 per quintal. Fixed costs were interest on term loans and depreciation, amounted to ₹135.68 per quintal. Consequently, the total processing cost was ₹2,755.63 per quintal. These results are consistent with findings from Himachal Pradesh by Mandial (2025), who noted that raw material and labor were the dominant cost components in wheat processing. Efficient management of processing costs is therefore critical for improving profitability and ensuring better returns for producers and processors.

3.2.1b Returns from processing of wheat

The returns from wheat processing in the study area showed that processing add value . Capacity utilization of processing unit was 0.96, which means unit operated at 96 per cent of its capacity. Gross returns were Rs. 3,400 per quintal, and after deducting processing and marketing costs, the net return was Rs. 494.37 per quintal. This finding was consistent with Mandial (2025), which showed that post-harvest processing increases profitability**.** Torane, 2023 also observed that processing resulted in higher returns, indicating the economic advantage of value addition in agricultural produce. Overall, processing provides an effective means to augment their income beyond farm level earnings.

3.2.1c Degree of value addition in wheat

The degree of value addition in wheat differs across marketing channels. According to results, the degree of value addition in channel -III was highest at processor's stage (23.79%) and lowest at the Trader's stage (4.90%). As a result, the processing channel exhibited the highest degree of value addition. Similar findings of higher value addition in after processing were reported by Sharma et al. 2010**.** In Channel II, intermediaries added 5.50 to 7.28 per cent value, whereas in Channel III, it ranged from 4.90 to 23.79 per cent, reflected higher value addition in longer marketing chains involving traders and processors. Similar findings were observed by Kumar (2022) in the apple value chain in Shimla, Himachal Pradesh, where post-harvest handling and processing significantly increased market value. This indicates that improved processing and marketing practices can enhance returns for farmers by effectively capturing value along the chain.

IV. CONCLUSION

The study on the cost and returns of processing and the degree of value addition of wheat at each stage of marketing bring forth the following points: Firstly, the cost and returns structure from processing suggested that the average cost of processing which includes variable costs as well as fixed costs was found to be Rs. 2755.63 per quintal. Total variable cost per quintal was Rs. 2619.95. Fixed cost was accounted Rs. 135.68 of total processing costs. On average, the plant generated a net return of Rs. 494.37 per quintal. Secondly, channel-I (Producer → Consumer) was identified as the most efficient marketing channel. Thirdly, the cost of processing and margin of processing unit were found to be high in channel III, making this channel the least efficient marketing route. Fourthly, according to the results, the degree of value addition in channel -III was highest at the flour miller's stage (23.79.60%). This indicated that the processing channel exhibited the highest degree of value addition, as the transformation of raw grain into flour significantly raises both its market price and consumer demand. Consequently, the processing channel exhibits the highest degree of value addition. And lastly, at channel II, the highest degree of value addition was found at retailer's stage (7.58 per cent) for the reason that at this stage the tasks of transportation, handling and direct retailing of produce to ultimate consumers were being conducted at this stage.

Therefore, from policy perspective, as the flour mill channel (Channel-III) provides the highest value addition, farmers should be encouraged to directly link with flour mills or form processing cooperatives/FPOs so that they can participate in value-added activities and capture a greater share of the consumer's rupee.

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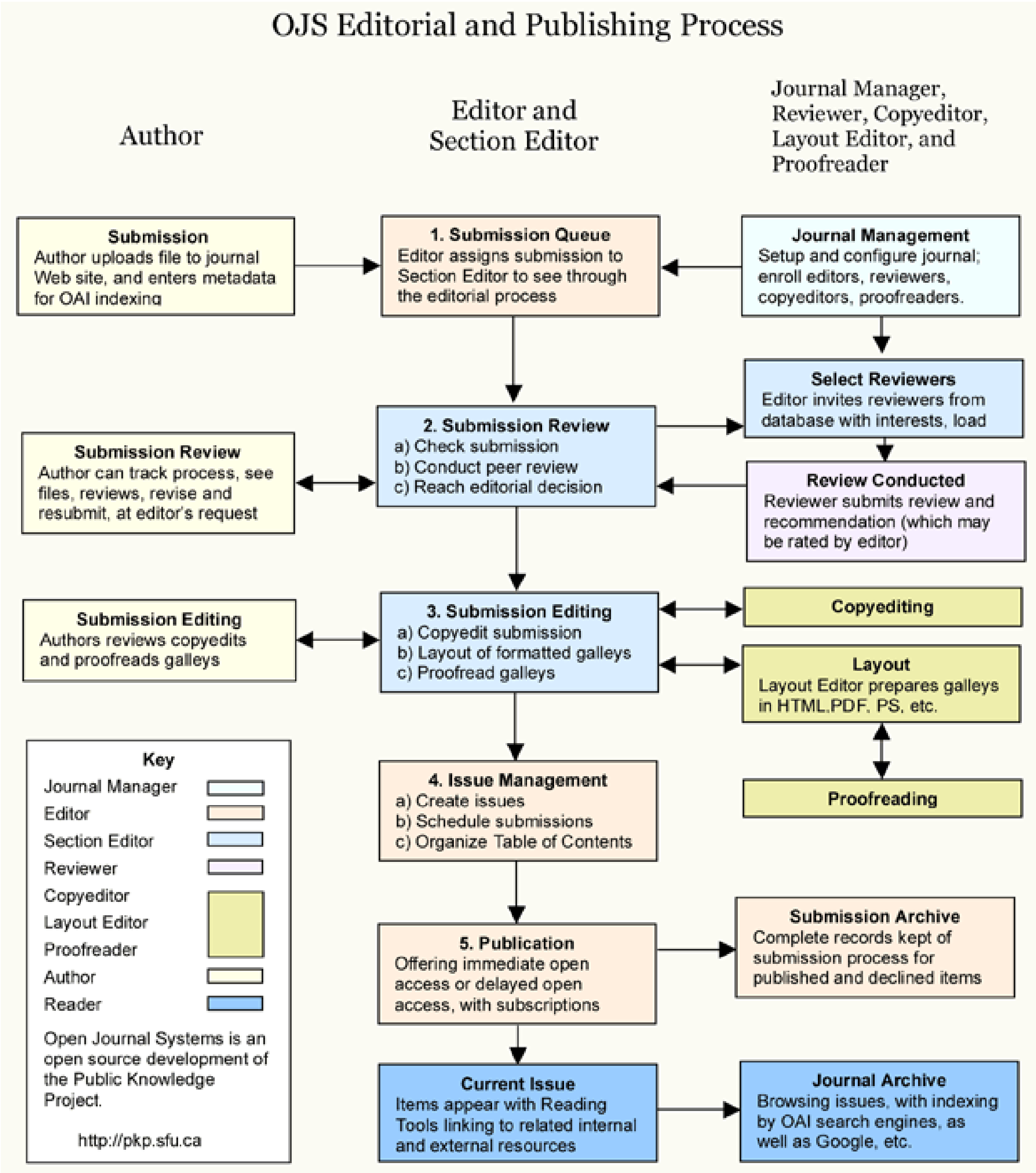

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