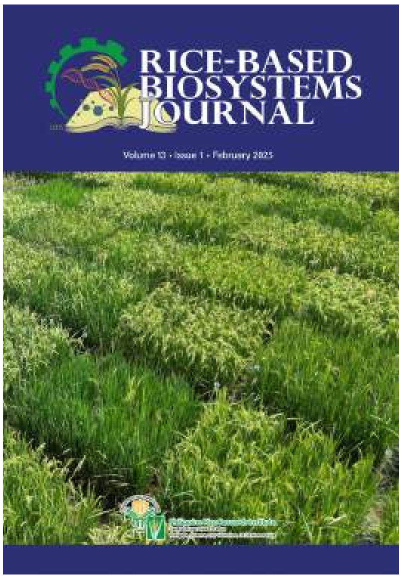
RICE-BASED BIOSYSTEMS JOURNAL

Volume 13 ▪ Issue 1 ▪ February 2025

Philippine Rice Research Institute
Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija



ABOUT THE COVER

The volume discusses a range of advanced strategies, including optimized crop farming patterns, leveraging soil microbial diversity, applying the Crop Environment Resource Synthesis (CERES) Rice model, utilizing the Multi-Crop Reduced-Till Planter (MCRTP) technology, and employing Polymerase Chain Reaction (PCR) diagnostics.

Rice-based Biosystems Journal
A bi-annual publication of Philippine Rice Research Institute

ISSN 2960-3692

Instructions on manuscript submission are found on pages 95-99.
For more information, please visit www.philrice.gov.ph/grants/call-publication/.

RICE-BASED BIOSYSTEMS JOURNAL

2015

VOLUME 13 ▪ ISSUE 1 ▪ FEBRUARY 2025

Published by:

DEPARTMENT OF AGRICULTURE
1898

Philippine Rice Research Institute
Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija

EDITORIAL TEAM

EDITOR-IN-CHIEF

NORVIE L. MANIGBAS
Scientist III and Chief Science Research Specialist, PhilRice
nlmanigbas@philrice.gov.ph • norviem@yahoo.com • norviemanigbas@gmail.com

EDITORIAL BOARD

CHARISMA LOVE B. GADO-GONZALES
Editor, PhilRice

CONSORCIA E. REAÑO
Statistical Editor, University of the Philippines Los Baños (UPLB)

PRODUCTION TEAM

JEREMHACE V. DEL PILAR
Editorial Assistant, PhilRice

CARLO G. DACUMOS
Layout and Design, PhilRice

EDITORIAL BOARD

JOHN C. DE LEON
Chair, Plant Breeder and Executive Director, PhilRice

VETHAIYA T. BALASUBRAMANIAN
Agronomist and Soil Scientist, Tami Nadu, India

CALIXTO M. PROTACIO
Professor, Institute of Crop Science, College of Agriculture and Food Science, UPLB

EUFEMIO T. RASCO JR.
Academician, National Academy of Science and Technology (NAST)

RODOLFO C. UNDAN
Professor of Agricultural Engineering and former President, Central Luzon State University (CLSU)

LUIS REY I. VELASCO
Professor of Entomology, UPLB

RUBEN L. VILLAREAL
Academician, NAST

MARILOU J. ANG-LOPEZ
Assistant Professor VII, School of Technology, University of the Philippines Visayas (UPV)

SANKALP U. BHOSALE
Deputy Platform Leader Rice Breeding Innovations
Lead, Product Development & Varietal replacement
International Rice Research Institute

ROLANDO T. CRUZ
Agronomist, Los Baños, Laguna. Philippines

EVELYN F. DELFIN
Agronomist, Los Baños, Laguna. Philippines

GLENN B. GREGORIO
Professor Institute of Crop Science
College of Agriculture and Food Science, UP Los Baños
Center Director
Southeast Asian Regional Center
Graduate Study and Research in Agriculture
(SEAMEO-SEARCA)
Los Baños, Laguna, Philippines
Academician, NAST

JOSE E. HERNANDEZ
Professor, Institute of Crop Science, College of Agriculture and Food Science, UPLB

YOICHIRO KATO
Assistant Professor Faculty of Agriculture,
The University of Tokyo, Tokyo, Japan

TANGUY LAFARGE
Crop Physiologist, Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), Montpellier, France

FELINO P. LANSIGAN
Professor of Statistics and Dean, College of Arts and Sciences, UPLB

CEZAR P. MAMARIL
Soil Scientist and Rice Farmer

MILAGROS R. MARTINEZ-GOSS
Professor Emeritus, Institute of Biological Sciences, UPLB

TEODORO C. MENDOZA
Professor, Institute of Crop Science,
College of Agriculture and Food Science, UPLB

AGNES C. ROLA
Academician, NAST and Professor,
College of Public Affairs, UPLB

STANLEY OMAR PB. SAMONTE
Associate Professor in Rice Breeding
Texas A&M AgriLife Research, USA

GENARO O. SAN VALENTIN
Soil Scientist and Senior Consultant, PhilRice

POMPE C. STA CRUZ
Director and Professor, Institute of Crop Science,
College of Agriculture and Food Science, UPLB

BERNARDO D. TADEO
President and CEO, Full Advantage Phils. International, Inc.

EMMANUEL R. TIONGCO
Plant Pathologist and Senior Consultant, PhilRice

GURDEV S. KHUSH
Member, US National Academy of Sciences
Adjunct Professor Emeritus
University of California-Davis
Former Head, Plant Breeding, Genetics, and Biotechnology
International Rice Research Institute

LEE TARPLEY
Professor, Plant Physiology
Texas A&M AgriLife Research Center at Beaumont

MAYUMI YOSHIMOTO
Senior Principal Scientist
Climate Change Adaptation Research
Institute for Agro-environmental Sciences
National Agriculture and Food Research Organization

GIHWAN YI
PROFESSOR
Director, Department of Agro-Industry
Kyungpook National University

INVITED REVIEWERS

DINDO KING M. DONAYRE
Scientist I and Senior Science Research Specialist, PhilRice

NORVIE L. MANIGBAS
Scientist III and Chief Science Research Specialist, PhilRice

MANUEL JOSE C. REGALADO
Retired Scientist II and Chief Science Research Specialist, PhilRice

RICARDO F. ORGE
Retired Scientist III and Chief Science Research Specialist, PhilRice

AILON OLIVER V. CAPISTRANO
Senior Science Research Specialist, PhilRice

LEYLANI M. JULIANO
Chief Science Research Specialist, PhilRice

ROSALY V. MANAOIS
Scientist I and Senior Science Research Specialist, PhilRice

ALVIN D. PALANOG
Senior Science Research Specialist, PhilRice Negros

ROEL R. SURALTA
Scientist III and Chief Science Research Specialist, PhilRice

ELMER G. BAUTISTA
Scientist I and Supervising Science Research Specialist, PhilRice

KRISTINE SAMOY-PASCUAL
Senior Science Research Specialist, PhilRice

JAIME A. MANALO IV
Scientist II and Supervising Research Specialist, PhilRice

JESUSA C. BELTRAN
Scientist I and Chief Science Research Specialist, PhilRice

LEONILO V. GRAMAJE
Senior Science Research Specialist, PhilRice

FRODIE P. WAING
Senior Science Research Specialist, PhilRice

RBBJ

VOLUME 13, ISSUE 1, FEBRUARY 2025

CONTENTS

FULL PAPER

RESEARCH NOTE

REVIEW

FULL PAPER

FUNGAL DISEASES OF ADLAY (*COIX LACRYMA-JOBI* L.) IN MAJOR CULTIVATION AREAS OF MINDANAO: IDENTIFICATION, PATHOGENICITY OF *HELMINTHOSPORIUM* SP., AND EVALUATION OF CONTROL STRATEGIES

Arnel C. Magbanua[2], Clark I. Maarat[1], Tamie C. Solpot[1], Jamille B. Sabado[2],
Jennifer T. Niones[2], and Jonathan M. Niones[2]*

[1]Plant Pathology Department, College of Agriculture, University of Southern Mindanao, 9407 Kabacan, Philippines
[2]Philippine Rice Research Institute, Science City of Muñoz, 3119 Nueva Ecija, Philippines
*Corresponding Author: jmniones@philrice.gov.ph

Abstract

Adlay (*Coix lacryma-jobi* L.) is an emerging alternative staple crop with increasing economic and nutritional importance in the Philippines. However, its productivity is threatened by fungal diseases, particularly those caused by *Helminthosporium* sp., along with other fungi commonly associated with the crop. This study recovered and identified fungal isolates associated with adlay in major areas in Mindanao; characterized and determined the pathogenicity of *Helminthosporium* sp. and evaluated potential control strategies. There were 28 fungal isolates recovered from symptomatic leaves, of which eight confirmed as pathogenic. These pathogenic isolates exhibited uniform cultural characteristics and induced identical disease symptoms, leading to the selection of a representative isolate for detailed cultural and morphological characterization. The selected isolate displayed characteristic pigmentation, colony texture, and growth patterns across various media, consistent with *Helminthosporium* species. Microscopic examination using Differential Interference Contrast (DIC) revealed septate conidiophores and multi-septate, pigmented conidia measuring 85–238 µm in length and 17–34 µm in width, reinforcing its taxonomic identity. *In vitro* bioassays of commercially available fungicides identified a formulation containing *Bacillus subtilis* strain QST 713 as the most effective treatment in suppressing fungal growth. These findings provide important baseline information for fungal disease management in adlay and contribute to the development of improved crop protection strategies.

Keywords: *adlay, Coix lacryma-jobi L., cultural characterization, fungal pathogens, Helminthosporium sp., morphological analysis, pathogenicity*

Introduction

With the growing population in the Philippines, demand for rice continues to rise; however, production struggles to keep pace due to weather disturbances (e.g., storms, drought), irrigation constraints, postharvest losses, and market forces. Although rice importation has been used to address supply gap, this approach may not be sustainable in the long term. One potential solution is the promotion of alternative staples crops capable of supplementing rice consumption.

Adlay, commonly known as Job's tears, is a tall grain-bearing tropical plant that is a promising alternative crop belonging to the family *Poaceae*. It exists in the wild and is also cultivated in East Asia, South America, Southeast Asia, and South Asia (Jampeetong et al., 2013). In the Philippines, it is abundant in Regions IX and X, the Cordillera Administrative Region (CAR) and is widely cultivated in Zamboanga del Sur as a substitute for and complement to rice (Gaitan, 2013).

Adlay has gained significant attention in the Philippines as a highly versatile and valuable grain. The Department of Agriculture recognizes its potential as a prominent alternative to rice, highlighting its resilience and benefits. Adlay is cost-effective in terms of grain production and serves as an economically viable option for farmers, especially when compared with traditional crops such as rice and corn. Unlike these conventional crops, adlay requires fewer inputs including fertilizers and pesticides, and needs minimal irrigation (Aradilla, 2018). Its ability to thrive on marginal lands with challenging environmental conditions, along with its relative resistance to pests and diseases, further enhances its appeal in agricultural systems (Aradilla, 2016; Gloria et al., 2015).

Adlay grain is gluten-free, rich in carbohydrates and-protein content and has a lower glycemic index than rice. Based on studies conducted by the Department of Science and Technology - Food and Nutrition Research Institute (DOST-FNRI), a 100 g serving of adlay contains 73.9 g carbohydrates, 12.8

g protein, and 1.0 g fat. It also contains essential minerals such as calcium (25 mg), phosphorus (43.5 mg), iron (5 mg), and notable levels of niacin (4.3 mg), thiamine (0.28 mg), and riboflavin (0.19 mg), which are higher than those of brown rice (Jover et al., 2020).

Over the years, studies on adlay's benefits and nutritional content have increased, but research on the fungal pathogens associated with this grain crop remains limited. Fungal pathogens have a devastating impact on global food security, as well as on human and animal health (Avery et al., 2019; Fones et al., 2020). In cereal crops such as wheat, barley, corn, oats, and rice, fungal pathogens cause yield losses and compromise grain quality, contributing to billions of dollars in annual losses and higher costs for consumers.

Therefore, this study was conducted to isolate and identify the fungal pathogens associated with adlay in major cultivation areas across Mindanao, particularly in Regions X, XI, and XII, where the crop is extensively grown. By documenting the fungal diseases affecting adlay, this research established a clearer understanding of pathogen diversity and distribution across production sites. Special emphasis is given to *Helminthosporium* sp., a major foliar pathogen known to cause leaf spot diseases in cereals and grasses, to determine its pathogenicity and role in disease development in adlay. Furthermore, the study evaluated potential control strategies to provide science-based recommendations for disease management. In doing so, this research contributes to the limited body of knowledge on adlay pathology and supports the development of effective measures to minimize yield losses, ensure sustainable production, and strengthen the economic value of adlay in Mindanao.

Materials and Methods

Collection Sites

The study was conducted in the Mindanao Region, specifically in Regions X (Northern Mindanao Integrated Agricultural Research Center – NOMIARC, Malaybalay City), XI (Malita, Davao Occidental), and XII (North Cotabato – Pinamaton, Matalam; New Consolation M'lang; New Culasi, Tulunan and South Cotabato – Bololmala, Tupi). These regions were selected due to their diverse climatic conditions and the known cultivation of adlay at mature and younger stages. The study sites were selected based on the prevalence of adlay crops and reports of plant diseases affecting these crops. Various local farms and agricultural research areas were included across Region X, XI, and XII to ensure a representative sample of adlay plants.

Sample Collection and Processing

Leaves of adlay plants exhibiting symptoms of disease such as leaf spot and leaf blight, were collected from different farms in the selected regions. Diseased leaves of adlay were classified based on their growth stage: mature and younger plants.

Each plant sample was thoroughly examined to identify visible disease symptoms such as leaf spots, wilting, discoloration, lesions, and other abnormalities. Disease symptoms were documented and initial visual assessments were conducted to determine the likely disease type based on the observed signs. Symptomatic leaf samples were placed in paper bags and transported to the laboratory for further analysis.

Isolation of Pathogen

Isolation of fungal pathogens from adlay followed the standard protocol of Al-Jaradi et al. (2018). Diseased samples were washed and air-dried. Infected portions at the advancing margin of lesions were cut using a sterile scalpel and then immersed in 10% sodium hypochlorite (NaOCl) for 2-3 min. The tissue pieces were then transferred to sterile distilled water (SDW) for 2-3 min and dried on sterile filter paper. The disinfected diseased samples were then inoculated onto Potato Dextrose Agar (PDA) plates. Plates were incubated in an inverted position at room temperature (25±2°C) in the laboratory for 7-10 days. Morphologically distinct isolates were subcultured to purify and obtain pure isolates. As soon as the fungal mycelium grew out of the tissue slice, it was transferred to fresh PDA slants for purification and culture.

Pathogenicity Test

Pathogenicity tests followed the procedure described by Al-Jaradi et al. (2018). Fungal isolates obtained from diseased adlay plants were revived and cultured on PDA for seven days at room temperature (25 ± 2 °C). Pure cultures were maintained for subsequent pathogenicity assays.

Healthy adlay seedlings were grown in sterilized soil in polyethylene bags (12 × 12 inches) under greenhouse conditions. Plants were maintained for four weeks until they reached the four-leaf stage (Figure 1).

Figure 1. Pathogenicity experimental set-up.

For inoculum preparation, fungal isolates were grown on PDA for 7–10 days. A conidial suspension was prepared by flooding culture plates with sterilized distilled water and gently scraping the mycelial surface with a sterile loop. The suspension was filtered through sterile cheesecloth to remove mycelial debris and adjusted to approximately 40,000 conidia mL^{-1} using a hemocytometer.

One-month-old acclimatized seedlings were inoculated by spraying the conidial suspension (40,000 conidia mL^{-1}) onto test plants using a handheld atomizer until runoff. Control plants were sprayed with sterile distilled water. After inoculation, plants were covered with plastic bags for 48 h to maintain high humidity conducive to infection.

Plants were maintained under greenhouse conditions (25 ± 2 °C; 12-h photoperiod), and disease symptoms were observed daily for up to 14 days after inoculation. The appearance of leaf spots, necrotic lesions, and blight was recorded. Fungal isolates that induced disease symptoms similar to those observed in naturally infected adlay plants were considered pathogenic.

Identification of Fungal Isolates

A. Cultural characterization

Only confirmed pathogenic isolates were subjected to further cultural characterization, including growth patterns, colony morphology, and pigmentation on different media. Pure cultures of these isolates, initially grown on PDA, were subcultured onto various selective and differential media, including V8 juice agar, carrot agar, adlay extract agar, corn meal agar, malt extract agar, and water agar.

Morphological characteristics such as mycelial color, texture, density, and colony elevation were qualitatively assessed. Colony growth was quantitatively measured on the sixth day of incubation, and spore production was recorded.

B. Morphological characterization

To further characterize the fungal isolate, source plants from the pathogenicity test were subjected to conventional taxonomic procedures, focusing on morphological features of conidia and conidiophores observed under a DIC microscope. Additional morphological parameters, including conidial length, width, and number of septa, were recorded. Identification was conducted using the taxonomic key of Alexopoulos et al. (1996). Preliminary identification was subsequently verified and confirmed by a plant pathologist and career scientist.

Inhibitory Activity of Commercially Available Fungicides Against Pathogenic Isolates from Adlay

The inhibitory activity of different commercially available fungicides was tested against the pathogenic fungal isolates via in vitro bioassays arranged in a completely randomized design (CRD). Fungicide active ingredients, rather than brand names, were disclosed; treatments were labeled as T1–T10. Sterile distilled water (SDW) served as the negative control, while Benomyl, Crop Vaccine with Bialexin, and Trianum served as positive controls.

Each treatment was replicated four times. For each replicate, 20 mL PDA was supplemented with 1 mL of the treatment solution. Once the agar had solidified, a 6-mm-diameter mycelial disc, excised from a seven-day-old colony of the pathogenic fungal isolate, was placed at the center of each PDA plate. Plates were incubated at room temperature for 72 h.

After incubation, the diameter zone of growth (DZG) of the fungal pathogen was measured (mm). Treatment efficacy was interpreted using the scale of Alcordo and Dionio (1993): 0–10 mm = Very Effective (VE); 11–20 mm = Effective (E); 21–30 mm = Moderately Effective (ME); and ≥31 mm = Not Effective (NE). Data were subjected to analysis of variance (ANOVA), and treatment means were separated using Tukey's HSD test at the 1% level of significance, using the Statistical Tool for Agricultural Research (STAR) software.

Results and Discussion

Collection Sites of Diseased Leaf Samples

Collection sites and land areas of adlay plantations are shown in Table 1 and Figure 2A–F. Region XII had the largest land area dedicated to adlay cultivation. In North Cotabato, adlay was cultivated in Pinamaton, Matalam; New Consolation, M'lang; New Culasi, Tulunan. In South Cotabato, adlay cultivation was observed in Bololmala and Tupi, with areas ranging from 0.25 ha (small-scale or garden-level) to more than 3 ha (large-scale commercial plantations).

In Region X, the Northern Mindanao Agricultural Research Center (NOMIARC), Malaybalay City, cultivated adlay in a small-scale commercial plantation. In Region XI, Malita, Davao Occidental, had the most extensive adlay cultivation, with multiple farmers planting the crop on areas ranging from 3 to more than 5 ha. Figure 2G illustrates the generated map of the surveyed collection areas. Among all surveyed plantations, Malita, Davao Occidental, had the largest land area dedicated to adlay production, classifying it as a large-scale commercial plantation.

The survey also revealed that 'Gulian' was the most widely cultivated among the five identified adlay varieties: Gulian, Pulot, Mataslay, Kibuwa, and Guinampay (Table 1). Adlay cultivation varied across Regions X, XI, and XII (Table 1; Figure 2A–G). Region XII had the largest overall area, with large-scale plantations (3.0 ha) in Matalam and Tulunan and smaller sites in M'lang and Tupi. Region X had a 1.0-ha plantation at NOMIARC, Malaybalay City.

The largest production area was in Malita, Davao Occidental (Region XI), with multiple large-scale plantations (3–5 ha), indicating strong commercial activity. Mapping of sites (Figure 2G) shows clustering in Region XII, with Malita as the main production hub. Among the five identified varieties, Gulian was the most cultivated, suggesting favorable agronomic traits or farmer preference. These results highlight adlay's regional expansion and its potential for larger-scale production.

Table 1. Collection sites and land areas of adlay commercial productions.

Region/ province	Location	Cultivation	Area (ha)
Bukidnon			
X	NOMIARC, Malaybalay City	Small scale commercial plantation	1.0
Davao			
XI	Malita, Davao Occidental	Large scale commercial plantation	3-5
North Cotabato			
XII	Pinamato, Matalam	Large scale commercial plantation	3.0
	New Consolation, M'lang	Garden	0.25
	New Culasi, Tulunan	Large scale commercial plantation	3.0
South Cotabato			
XII	Bololmala Tupi	Small scale commercial plantation	1.0

*Note: classification of Adlay cultivation: Garden – less than 1 hectare; Small Scale Commercial Plantation; 1- 2 hectares; Large Scale Commercial Plantations – 3 or more hectares.

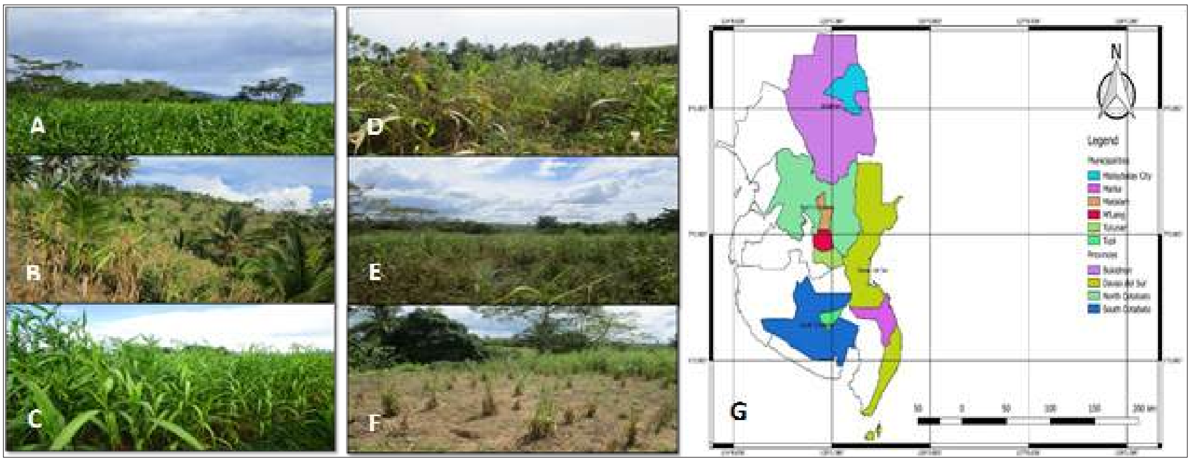


Figure 2. Collection sites of diseased leaf samples: (A) NOMIARC, Malaybalay, Bukidnon, (B) Malita, Davao Occidental, (C) Bololmala, Tupi, South Cotabato, (D) Pinamataon, Matalam, (E) New Consolacion, M'lang, (F) New Culasi, Tulunan, (G) Map of the collection sites generated using QGIS.

List of Fungal Isolates

There were 28 fungal isolates, labeled ACMIso F1–F28, obtained from adlay leaf samples (Figure 3; Table 2). These comprised 15 isolates from leaves exhibiting leaf spot symptoms and 13 isolates from leaves displaying leaf blight symptoms. Figure 3 illustrates the fungal isolates recovered from adlay, while Table 2 summarizes the collection sites, symptomatology, and corresponding adlay cultivars associated with each isolate. Leaf spot and leaf blight symptoms were common across varieties and locations.

Pathogenicity Test

Pathogenicity tests were conducted to determine the ability of fungal isolates to induce symptoms in adlay under controlled conditions. Among the 28 fungal isolates tested, eight (F2, F6, F13, F15, F16, F20, F23, and F26) exhibited pathogenicity, as evidenced by the development of leaf spot symptoms within 3–5 days after inoculation (Figure 4C).

Infected leaves initially exhibited small chlorotic spots that later expanded into necrotic lesions with well-defined dark brown margins (Figure 4C). Symptoms observed under greenhouse conditions closely resembled those in naturally infected field samples, confirming the role of these isolates as causal pathogens (Figures 4A–B).

In contrast, 20 isolates did not induce disease symptoms in inoculated plants, indicating that they were non-pathogenic or behaved as endophytes. These isolates may play neutral or potentially beneficial roles in the plant microbiome, warranting further

Table 2. Collection sites, symptoms, and cultivars corresponding to fungal isolates.

Isolate	Symptom/s and Cultivar	Location
F1	Leaf spot / Pulot	Bololmala, Tupi
F2	Leaf spot / Pulot	Bololmala, Tupi
F3	Leaf blight / Tupi	Bololmala, Tupi
F4	Leaf blight / Gulian	Bololmala, Tupi
F5	Leaf blight / Gulian	Bololmala, Tupi
F6	Leaf spot / Gulian	Bololmala, Tupi
F7	Leaf blight / Gulian	Bololmala, Tupi
F8	Leaf blight / Gulian	Bololmala, Tupi
F9	Leaf blight / Kibuwa	NOMIARC, Bukidnon
F10	Leaf spot / Kibuwa	NOMIARC, Bukidnon
F11	Leaf blight / Kibuwa	NOMIARC, Bukidnon
F12	Leaf blight / Kibuwa	NOMIARC, Bukidnon
F13	Leaf spot / Kibuwa	NOMIARC, Bukidnon
F14	Leaf spot / Kibuwa	NOMIARC, Bukidnon
F15	Leaf spot / Gulian	Matalam
F16	Leaf spot / Gulian	Matalam
F17	Leaf blight / Gulian	Matalam
F18	Leaf blight / Gulian	Matalam
F19	Leaf spot / Gulian	M'lang
F20	Leaf blight / Gulian	M'lang
F21	Leaf blight / Gulian	M'lang
F22	Leaf blight / Gulian	M'lang
F23	Leaf spot / Gulian	Tulunan
F24	Leaf spot / Gulian	Tulunan
F25	Leaf spot / Gulian	Malita, Davao
F26	Leaf spot / Gulian	Malita, Davao
F27	Leaf blight / Gulian	Malita, Davao
F28	Leaf blight / Gulian	Malita, Davao

Figure 3. Twenty-eight fungal isolates obtained from diseased adlay leaf collected samples.

Figure 4. Symptoms of leafspot caused by *Helminthosporium* sp. on adlay: (A – B) leaf spot symptoms on naturally infected adlay in the field; (C.) leaf spot symptoms on infected adlay under greenhouse conditions, three days after inoculation.

investigation into their ecological functions and possible antagonistic properties against pathogenic fungi. Confirmation of pathogenicity in selected isolates underscores the potential impact of fungal infections on adlay cultivation.

Identification of Fungal Isolates

Cultural characteristics. All pathogenic isolates produced leaf spot symptoms in pathogenicity tests. On PDA, colonies initially appeared white and later became gray with black–grayish margins as they matured (Figure 5C). Similar cultural growth was observed on V8 juice agar (Figure 5A), carrot agar (Figure 5B), adlay extract agar (Figure 5D), corn meal agar (Figure 5E), malt extract agar (Figure 5F), and water agar (Figure 5G). Because of their similarity, only one representative of the eight isolates was selected for detailed cultural characterization.

This representative isolate, obtained from leaf spot samples, produced whitish to pale gray, cottony mycelium on PDA. It was subsequently cultured on six agar media: V8 juice agar, carrot agar, adlay extract agar, corn meal agar, malt extract agar, and water agar. The isolate showed variation in mycelial pigmentation across the media (Figure 5; Table 3), likely influenced by factors such as nutrient composition, pH, substrate type, and environmental conditions including temperature, light, and oxygen availability (Keller et al., 2005).

On PDA, the fungal isolate initially appeared cream to white, gradually transitioning to mouse

Table 3. Cultural characteristics of *Helminthosporium* sp. grown on different agar media.

Nutrient Medium	Colony Color (front)	Colony Color (back)	Texture	Surface	Elevation	Margin
V-8 juice agar	Mouse gray with white margin	Sulphur yellow, black	Velvety	Smooth	Flat	Lobate
Carrot agar	Pale mouse gray with white margin	Straw	Fluffy	Contoured	Raised	Undulate
PDA	Mouse gray with pale mouse gray margin	Black	Velvety	Smooth	Flat	Entire
Adlay extract agar	Mouse gray	Black	Felty	Smooth	Flat	Entire
Corn meal agar	Fuscous black	Gray	Wooly	Concentric	Flat	Branching
Malt extract agar	Pale mouse gray with white margin	Black	Velvety	Smooth	Flat	Irregular
Water agar	Gray, black	Black	Wooly	Smooth	Flat	Branching

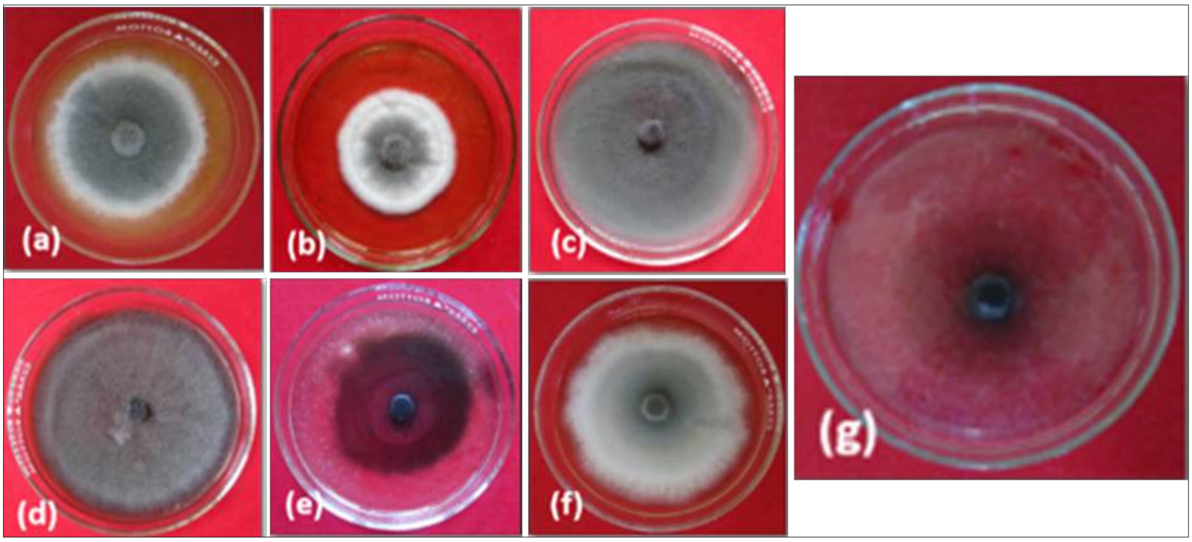


Figure 5. *Helminthosporium* sp. grown on (a) V-8 juice agar, (b) carrot agar, (c) potato dextrose agar, (d) adlay extract agar, (e) cornmeal agar, (f) malt extract agar, and (g) water agar.

gray with a black–grayish margin as it matured. This progression from white to pale gray during early growth to mouse-gray or olivaceous black at maturity is a distinguishing feature of *Helminthosporium* spp. associated with melanin production (Ellis, 1971; Manamgoda et al., 2014). Pigmentation was especially pronounced on PDA, where colony margins developed a distinct blackish-gray hue over time. Melanin synthesis in *Helminthosporium* spp. contributes to stress tolerance and survival under adverse environmental conditions (Butler and Day, 1998).

The colony texture was cottony, fluffy, and woolly at the center, gradually becoming velvety and slightly raised at the margins—another diagnostic trait of this genus (Ellis, 1971). Cultural characteristics across all media are summarized in Table 3. Colony growth and spore production were also assessed: the isolate showed rapid mycelial expansion, reaching an average colony diameter of 84.17 mm after six days of incubation at room temperature, and producing 1.6 × 10^3 spores (Table 4). PDA supported both the fastest growth and highest sporulation, indicating that it is the most suitable medium for laboratory development of this pathogen.

Helminthosporium spp. are widely recognized as pathogens of grain crops, having been isolated from maize (e.g., *H. maydis*, causal agent of Maydis leaf blight) (Bhavani et al., 2016) and rice (*H. oryzae*, causal agent of brown spot disease) (Elshenawy et al., 2018). Their occurrence in cereals highlights the agricultural significance of this genus, which can cause substantial yield losses under favorable conditions. The observed velvety colony texture, pigmentation patterns, and growth rate are consistent with previous descriptions of *Helminthosporium* spp. (Nayad and Alam, 2024; Jaiganesh and Kannan, 2019). These morphological traits are key indicators for species identification and offer insights into the ecological adaptability of the isolate, reinforcing its classification within the genus *Helminthosporium*.

Morphological Characterization

To confirm the identity of the pre-identified *Helminthosporium* sp., a plant exhibiting leaf spots from the pathogenicity test was subjected to morphological examination using a DIC microscope. This analysis was conducted in collaboration with a plant pathologist who provided expert validation of the observations.

Microscopic analysis revealed that conidiophores were simple, septate, and bore macroconidia at their apical regions (Figures 6B and 6D). Macroconidia were elongated, multicellular, and septate (Figures 6C and 6E). These asexual spores exhibited brown to dark brown pigmentation, a characteristic commonly associated with *Helminthosporium* spp. (Ellis, 1971; Sivanesan, 1987). Morphological variability was observed in the conidia, which appeared either straight or slightly curved, with 3–14 transverse septa. Conidial dimensions ranged from 85 to 238

Table 4. Colony diameter and spore production of the fungal isolate.

Nutrient Medium	Colony Diameter[a/] (mm)	Spore Production
V-8 juice agar	68.50	$1.6x10^3$
Carrot agar	52.33	$6.6x10^2$
PDA	84.17	$1.3x10^3$
Adlay extract agar	82.6	$2.6x10^3$
Corn meal agar	77.00	$3.3x10^2$
Malt extract agar	66.17	$6.6x10^2$
Water agar	41.83	$3.3x10^2$

Figure 6. *Helminthosporium* sp., under 400x (a), conidia attached to conidiophore (b), septation of the conidiophore (c-d) and under 1000x (C–E).

µm in length and 17 to 34 µm in width, as observed under the low-power objective (LPO) of a compound microscope.

These characteristics are consistent with diagnostic descriptions of *Helminthosporium* spp., which are known for their elongated, multi-septate conidia with distinct pigmentation patterns (Alcorn, 1988; Manamgoda et al., 2014; Jaiganesh and Kannan, 2019). Conidial structure and pigmentation are critical for fungal taxonomy and pathogenicity, influencing spore dispersal, survival, and adaptation to environmental stress (Barnett and Hunter, 1998). Figures 6A–E illustrate the conidial morphology and septation patterns observed under LPO.

To further confirm the fungal identity, the symptomatic leaf sample was re-cultured on PDA. The resulting colony exhibited the same cultural characteristics as the original isolate, reinforcing the identification of the organism as *Helminthosporium* sp. Although no molecular sequencing was conducted, the combination of pathogenicity tests, cultural traits, and morphological features provides strong evidence for classification within this genus, consistent with classical taxonomic keys (Ellis, 1971; Sivanesan, 1987).

Taken together, the pathogenicity test results (Figures 3–4), cultural characterization (Figure 5; Tables 3–4), and microscopic features (Figure 6) confirm the identity of the pathogenic isolates as *Helminthosporium* sp. Their high sporulation capacity and pigmentation suggest ecological adaptability, which may contribute to disease persistence and spread in adlay cultivation areas in Mindanao. This highlights their significance as causal pathogens in regions where adlay is widely grown.

Inhibitory Efficacy of Different Commercially Available Fungicides Against Helminthosporium *sp.*

The efficacy of various fungicide treatments in inhibiting *Helminthosporium* sp. was assessed by measuring the DZG. Table 5 presents the different treatments, active ingredients, controls, and their corresponding DZG values and degree of efficacy (DE) used in the inhibitory activity assay.

SDW, used as the negative control, exhibited the largest DZG at 40.69mm and was rated as NE, confirming its lack of inhibitory activity. In contrast, the positive control Benomyl showed the highest antifungal effect, with a minimal DZG of 0.12mm classified as VE, signifying almost complete suppression of *Helminthosporium* sp. growth.

Among the experimental treatments, T8 (*B. subtilis* strain QST 713) achieved the lowest mean DZG (9.31mm) among the test formulations, statistically grouping with Benomyl (0.12mm) but significantly

Table 5. The different treatments, active ingredients, controls, and their corresponding (DZG) Diameter Zone of Growth values and (DE) Degrees of efficacy `used in the inhibitory activity assay.

Fungicide	Active Ingredient	DZG[a/] (mm)	DE[b/]
T1	Seaweed extract	22.69[b]	ME
T2	Beneficial microorganisms, natural antibiosis and plant/botanical extract	15.06[bcd]	E
T3	Vegetable, herb and fruit trees extract. Amino acids, lignins, saponins and chrysoponic acid	13.25[cd]	E
T4	Lactic acid bacteria	15.88[bcd]	E
T5	Tea tree (*Melaleuca alternifolia*) Extract	10.56[d]	E
T6	Effective microorganisms and decomposers	13.44[cd]	E
T7	*Bacillus amyloliquefaciens* D-203	10.62[d]	E
T8	*Bacillus subtilis* QST 713	9.31[d]	VE
T9	Effective microorganisms	20.94[bc]	ME
T10	*Bacillus amyloliquefaciens* + biopesticide	10.69[d]	E
Control			
Positive	Benomyl	0.12[e]	VE
Positive	Crop Vaccine with Bialexin	11.19[d]	E
Positive	Trianum	16.25[bcd]	E
Negative	Sterile Distilled Water	40.69[a]	NE

*[a/] Means in column followed by common letter superscript are not significantly different at 1% level, Tukey's Test.

*[b/] Degree of efficacy: VE = Very Effective; E = Effective; ME = Moderately Effective; NE = Not Effective.

different from all moderately effective treatments. This indicates that T8 was the most effective bio-based treatment with activity comparable to the chemical check. Treatments T5 (Tea tree extract, 10.56mm), T7 (*B. amyloliquefaciens* D-203, 10.62mm), and T10 (*B. amyloliquefaciens* + biopesticide, 10.69mm) clustered within the same statistical group (letter "d"), confirming their equivalence in efficacy to T8 and Crop Vaccine with Bialexin (11.19mm).

Other treatments, including T2, T3, T4, T6, and Trianum (positive control), recorded DZGs between 13.25 and 16.25mm (letters "bcd"), which were statistically less effective than T8 but still significantly more effective than T1 (22.69mm) and T9 (20.94mm). The latter two treatments were rated as ME and statistically grouped closer to the negative control, reflecting weaker inhibition.

ANOVA confirmed significant differences among treatments ($P < 0.01$) and Tukey's HSD test separated the means into distinct efficacy groups. Overall, the data demonstrate that bio-based products formulated with *Bacillus* spp. (T7, T8, T10) were statistically among the most effective treatments, with T8 (*B. subtilis* strain QST 713) showing activity comparable to the chemical fungicide Benomyl.

The observed variability in antifungal activity may be attributed to the distinct modes of action of each active ingredient. The most effective treatments likely disrupted fungal cell wall integrity, inhibited spore germination, or interfered with key metabolic pathways essential for fungal growth and survival (Barnett and Hunter, 1998). In particular, *B. subtilis*, may exhibit antifungal activity through the production of membrane-active lipopeptides (e.g., iturins, fengycins, bacillomycins, and the recently characterized AF3), which destabilize fungal cell membranes, increase permeability, induce oxidative stress, and ultimately trigger apoptosis in fungal cells (Ramesh et al., 2024).

Conclusion and Recommendations

This study confirmed *Helminthosporium* sp. as a fungal pathogen affecting adlay in Mindanao, Philippines. Of 28 fungal isolates recovered from symptomatic leaves, eight were pathogenic, exhibiting uniform cultural characteristics and inducing similar leaf spot symptoms. A representative isolate was further characterized, showing colony pigmentation, texture, and growth patterns consistent with *Helminthosporium* species. Microscopic examination using DIC microscopy revealed septate conidiophores and multi-septate, pigmented conidia.

Pathogenicity tests confirmed the isolate's role in disease development. *In-vitro* bioassays identified a fungicide containing *B. subtilis* strain QST 713 as the most effective inhibitor, highlighting its potential as a biological control agent. These findings provide essential baseline data for fungal disease management in adlay.

Effective management of *Helminthosporium* sp. requires an integrated approach combining biological, cultural, and chemical strategies. Further research should focus on resistant cultivars, optimized crop rotation, field validation of *B. subtilis* QST 713, and molecular techniques to confirm species identity and assess genetic diversity. Promoting farmer awareness, early disease detection, and regular pathogen surveillance will support sustainable adlay production, reduce crop losses, and ensure the crop's long-term viability.

Acknowledgment

The authors expressed their sincere gratitude to the agricultural research centers and local farms in Mindanao of Regions X, XI, and XII, for granting access for the sample collection in their *Adlay* plantations. Their cooperation and assistance were invaluable in the successful completion of this research study. The authors also extend their deep appreciation to Dr. Noemi Tangonan, plant pathologist and Career Scientist I, who provided insights and expert validation of the fungal isolates, ensuring the accuracy and reliability of the identification process. Her expertise and guidance significantly contributed to the scientific integrity of this research.

Literature Cited

Alcorn JL (1988) The taxonomy of *Helminthosporium* species. Annual Review of Phytopathology ***26***(1): 37 - 56

Alexopoulos CJ, Mims CW, Blackwell M (1996) *Introductory Mycology*, 4th Edition. John Wiley & Sons Inc.

Al-Jaradi A, Al-Mahmooli I, Janke R, Maharachchikumbura S, Al-Saady N, Al-Sadi AM (2018) Isolation and identification of pathogenic fungi and oomycetes associated with beans and cowpea root diseases in Oman. PeerJ 6: e6064. Retrieved from https://doi.org/10.7717/peerj.6064

Aradilla AR (2016) Phased planting: Determining the best time to plant Adlay (*Coix lacryma-jobi* L.) in Southern Bukidnon, Mindanao, Philippines. International Journal of Education and Research ***4*** (5): 419 - 430

Aradilla AR (2018) Phenology, growth and yield performance of Adlay (*Coix lacryma-jobi* L.) grown in adverse climatic conditions. International Journal of Research and Review ***5***: 16 - 24

Avery SV, Singleton I, Magan N, Goldman GH (2019) The fungal threat to global food security. Fungal Biology ***123***: 555 - 557

Barnett HL, Hunter BB (1998) Dematiaceous Hyphomycetes. *In* Barman LC, Begum F, Ahmmed ANF, Akter UH, Rashid K, Alpona MAT, Jahan I. Prevalence of Associated Seed Borne Fungi of Jute and Alliad Fiber Crops. Illustrated Genera of Imperfect Fungi, 4th ed. St. Paul: APS Press ***16***(3): 218

Bhavani TV, Gohil VP, Patel JK (2016) Isolation, pathogenicity and culture media study of *Helminthosporium maydis* causing Maydis leaf blight disease of maize. Advances Life Sci ***5***(1): 77 - 80

Butler MJ, Day AW (1998) Fungal melanins: A review. Canadian Journal of Microbiology ***44***: 1115 - 1136

Ellis MB (1971) *Dematiaceous hyphomycetes*. Commonwealth Mycological Institute, Kew, Surrey, UK

Elshenawy MM, Elgamal WH, Anis GB, Awad F (2018) Combined genetic analysis of brown spot (*Helminthosporium oryzae*) disease for developed hybrid combinations and their parental lines in hybrid rice. Sustainable Food Production ***1***: 37 - 48

Fones HN, Bebber DP, Chaloner TM, Kay WT, Steinberg G, Gurr SJ (2020) Threats to global food security from emerging fungal and oomycete crop pathogens. Nature Food ***1***: 332 - 342

Gaitan K (2013) Adlay: A rice-like versatility. Devcom Convergence 31: [online]. Retrieved from https://devcomconvergence.wordpress.com/page/7/ (accessed February 13, 2025)

Gloria AL, Alegado JC Jr, Boco MDA (2015) Adaptability trial of five varieties of Adlay (*Coix lacryma-jobi* L.) grown in marginal land, under San Miguel environment condition, Surigao Del Sur, Mindanao, Philippines. SDSSU Multidisciplinary Research Journal ***3***: 70 - 77

Jaiganesh V, Kannan C (2019) Studies on the cultural characters and pathogenicity studies of brown leaf spot of rice caused by *Helminthosporium oryzae* (syn: *Bipolaris oryzae*). Plant Archives ***19***(S1): 585 - 587

Jampeetong A, Konnerup D, Piwpuan N, Brix H (2013) Interactive effects of nitrogen form and pH on growth, morphology, N uptake and mineral contents of *Coix lacryma-jobi* L. Aquatic Botany ***11*** 1***:*** 144 - 149

Jover PC, Aragon CT, Quicoy CB, Billedo NMP, Paller RA (2020) Technology and investment profile of soy baby food. SEARCA, Los Baños, Laguna, Philippines. Retrieved from https://www.searca.org/pubs/monographs?pid=483 (accessed February 13, 2025)

Keller NP, Turner G, Bennett JW (2005) Fungal secondary metabolism—from biochemistry to genomics. Nature Reviews Microbiology ***3***: 937 - 947

Nayab N, Alam MA (2024) Identification and characterization of *Helminthosporium* species causing diseases in sorghum and some lesser millets of Bihar. ENVIS Bulletin Himalayan Ecology 31: 148 - 152

Manamgoda DS, Rossman AY, Castlebury LA, Crous PW, Madrid H, Chukeatirote E, Hyde KD (2014) The genus *Bipolaris*. Studies in Mycology ***79***: 221 - 235

Ramesh S, Roy U, Roy S, Rudramurthy SM (2024) A promising antifungal lipopeptide from *Bacillus subtilis*: its characterization and insight into the mode of action. Applied Microbiology Biotechnology ***108***: 161

Sivanesan A (1987. Graminicolous species of *Bipolaris, Curvularia, Drechslera, Exserohilum* and their teleomorphs. Mycological Papers ***158***: 1 - 261.

UPTAKE OF PALAYCHECK PRIMER KEY MESSAGES AMONG FARMER FIELD SCHOOL GRADUATES IN BAYAMBANG, PANGASINAN

Christina A. Frediles[1]*, Jaime A. Manalo IV[1], Chrysl Avegeil N. Vallejo[2],
and Eugenia G. Baltazar[2]

[1] Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
[2] Central Luzon State University, Science City of Muñoz, 3119 Nueva Ecija, Philippines
*Corresponding Author: christinafrediles@gmail.com or cafrediles@philrice.gov.ph

Abstract

This study examined the stages of change associated with the uptake of key messages from the PalayCheck Primer among Farmer Field School (FFS) graduates in Bayambang, Pangasinan. Guided by the Transtheoretical Model, six stages were assessed: Pre-contemplation, Contemplation, Preparation, Action, Maintenance, and Termination. Of the 38 participants, nine were in the Pre-contemplation stage, continuing with traditional practices due to persistent habits, visual impairment, or transfer of farm responsibilities to family members. Two farmers were in the Contemplation stage, expressing willingness to adopt the primer's recommendations once the next planting season begins. The majority (27) were in the Action stage, having implemented at least one PalayCheck recommendation. Only recommendations on variety and seed selection and crop establishment enabled farmers to reach the Maintenance stage. Regular meetings of the RiceBIS Bayambang Agricultural Cooperative appeared to support sustained adoption by facilitating collective planning and access to free certified inbred seeds. No participants were identified in the Preparation or Termination stages. Findings highlight the importance of understanding farmers' readiness for change when designing or delivering extension interventions. Farmers also suggested improvements to the primer such as versions tailored for rainfed areas, larger text and images, and additional content on pest management and safe pesticide use. By focusing on how FFS graduates learned and applied the PalayCheck recommendations, rather than merely documenting the primer's benefits, this study underscores the need to align extension materials with farmers' capacities, production contexts, and stage of readiness for behavioral change.

Keywords: *feedback from farmers, interventions, Palaycheck primer, transtheoretical model of change*

Introduction

In the late 1970s, the Philippines was a marginal exporter of rice (USDA, 2016). The rapid growth in rice production during this period has been attributed to the widespread adoption of modern rice varieties, as noted in a chapter of *Competitiveness of Philippine Rice in Asia*. However, from the mid-1980s to the late 1990s, growth in rice production stalled, and the Philippines became a marginal rice importer (Bordey and Castañeda, 2011). In 2023, Filipino rice farmers made history by producing more than 20 Mmt (million metric tons) of *palay*. Despite this achievement, rice remains expensive and unaffordable for many poor Filipinos, with regular milled rice costing an average of 0.75 USD/kg. This indicates that, despite production gains, the country remains far from achieving rice security. High *palay* production costs contribute significantly to elevated rice prices. To produce 1 kg of *palay*, Filipino farmers spend 0.22 USD, whereas farmers in Vietnam, Thailand, and India spend only 0.12, 0.16, and 0.16 USD, respectively (Moya et al., 2016). To reduce production costs and improve competitiveness, Bordey et al. (2016) recommended strategies such as the use of hybrid seeds, more frequent fertilizer splitting, and increased training and education for farmers.

Numerous development interventions have been implemented to enhance farmers' uptake of technologies aimed at increasing yields and reducing production costs. These interventions have been evaluated primarily in terms of effectiveness and outcomes. The literature identifies several factors that influence behavior change, including farmers' preferences for accessing information based on time availability, farm activities, and needs (Layaoen, 2016; Manalo et al., 2022); the effectiveness of peer-based learning in enhancing participation and reinforcing knowledge application (Devaraj et al., 2020; Hwang and Chang, 2016; Palis, 2006); and the importance of materials being clear, complete, and easy to understand (Layaoen, 2016; Manalo et al., 2022; Relado, 2008; Sisteberio, 2001; Tanzo et al., 2009).

While the effectiveness of interventions has been studied extensively, there has been limited exploration of the dynamic process of change that farmers undergo—from having no intention to adopt technologies to becoming fully equipped and competitive rice farmers. Understanding this process is crucial for identifying barriers that prevent farmers from adopting technological interventions and for tailoring support accordingly.

Farmers pass through distinct stages before adopting a technology. This study aimed to assess the stages of change in the uptake of the PalayCheck Primer's key messages using the Transtheoretical Model of Change (TTM). By examining the experiences of Farmer Field School (FFS) graduates in Bayambang, Pangasinan, the study sought to (1) describe their stages of change in relation to specific PalayCheck recommendations and (2) gather feedback on how to enhance the uptake of the PalayCheck Primer's key messages. In doing so, it recognizes that farmers significantly contribute to the design and improvement of extension materials by bringing their own perspectives (David and Cobbah, 2008).

The PalayCheck Primer is one of the knowledge products produced by Philippine Rice Research Institute (PhilRice) in Filipino. It was primarily developed for irrigated lowland farms and serves as a guide for rice farmers in applying the Key Checks. Each Key Check consists of several parts: (1) Crop Management Area, which identifies the focus; (2) Importance, which highlights its role in achieving optimal yield; (3) Assessment, which evaluates whether the Key Check has been met; and (4) Recommendation, which details the practices required to fulfill it. The PalayCheck system itself is an integrated crop management approach that provides recommendations based on best management practices tailored to specific agro-ecological conditions. Distribution of the PalayCheck Primer forms part of PhilRice's extension services and is intended to equip farmers with the knowledge and skills necessary to improve farming practices. Through print media such as the PalayCheck Primer, PhilRice reinforces knowledge gained from training, recognizing the vital role of communication in agricultural and rural development.

Materials and Methods

This study employed a qualitative approach, aligned with the objectives of exploring the stages of change among farmer-participants in the uptake of the PalayCheck Primer's key messages and gathering feedback to enhance adoption. Qualitative research focuses on understanding the why, how, and processes involved, as well as the influences and context shaping the phenomenon of interest. It seeks a contextualized understanding of behaviors, beliefs, and motivations (Hennink et al., 2020). Given the paucity of similar studies at PhilRice or in comparable research organizations, a qualitative approach is well-justified.

The study was guided by key concepts from the Transtheoretical Model of Change (TTM), also known as the Stages of Change Model (DiClemente et al., 2015). The TTM explains how behavior change occurs over time and is characterized by six stages: (1) Pre-contemplation, (2) Contemplation, (3) Preparation, (4) Action, (5) Maintenance, and (6) Termination.

According to DiClemente et al. (2015), Pre-contemplation is the stage in which people do not intend to make a change in the near future (often defined as the next six months). Contemplation is the stage where people intend to change within the next six months and are aware of both the pros and cons of changing. Preparation represents the stage where people have a plan of action and intend to take action in the immediate future (within a month). Action is the stage in which people make the behavior change, and Maintenance is the stage where they work to prevent relapse. Termination represents the stage where individuals have complete self-efficacy and no temptation to revert to previous behavior.

Prochaska and DiClemente (1997) conceptualize behavior change as a process involving progression through these stages. Movement from one stage to another is variable, and individuals may regress to earlier stages before eventually progressing to Maintenance or Termination. Specific interventions are required to reduce resistance, facilitate progress, and prevent relapse.

In this study, Pre-contemplation referred to farmers who owned or had been given the Primer but had not read it or had no expressed intention of using its recommendations. Contemplation described farmers who acknowledged the relevance of the Primer. Farmers in this stage are aware of the pros of changing but also can identify the cons. In this stage, the farmer is intending to change within the next six months. Action referred to farmers who had already implemented at least one recommendation from the Primer, such as using certified inbred seeds, following the recommended seeding rate, or practicing synchronous planting. Maintenance was defined as sustained and consistent practice of the recommendations over several cropping seasons, such as repeated use of certified seeds or regular coordination with other farmers for synchronous planting. Maintenance represents the stage where people work to prevent relapse. There were no research participants under the Preparation and Termination stages. Preparation stage is defined as the phase where individuals are seriously considering changing their behavior within the next month. The absence of participants in this stage is due to none of them indicating that they were seriously contemplating behavior change within the next month. Similarly, no farmer-participants were found in the Termination stage, which Prochaska and Velicer (1997) described as the phase where individuals have maintained their behavior for more than five years, possessed 100% self-efficacy in sustaining the behavior, and experienced 0% temptation to revert to the undesired behavior. The PalayCheck Primer was distributed in 2020 to FFS graduates in Bayambang, Pangasinan. Given this timeframe, no farmer-participants could yet qualify for the Termination stage.

Individual interviews and field observations provided the basis for assigning participants to stages. Of the 38 farmers, nine were classified as being in Pre-contemplation, as they either did not read the Primer or continued to rely on traditional methods. Two farmers were in Contemplation, expressing willingness to try recommendations in the next season. None were in the Preparation stage. The majority (27 farmers) were in Action, applying at least one recommendation from the Primer. A subset of these farmers reached Maintenance in relation to specific practices, such as seed selection and crop establishment. No farmers were classified in Termination. These assignments indicate that the TTM framework effectively captured farmers' progression from mere awareness of the Primer to observable behavior change in their farming practices.

A case study design was used to investigate the experiences of FFS graduates from Bayambang, Pangasinan. Bayambang was chosen because rice is one of its primary sources of livelihood, alongside corn, onion, and vegetables. The municipality is the fourth-largest rice-producing municipality in the province, with 7,702 ha dedicated to rice cultivation, yet it is ranked as the second-lowest-yielding municipality in District 3 of Pangasinan, with an average yield of only 3.44 t ha^{-1}. This stark contrast provides a compelling backdrop for examining technology uptake.

Bayambang is also one of PhilRice's project sites where farmers have undergone training on rice production. Many farmers in this municipality received copies of the PalayCheck Primer. The study was conducted to evaluate farmer-participants' perceptions regarding the Primer's comprehensiveness, understandability, readability, and usefulness.

Case studies seek in-depth understanding of phenomena in real-life contexts (Dobson, 1999). This approach is relevant because it allows detailed exploration of farmers' dynamic change processes. It also enables the collection of rich feedback on how to enhance uptake of the PalayCheck Primer to better tailor future interventions and support strategies.

In this research, individual interviews with 38 participants and field observations were conducted. Seidman (2013) explains that semi-structured, conversational interviews allow flexible and open-ended discussion, enabling the interviewer to explore topics in greater depth and follow emerging themes. Such interviews support natural dialogue and can reveal insights not easily captured through structured surveys (Kvale, 1996).

A structured interview guide was used, focusing on the influence of the PalayCheck Primer on participants decisions to try and/or adopt the technologies, as well as their feedback on improving the uptake of key messages. The guide was also designed to identify which stage of change each participant reflected the Transtheoretical Model.

Additional questions solicited suggestions to improve content, readability, and contextual relevance. Since one-on-one interviews were employed, participants were able to express themselves freely and without hesitation.

Results and Discussion

This section is composed of two parts. The first examines the stages of change in the uptake of the PalayCheck Primer's key messages. The second presents farmers' feedback on how uptake could be enhanced.

Participant Profile

The 38 FFS graduates (24 male, 14 female) who participated in the study were all members of the RiceBIS Bayambang Agricultural Cooperative. They differed in age, education, and farming background. Ages ranged from 15–24 years to above 65 years, with most belonging to the 55–64 age group. In terms of educational attainment, six participants had completed elementary education, 24 reached the secondary level, five attained college-level education, and three completed vocational courses. With respect to civil status, 32 were married, two were single, and four were widowed.

Farming experience also varied. Twenty-one had been engaged in farming for more than 31 years, five for 21–30 years, six for 11–20 years, and six for less than 10 years. In terms of landholding, 20 farmers owned 1–5 ha, while 18 cultivated less than 1 ha. Seventeen were landowners, 12 were share-tenants, and 12 both owned land and engaged in share-tenancy. Regarding farming environments, 11 participants managed irrigated farms, 14 cultivated rainfed farms, and 13 operated both irrigated and rainfed areas. Twenty-seven participants reported additional sources of income, including running sari-sari stores, vending, vegetable production, and tricycle driving.

This study was limited to assessing knowledge and learning derived from the PalayCheck Primer. It is recognized, however, that farmer training may also contribute to learning, making it difficult to fully disentangle knowledge gained from the Primer from that reinforced by training and other extension activities. During interviews, participants were consistently reminded to base their responses on what they had learned from the Primer.

Stages of Change in the Uptake of PalayCheck Primer Key Messages

Farmers in Pre-contemplation and Contemplation. Pre-contemplation is the stage where individuals are unprepared to change their current behavior, while Contemplation is when individuals have considered taking action. Among the 38 participants who received the PalayCheck Primer, 11 reported that they had not read it. Of these, nine were classified as being in Pre-contemplation. They were not ready to adopt changes, inclined to continue using traditional practices, visually impaired, unable to recall content, or had transferred farm responsibilities to family members. Two participants were in Contemplation, aware of the Primer's existence and potential benefits but recalling its content only during the planting season.

These findings (Table 1) align with Velicer et al. (1998), who reported that individuals in Pre-contemplation do not intend to take action in the foreseeable future and may be uninformed or under-informed about the consequences of their current behavior. Similarly, farmer-participants in this study had not yet engaged with information that could improve their farming practices. Visual impairment also emerged as a concern, as some participants found the Primer difficult to read due to small print, which may have discouraged them from using it. Doak et al. (1985) note that readability issues can discourage readers and impede learning, while Taylor (2012) emphasizes readability as a crucial starting point for message comprehension.

Some farmers indicated that they no longer felt the need to read the Primer because they had passed farming responsibilities on to their children. Although Conway (2022) highlights how generational renewal can affect older farmers' mental health and well-being, such issues were not prominent in this study. Even so, Conway's recommendation to implement farmer-sensitive actions at policy and societal levels remains relevant for easing fears and anxieties associated with retirement from farming.

Other farmers reported that they did not read the Primer because they preferred traditional methods over recommended technologies. This aligns with Truong and Ngoc (2008), who found that farmers often remain attached to traditional practices due to concerns that unfamiliar technologies may reduce yields or be unsuitable for their conditions. They also observed that perception and education level

Table 1. Farmer-participants in pre-contemplation and contemplation stages.

Stages of Change	Number of Responses	Research Participants	Examples
Pre-contemplation	9	Farmer 18 Age: Over 65; Sex: F Educational Attainment: HS	I just don't remember anything. I didn't read that, ma'am.
		Farmer 26 Age: 55-64; Sex: F Educational Attainment: Elem	I don't remember, ma'am, but I have a copy of that set aside, ma'am. I have it, ma'am, but I just can't remember anymore.
		Farmer 32 Age: 55-64; Sex: M Educational Attainment: HS	I haven't yet, ma'am, because my vision is a bit blurry.
		Farmer 5 Age: 55-64; Sex: M Educational Attainment: HS	We don't read it, ma'am; we actually do the traditional way.
		Farmer 21 Age: Over 65; Sex: F Educational Attainment: Elem	I don't remember, ma'am. It's my children who are working now because our fields are next to each other.
Contemplation	2	Farmer 24 Age: 55-64; Sex: F Educational Attainment: Elem	I know that will help.
		Farmer 20 Age: 55-64; Sex: M Educational Attainment: HS	So for now, not yet, because it's not planting season.

significantly influence technology adoption—a relevant point given that most participants in this study had only secondary education or below.

Participants in Contemplation were aware of the pros and cons of change and intended to make changes within the next six months (Velicer et al., 1998). Although these farmers recognized the benefits of the PalayCheck Primer, they had not yet applied its recommendations because they did not need the information at that time. They mentioned that they planned to read and apply the content during the planting season. This behavior is consistent with the findings of Manalo et al. (2022), who reported that farmers' interest in reading materials is shaped by time availability, farm activities, and immediate needs. It also aligns with Layaoen (2016), who observed that farmers accessed information on climate change and rice production based on specific needs, especially during extreme weather conditions.

Farmers in the Action Stage

The Action stage occurs when individuals have taken observable steps toward behavior change. Of the 38 participants, 27 reported that they had implemented at least one recommendation from the PalayCheck Primer.

The most commonly adopted recommendations were use of certified seeds and field leveling (Figure 1). Adoption of certified seeds can be attributed not only to learning from the Primer but also to the support provided by the Rice Competitiveness Enhancement Fund (RCEF) through free certified inbred seeds. As members of the RiceBIS Bayambang Agricultural Cooperative, many participants regularly attended meetings to plan planting schedules and coordinate seed distribution. This consistent access to certified seeds, combined with cooperative structures, reinforced adherence to PalayCheck recommendations on variety and seed selection and crop establishment.

The second most adopted set of recommendations related to the correct amount, element, and timing of nutrient application. The third was application of pesticides only when necessary and conservation of beneficial organisms. The fourth was adoption of the recommended planting distance. The least adopted recommendations were those related to water, harvest, and post-production management. Each farmer classified in Action applied at least one recommendation, but none fully implemented all recommendations specified in the Primer.

Importantly, the stages of adoption in this study refer to the uptake of specific recommendations rather than comprehensive adoption of all Key Checks. While many farmers practiced variety and seed selection (e.g., shifting to certified inbred seeds, following recommended seeding rates and planting distances), fewer consistently followed recommendations related to water, pest, and nutrient management, and very few applied harvest and postharvest recommendations. Adoption was thus selective and often concentrated on practices that were easier to implement, more visible, or strongly reinforced by cooperative activities such as synchronous planting.

Each Key Check includes an assessment step to help farmers determine whether proper management was achieved. However, findings suggest that most farmers did not systematically apply these assessment procedures as outlined. Instead, they relied on observable field outcomes (e.g., better germination, reduced weed pressure, higher yields) rather than structured assessments. This indicates that while the Primer influenced behavior, its diagnostic function was underutilized.

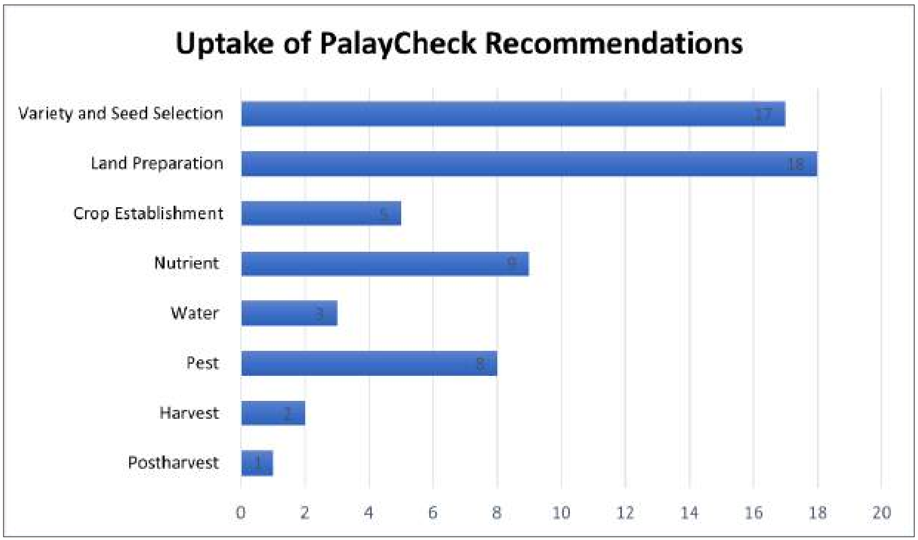


Figure 1. Uptake of Palaycheck recommendations.

Participants also contextualized their adoption of other Key Checks. Some stated that nutrient management recommendations were easier to adopt because they could be integrated into existing practices and could be linked to visible improvements in crop growth. Others reported that applying pesticides only when necessary and conserving beneficial organisms helped reduce costs and was therefore practical. Adopting recommended planting distances was justified as a way to obtain healthier seedlings and better yield potential. In contrast, water, harvest, and post-production recommendations were least adopted, largely due to limited irrigation facilities, lack of postharvest equipment, and perceived mismatch of recommendations with rainfed conditions.

These narratives show that farmers weighed PalayCheck recommendations against their own contexts. Behavior change occurred where recommendations were supported by enabling conditions such as access to inputs, cooperative support, and visible benefits while adoption was constrained where contextual barriers persisted.

Voas (2014) defines behavior as the expression of action. Although behavior change is often equated with action, Prochaska and Velicer (1997) emphasize that Action is only one of six TTM stages and does not yet represent complete behavior change. True behavior change occurs when individuals move beyond Action and sustain new practices over time.

Farmers in the Maintenance Stage

Nineteen participants (50%) had reached the Maintenance stage with respect to variety and seed selection and crop establishment recommendations (Figure 2). Maintenance occurs when continuous effort is required to sustain behavior. Patten et al. (2000) describe this stage as the phase where individuals work to sustain gains made during Action, while Velicer et al. (1998) characterize it as the phase where individuals actively work to prevent relapse.

Most participants regularly attended RiceBIS cooperative meetings to plan planting schedules and organize distribution of free certified seeds in their communities. This ongoing participation likely helped them avoid regression from Maintenance to earlier stages by reinforcing adherence to recommendations on variety and seed selection and crop establishment.

High-quality seeds such as certified inbred seeds are pure, contain fewer weed seeds, are free from visible seed-borne diseases, are full and uniform in size, and have at least 85% germination. The use of quality seeds combined with proper crop management can result in a 10% or more increase in yield. Technologies adopted under crop establishment included synchronous planting, recommended seeding rate, and recommended planting distance. Synchronous planting—planting within 14 days before or 14 days after the common planting schedule—allows the field to rest for at least 30 days, breaking insect pest cycles whose average life cycle is about 30 days. Recommended spacing (e.g., 20 × 20 cm) provides sufficient room for seedlings to grow, produce productive tillers, and increase yield potential.

Only four participants reported both using free seeds and purchasing certified seeds from the market. The relatively low rate of purchasing behavior is consistent with Sirutyte (2017), who found that even when knowledge of certified seeds increased through interventions, willingness to pay did not necessarily change significantly. This suggests that awareness of benefits, as highlighted in the PalayCheck Primer,

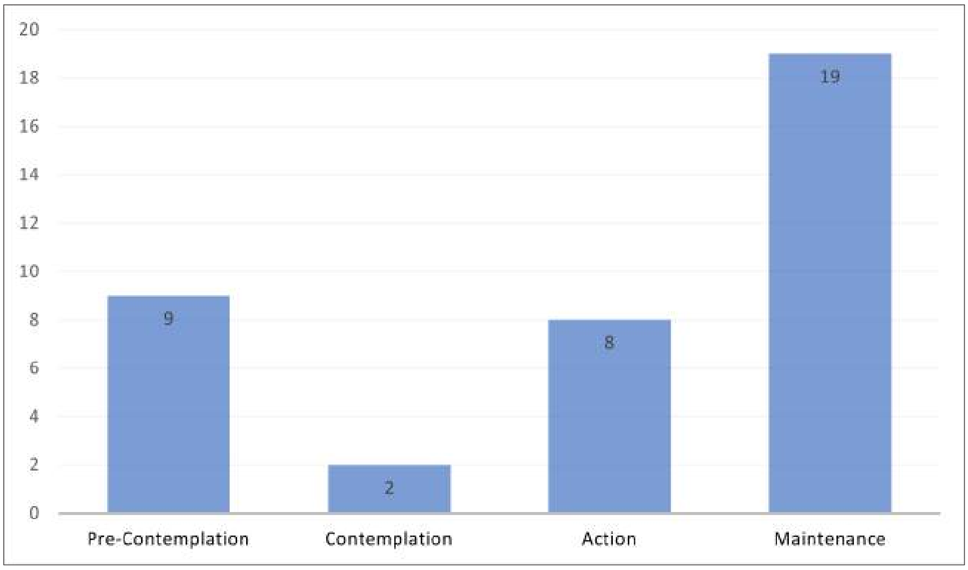


Figure 2. Farmer-participants reaching maintenance stage on variety and seed selection and crop establishment recommendations from the Palaycheck primer.

Table 2: Participants who used certified inbred seeds, practiced synchronous planting, and followed the recommended planting distance.

Crop Management	Number of Responses	Research Participants	Examples
Synchronous planting	1	Farmer 17 Age: 25-54; Sex: M Educational Attainment: HS	We are now keeping up with the planting schedule. Without seeds, we wouldn't be able to plant. So now we have organized ourselves, and a schedule when to plant. We can now keep up because of the availability of seeds and water. We have regular meetings to ensure we plant at the right time.
Seeding rate at 40 kg/ha	1	Farmer 19 Age: Over 65; Sex: M Educational Attainment: HS	Previously around 60 kg. Now it's about 40 kg per hectare.
Recommended planting distance	4	Farmer 1 Age: 15-24; Sex: F Educational Attainment: College	Before, planting was done manually and seeds were seeded, but now there is knowledge about measurements and it's no longer just estimations like before.
		Farmer 33 Age: 25-54; Sex: F Educational Attainment: HS	There was no distance before, ma'am, we just seed it directly. Now, it's measured using a ruler.
		Farmer 23 Age: Over 65; Sex: M Educational Attainment: HS	We first eliminate the weeds, and practice recommended planting distance.
Use of certified inbred seeds	13	Farmer 19 Age: Over 65; Sex: M Educational Attainment: HS	I have tried the recommendation on seed selection, and it is effective. I first tried NSIC Rc 216.
		Farmer 7 Age: Over 65; Sex: F Educational Attainment: Elem	Now, we use certified seeds. Before, when there were no certified seeds, we stored farm-saved seeds ourselves, but now we use certified seeds.
		Farmer 38 Age: 55-64; Sex: F Educational Attainment: Elem	Before, as long as the seeds performed well, we kept planting them. But not anymore; we use high-quality seeds such as 380 and 216. Now, we are using 480.
		Farmer 4 Age: 25-54; Sex: M Educational Attainment: College	Before, we use farm-saved seeds, but now the seeds we get are certified and come from the coop.
		Farmer 17 Age: 25-54; Sex: M Educational Attainment: College	Before, we planted whatever we harvested. Now, we use high-quality seeds, and the RCEF provides free certified seeds.
		Farmer 3 Age: 55-64; Sex: M Educational Attainment: HS	Before, we used to store seeds ourselves; now we are given high-quality seeds.
		Farmer 14 Age: 55-64; Sex: F Educational Attainment: HS	Before, we used to rely on what we harvested, but not anymore. Now, we use high quality seeds. Now we do buy seeds because sometimes what they [RCEF] provide is not enough. I have bought some seeds [NSIC Rc] 216 and Rc 180.
		Farmer 27 Age: Over 65; Sex: M Educational Attainment: HS	Before, we use farm-saved seeds; now, we buy certified seeds.
		Farmer 10 Age: 55-64; Sex: F Educational Attainment: HS Age: 55-64; Sex: M Educational Attainment: HS	Before, we plant farm-saved seeds; now, we buy certified seeds.
		Farmer 31 Age: 25-54; Sex: M Educational Attainment: College	Before, we would save some seeds after the harvest; now, we buy certified seeds.

does not automatically translate into increased market-based uptake.

No participants were classified in the Preparation or Termination stages. Preparation is the phase where individuals seriously consider behavior change within the next month. The absence of farmers in this stage reflects the fact that none indicated such an imminent intention. Similarly, no participants met the Termination criteria described by Prochaska and Velicer (1997), which require maintaining behavior for more than five years, complete self-efficacy, and no temptation to revert. Since the PalayCheck Primer was distributed only in 2020, the five-year requirement could not yet be met.

Feedback to Enhance Uptake of the PalayCheck Primer's Key Messages

Farmer-participants provided several suggestions to improve the PalayCheck Primer (Figure 3). They recommended producing a version suitable for rainfed areas and emphasized the need to highlight important information by enlarging text and images for easier reading. They also suggested including more detailed guidance on pest management, increasing beneficial organisms, and coping with sudden drought or La Niña events. Additionally, they requested information on the implications of excessive chemical use on rice, human health, and the environment, and wanted the Primer to clearly stress that producing high-quality rice can lead to increased income.

Interview transcripts were analyzed using thematic analysis (Braun and Clarke, 2006). Results were then entered into a word cloud generator (https://www.wordclouds.com) to visually represent farmers' suggestions. In the word cloud, larger words indicated more frequently mentioned suggestions. The word cloud was used as a creative visualization tool rather than as a formal analytical method. Figure 3 shows the key suggestions for improving the uptake of PalayCheck Primer key messages. The most frequently suggested addition was a PalayCheck version for rainfed rice (*PalayCheck para sa Sahod-Ulan*), reflecting the fact that many participants cultivated rainfed fields. This is consistent with Mariano et al. (2012), who found that technology choice largely depends on environmental suitability and that understanding farmer characteristics and production conditions is essential before disseminating technologies at scale. They emphasize the importance of baseline surveys to match technologies with farmer characteristics and agro-ecological conditions, thereby reducing diffusion costs and adoption constraints. Chaka (2003) similarly concluded that information must be tailored to specific audiences for it to be effective. Mentions of specific information needs such as increasing beneficial organisms and controlling pests underscore the importance of contextualized information. Glendenning et al. (2010) recommend including context-specific, relevant information when designing extension approaches, rather than relying solely on generic messages. Some of the farmer-participants also suggested improving font size and images to make the Primer easier to read and understand. This aligns with Kassem et al. (2017),

Figure 3: Suggestions for improving the uptake of PalayCheck primer key message.

who found that improving readability of extension pamphlets significantly enhanced farmers' knowledge and adoption of agricultural practices. Taylor (2012) also emphasizes that readability is a crucial starting point for comprehension. While Chaka (2003) notes that reading is essential for agricultural literacy, he also highlights that it is only one of several factors that contribute to understanding.

Conclusion and Recommendations

Farmers undergo distinct stages before adopting new technologies. Examining the stages of change among FFS graduates in Bayambang, Pangasinan, in relation to the PalayCheck Primer's key messages using the Transtheoretical Model helps clarify where they are in the change process and how interventions can be better aligned with their readiness. Most participants demonstrated behavior change by adopting practices such as using certified seeds, practicing synchronous planting, applying the correct amount and timing of nutrients, observing proper planting distance, and using pesticides only when necessary. With support from their cooperative and access to RCEF-distributed seeds, some farmers reached the Maintenance stage in variety and seed selection and crop establishment. However, progression to higher stages of adoption was hindered by reliance on traditional practices, poor eyesight that limited reading of the Primer, generational transfer of responsibilities, seasonal dependence in recalling information, limited applicability of some recommendations to rainfed conditions, and lack of detailed guidance on pest management. As a result, many farmers remained in Pre-contemplation or Action rather than advancing further. Of the 38 participants, nine were in Pre-contemplation, two in Contemplation, and 27 in Action. None reached Termination. Given that this stage requires more than five years of sustained behavior, its operationalization in an agricultural context where five years can correspond to about ten cropping seasons may need reconsideration. The dynamic and diverse nature of agricultural systems suggests that the TTM may need recalibration for sector-specific applications.

Only recommendations related to variety and seed selection and crop establishment led to some farmers reaching Maintenance. Regular cooperative meetings and access to free certified inbred seeds likely supported this. A few farmers also purchased certified seeds, indicating strong commitment to these practices. However, only a subset of the Primer's recommended technologies has been widely practiced. This points to the need for more engaging and context-sensitive development strategies to encourage farmers to progress further across a broader range of recommendations.

Farmers' suggestions for improving the Primer such as developing a rainfed version, enlarging text and images, adding detailed guidance on pest management, beneficial organisms, extreme weather, and chemical use, and emphasizing links between quality production and income highlight the importance of involving farmers in the design and refinement of extension materials. Enlarging font size and images may deviate from conventional aesthetics but is critical for aging farmers. Incorporating farmers' feedback can help ensure that information is relevant, usable, and aligned with their capacities and conditions. Access to information materials such as the PalayCheck Primer is one key factor influencing technology uptake, but it is not sufficient on its own. Follow-up activities are recommended to support and sustain adoption. These may include technology demonstrations linked to PalayCheck recommendations; integration of Primer use with cooperative activities (e.g., planning, seed distribution, synchronized planting); and continued government support, such as free or subsidized certified seed distribution, particularly for rainfed farmers.Further research could examine how the TTM might be adapted or recalibrated for agricultural contexts, where cropping seasons, climate variability, and market conditions shape the pace and stability of behavior change.

Acknowledgment

The authors thank the farmer-respondents from Bayambang, Pangasinan who served as voices representing the stages of change in the uptake of PalayCheck primer technologies. Their time, insights, and openness were invaluable to this study.

Literature Cited

Ashraf N, Jack KB, Kamenica E (2013) Information and subsidies: Complements or Substitutes? Journal of Economic Behavior & Organization ***88***: 133 - 13

Bordey FH, Castañeda AC (2011) Philippine rice industry series. Philippine Rice Research Institute

Bordey FH, Beltran JC, Launio CC, Litonjua AC, Mataia AB, Manalili RG, Moya PF (2016) Rice yield and its determinants. *In* Bordey FH, Moya PF, Beltran JC, Dawe DC (Eds.), Competitiveness of Philippine rice in Asia (pp. 87). Philippine Rice Research Institute & International Rice Research Institute

Bordey FH, Beltran JC, Launio CC, Litonjua AC, Mataia AB, Manalili RG, Moya PF (2016) Rice yield and its determinants. In Bordey FH, Moya PF, Beltran JC, Dawe DC (eds.), Competitiveness of Philippine rice in Asia (p. 87). Philippine Rice Research Institute & International Rice Research Institute

Braun V, Clarke V (2006) Using thematic analysis in psychology. Qualitative Research in Psychology ***3***(2): 77 - 101

Chaka MP (2003) The usability and effectiveness of a printed information booklet: A survey amongst small-scale rural farmers (Master's thesis). University of Pretoria

Conway SF, Farrell M, McDonagh J, Kinsella A (2022) 'Farmers Don't Retire': Re-Evaluating How We Engage with and Understand the 'Older' Farmer's Perspective. Sustainability ***14***(5): 2533

David S, Cobbah EAN (2008) From our perspective: developing printed extension materials with cocoa farmers in Ghana. International Journal of Agricultural Sustainability ***6***(4): 267 - 276

DiClemente CC, Prochaska JO, Norcross JC (2015) The transtheoretical stages of change. Retrieved from http://www.prochange.com/transtheoretical-model-of-behavior-change (accessed September 13, 2024)

Doak CC, Doak LG, Root JH (1985) Teaching patients with low literacy skills. J.B. Lippincott Company. Retrived from https://catalog.nlm.nih.gov/discovery/fulldisplay/alma995897153406676/01NLM_INST:01NLM_INST (accessed September 13, 2024)

Dobson PJ (1999) Approaches to Theory Use in Interpretive Case Studies—a Critical Realist Perspective. 10th Australasian Conference on Information Systems Church lands. Edith Cowan University

Fidanci I, Ozturk O, Mustafa U (2017) Transtheoretic model in smoking cessation. J Exp Clin Med ***34***(1)

Glendenning CJ, Babu S, Asenso-Okyere K (2010) Review of agriculture extension in India: Are farmers' information needs being met? International Food Policy Research Institute

Hennink M, Hutter I, Bailey A (2020) Qualitative research methods. Sage Publications. DOI:10.1007/s11135-023-01660-5

Hwang G, Chang S (2016) Effects of a peer competition-based mobile learning approach on students' affective domain exhibition in social studies courses. British Journal of Educational Technology ***47***(6): 1217 - 1231

Imran M, Almusharraf N (2023) Qualitative Research Methods, by Monique Hennink, Inge Hutter, and Ajay Bailey. SAGE Publications ***57***: 4935 - 4938

Kassem HS, Abdel-Magieed MA, El-Gamal HM, Aldosari F (2017). Effect of readability on farmers' knowledge: An Assessment of some Agricultural Extension Pamphlets. Life Science Journal ***14***(4): 16 - 22

Kvale S (1996) InterViews: An Introduction to Qualitative Research Interviewing. Sage Publications ***19***(2): 267 - 270

Layaoen, M (2016) Improving the usefulness of PhilRice knowledge products on climate change and rice production technologies: A re-entry project report presented to the faculty of the Public Management Development Program. Philippine Rice Research Institute

Manalo HB, Frediles CA, Berto AB, Berto J (2022) Effectiveness of the Gabay sa Makabagong Pagpapalayan brochure in influencing behavior change among RCEF beneficiaries. Philippine Rice Research Institute

Moya PF, Bordey FH, Beltran JC, Manalili RG, Launio CC, Mataia AB, Litonjua AC, Dawe DC (2016) Cost of rice production. *In* F. H. Bordey, P. F. Moya, J. C. Beltran, & D. C. Dawe (eds.), Competitiveness of Philippine rice in Asia. Philippine Rice Research Institute & International Rice Research Institute (pp. 99 - 117)

Palis FG (2006) The role of culture in farmer learning and technology adoption: A case study of farmer field schools among rice farmers in Central Luzon, Philippines. Agriculture and Human Values ***23***(4): 491 - 500

Patten S, Vollman AR, Thurston WE (2000) The utility of the Transtheoretical Model of behavior change for HIV risk reduction in injection drug users. Journal of the Association of Nurses in AIDS Care ***11***(1): 57 - 66

Prochaska JO, Velicer WF (1997) The transtheoretical model of health behavior change. American Journal of Health Promotion ***12***(1): 38 - 48

Relado RZ (2008) Assessing the usefulness of Philippine rice extension materials (Master's thesis). Pennsylvania State University

Seidman I (2013) *Interviewing as qualitative research: A guide for researchers in education and the social sciences* (4th ed.). Teachers College Press

Sirutyte I (2017) Information barriers and farmers' willingness to adopt certified seeds: Evidence from rural Uganda (Master's thesis). Wageningen University

Sisteberio M (2001) Communication strategies in promoting agricultural technologies through the PCARRD's Farmers-Scientist Bureau (FSB) Magsasaka Siyentista (MS) in Majayjay, Laguna, Philippines (Master's thesis). University of the Philippines, Los Baños

Taylor G (2012) Readability of OHS documents: A comparison of surface characteristics of OHS text between some languages. Safety Science ***50***(7): 1627 - 1635

Truong T, Ngoc C (2008) Factors affecting technology adoption among rice farmers in the Mekong Delta through the lens of the local authorial managers: An analysis of qualitative data. Omon rice ***16***: 107 - 112

Velicer WF, Prochaska JO, Fava JL, Norman GJ, Redding CA (1998) Smoking cessation and stress management: Applications of the transtheoretical model of behavior change. Homeostasis ***38***(4): 216 - 233

Voas D (2014) Towards a Sociology of Attitudes. Sociological Research Online ***19***(1). Retrieved from https://www.researchgate.net/publication/271155099_Towards_a_Sociology_of_Attitudes (accessed September 13, 2024)

UNDERSTANDING FARMERS' USE OF THE *GABAY SA MAKABAGONG PAGPAPALAYAN* BROCHURE TO ENSURE ITS EFFECTIVENESS IN PROVIDING INFORMATION

Hanah Hazel Mavi B. Manalo*, Anna Marie B. Berto, Christina A. Frediles,
Reuel M. Maramara, and Jayson C. Berto

Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
*Corresponding Author: hanahhazelmavi@gmail.com or hhmbmanalo@exchange.philrice.gov.ph

Abstract

Printed information, education, and communication (IEC) materials are widely used to transfer knowledge to farmers, with knowledge considered a prerequisite for changes in attitude and practice. However, producing and distributing printed IECs entails substantial costs, underscoring the need to understand how intended users actually engage with these materials. This study examined how 154 beneficiaries of the Rice Competitiveness Enhancement Fund (RCEF) Seed Program from Capiz, Aklan, Bohol, Masbate, Quirino, Pampanga, Davao Oriental, and Davao del Sur utilized the brochure *Gabay sa Makabagong Pagpapalayan*, which was distributed in 2020 and 2021 in all RCEF-covered provinces. Guided by Krikelas's Model of Information-Seeking Behavior, in-depth interviews were conducted, transcribed, and thematically analyzed. Results show that farmers' interaction with the brochure was highly need-based. Reading was infrequent and driven by urgent, farm-related information needs that farmers could not address using their existing knowledge. It was also selective, as farmers focused only on sections directly related to their immediate concerns (e.g., nutrient management, crop establishment, harvest). These findings suggest that farmers regard their own experience as the primary information source and turn to printed IECs only when this internal source proves insufficient. Drawing on these results, the study recommends problem-centered communication in packaging information for farmers, careful timing and prioritization of content in IECs, improved durability of printed materials, and the availability of complementary and accessible alternative information sources.

Keywords: *information-seeking behavior, infrequent reading, need-based reading, printed IEC materials, selective reading*

Introduction

The Philippine government invests substantial resources in producing printed agricultural information materials to support technology delivery to rice farmers. From 2019 to 2024, for example, the Rice Competitiveness Enhancement Fund (RCEF)–Extension Program alone spent about PhP 97 million on various printed rice-related materials. Printed information, education, and communication (IEC) materials are intended to facilitate changes in farmers' knowledge and attitudes (Redman & Paul, 1997; Sheela, 2004), which are necessary precursors to changes in practice. Despite these investments, evidence on the actual effectiveness of printed IECs in improving yield or quality of life among farmers remains limited.

In the literature, farmers are reported to seek information primarily to bridge information gaps and overcome production constraints (Brhane et al., 2017). Access to relevant information enables them to gain new knowledge, including modern technologies (Brhane et al., 2017; Kabir et al., 2014). Farmers' information-seeking behavior is shaped by factors such as information needs, characteristics of information channels, perceptions of agricultural information, training, land ownership, and type of farming system (Mahindarathne & Min, 2019). Sociodemographic characteristics including age, education, gender, farming experience, location, and income also play key roles (Kavithaa et al., 2014; Linh et al., 2016; Lwoga et al., 2010; Mahindarathne & Min, 2019; Mwombe et al., 2014). Commonly sought topics include major crop management, crop protection, marketing, climate, credit and loan facilities, and animal disease control (Kabir et al., 2014; Lwoga et al., 2010; Rehman, 2010).

Print media (Duhan & Singh, 2017; Farooq, 2007; Ford & Babb, 1989; Korsching IV & Hoban, 1990; Memon et al., 2005; Murage, 2011; Njoku, 2022; Pathak, 2022; Rehman et al., 2011; Rehman, 2010), along with fellow farmers, agriculture professionals, and extension workers (Brhane et al., 2017; Idowu et al., 2020; Kabir et al., 2014), remains an important source of agricultural information. Pamphlets, magazines, and newspapers are among the most frequently used print formats (Duhan & Singh, 2017; Kughur et al., 2018; Pathak & Patel, 2022; Rehman, 2010). For many farmers, accessible communication channels include print (Nii et al., 2023; Njoku, 2022), radio, mobile phones, and television (Mwombe et al., 2014; Sennuga et al., 2020), whereas the internet and computers are less accessible, especially in rural areas (Mwombe et al., 2014).

Accessing information is not always straightforward. Global studies cite several barriers, including an insufficient number of extension workers (Tumbo et al., 2018), their limited availability for consultation, poor institutional response to information requests, lack of awareness of existing information sources, experts' limited problem-solving capacity, and weak knowledge-sharing cultures (Lwoga et al., 2010).

For print media specifically, newness and quality of content, relevance and comprehensiveness, timeliness of publication, farmers' interest, cost, access, and literacy levels all affect reception and utilization (Hosain, 2008; Kughur et al., 2018; Nii et al., 2023; Njoku, 2022; Rehman, 2010). Moreover, age, farming experience, farm size, household size, and access to extension workers significantly influence whether and how farmers use print materials (Njoku, 2022).

There is some evidence that printed IEC materials can influence technology adoption. In Nigeria and India, farmers reported adopting technologies—particularly those related to variety selection, crop establishment, and fertilizer use—based on printed materials, often in combination with advice from peers and extension agents (Idowu et al., 2020; Memon et al., 2005). ICT-based information (e.g., SMS advisories) has also been associated with improved technology uptake and productivity (Mwombe et al., 2014; Sennuga et al., 2020), while demonstrations and video have shown effectiveness in changing weed management practices among cassava farmers (Atser et al., 2023).

Despite this, few studies have examined how farmers actually interact with agricultural IEC materials. There is also limited work that views IEC production and use from the perspective of research-for-development organizations and a notable lack of studies in the rice sector. This study addresses this gap by investigating how rice farmers interact with a printed IEC material: *Gabay sa Makabagong Pagpapalayan*, a three-fold brochure containing recommendations on land preparation, seedling preparation and management, crop establishment, nutrient management, harvest management, and seed purification.

Specifically, this study aimed to identify salient information relating to farmers' frequency and timing of reading, as well as the selection of topics or content to read. The information on the timing and frequency of reading, as well as topic selection, will inform delivery schedules and messaging.

Metholodogy

The study was guided by James Krikelas's (1983) Model of Information-Seeking Behavior, which posits that information needs are shaped by an individual's environment (Igbinovia & Omehia, 2024). Information needs may be either deferred (potential needs) or immediate. Immediate information needs are those regarded as urgent and are addressed by consulting internal or external information sources. Based on this model, individuals initially rely on an internal source or their own knowledge and experience to address a perceived need. When internal resources are insufficient, they consult external sources that are easily accessible such as other people or documented information (e.g., brochures, pamphlets). This model is particularly appropriate for the present study, which focuses on how farmers interact with a printed IEC (Figure 1). Krikelas's model has been applied in business (Orrensalo, 2019), education (Akbar, 2022; Bukhari, 2018; Fitzgerald, 2020; Igbinovia & Omehia, 2024), health (Corcoran-Perry & Graves, 1990; Gardner, 2017; Okoniewski et al., 2014), and agriculture (Mahindarathne & Min, 2018), but has not previously been applied in the rice sector.

This qualitative study used purposive sampling to select research participants. Two criteria were applied: (1) they were beneficiaries of the RCEF Seed Program; and (2) they had read the three-fold brochure *Gabay sa Makabagong Pagpapalayan* (Figure 2). The brochure was distributed to RCEF farmer-beneficiaries in

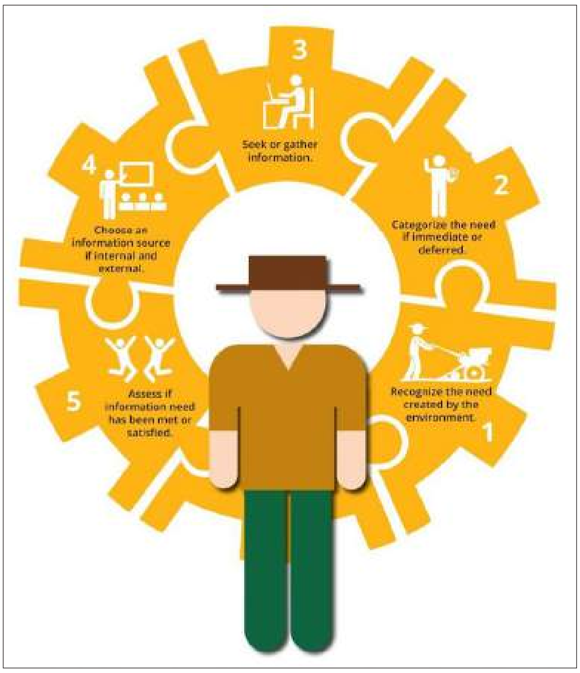


Figure 1. An illustration of farmers' use or interaction with a printed IEC material.

Gabay
sa Makabagong
Pagpapalayan

Paghahanda ng Lupa,
Pamumunla, Paglilipat-tanim,
Pag-aabono, at Pag-aani
at
Paraan sa pagpupuro
ng Binhing Palay

Figure 2. Gabay sa makabagong pagpapalayan brochure.

all covered provinces in 2020 and 2021. It aims to guide farmers in managing their crops from land preparation and seedling management, through crop establishment and nutrient management, to harvest management and seed purification.

Farmers came from low-yielding and high-yielding provinces identified by RCEF. Low-yielding provinces included Capiz, Aklan, Bohol, and Masbate, while Quirino, Pampanga, Davao Oriental, and Davao del Sur represented high-yielding provinces. In total, 154 RCEF Seed Program beneficiaries participated in the study. Their basic profile (e.g., age, sex, farming experience, farm size, and type of farming environment) is summarized in Table 1.

In-depth interviews were conducted in 2022. The interview guide was pretested first to identify potential biases in the data collection process and prevent these biases from emerging. Pretesting of the interview guide was conducted among 10 rice farmers in Nueva Ecija. The average length of the interview was 30 minutes. Questions were asked about farmers' frequency and timing of reading the brochure, as well as the selection of topics or contents they read. Thematic analysis, following the work of Marcus Renner and Ellen Taylor-Powell (2003), was conducted.

Regarding the ethical conduct of this research, participants were asked to sign a consent form that detailed all necessary information about the project, as well as their rights as research participants. The participants were made fully aware that they could withdraw their participation from this study by simply informing the project lead. All participants in this study were anonymized, and their identities were not disclosed in this paper or in any presentations made about the study.

Table 1: Socio-demographic profile of research participants.

Total Number of Participants	Province	Sex	Age	Civil Status	Educational Attainment	Years in Farming
154	Capiz: 19 Aklan: 23 Bohol: 14 Masbate: 20 Quirino: 19 Pampanga: 20 Davao Oriental: 20 Davao del Sur: 19	Female: 69 Male: 85	41 years old and above	Married	At least high school	More than 10 years

Results and Discussion

This section discusses how farmers interacted with or used the brochure by examining the frequency and timing of reading and the selection of topics or content to read. The findings are read following Krikelas's *Model of Information-seeking Behavior.*

Frequency or Timing of Reading

The frequency or timing of reading the brochure explains when farmers seek information. This is useful in identifying the proper timing of information delivery. It was found that the farmers read the brochure infrequently. The need for specific information determines the timing. In the case of the research participants, they recognized the need for information before or at the start of the cropping season, or if they encountered problems in the rice field.

> *"I was interested to know the content of the brochure so we can also use or apply the things we used not to know, to know new technologies." [Participant 2 from Aklan].*
>
> *"You do not worry about the things to do [in the farm] because you already have additional knowledge from the brochure." [Participant 4 from Capiz]*
>
> *"I last read the brochure when the prices of fertilizer were soaring." [Participant 3 from Davao Oriental]*
>
> *"I read every start of planting, then I read again the brochure for fertilizer application." [Participant 4 from Bohol]*
>
> *"The brochure is for farmers who lack knowledge in rice farming." [Participant 5 from Davao Oriental*

Using Krikelas's *Model of Information-Seeking Behavior*, it could be said that farmers recognized the need for information to improve their farm productivity, which was caused by an ongoing process associated with their rice farm. Farmers read the brochure to acquire knowledge related to crop establishment, land preparation, nutrient management, and harvest management to improve their farm productivity. Searching for information to bridge the information gap is a common reason reported in the literature (e.g., Brhane et al., 2017).

The information needed to increase their farm productivity was deemed immediate by the farmers. They felt the urgency to satisfy this need. The act of reading the brochure, following Krikelas, means that they recognized that their own knowledge proved inadequate to address the key issues on their farm. Hence, they tapped an external source, a documented form of knowledge, which in this case was the brochure. This observation is supported in the studies of Acheampong (2017) and Rahman and Khan (2020). These studies reported that farmers, especially during difficult and critical situations, often look to external sources for help in resolving their farm-related issues. This critical or difficult time, for instance, is illustrated in the quote from the participant in Davao Oriental, who stated that the brochure was read when the prices of inputs soared.

Another point, with respect to Krikela's model, is accessibility. The brochure proved to be an accessible external source of information, as shown in the example from Bohol. The participant read the brochure at the start and end of the cropping season. To extend this analysis, the brochure served as a companion medium for the participants, a description often attached to community radios. The brochure served as an accessible how-to guide, a lifeline for farmers. Kughur et al. (2018) share this finding in their research, where the majority of Nigerian farmer-respondents primarily accessed newspapers as a source of information, as these were readily available to them most of the time.

As the farmers in this study read the brochure before or at the start of the cropping season, or if field problems arose, they kept a copy of the brochure as a guide or reference. In this case, printed materials were valued by the farmers for their permanence, which was also similar to the finding of Stefano et al. (2004), who noted that farmers kept printed materials given to them for many years. This finding, regarding farmers keeping a copy of the brochure, is significant in the context of the Philippines. In the past, there had been some criticisms saying that farmers only *'tiklop, tago, and tambak'* [fold, keep, and pile] the printed materials given to them. We argue that this *'tiklop, tago, and tambak'* must actually be viewed positively. Farmers do this for future reference, and not as a way to dismiss the information written in the material given to them. The quotes below from participants in Davao Oriental, Bohol, and Pampanga illustrate this point:

> *"I read it before the start of the cropping season. I kept a copy of the brochure. I have a folder where I keep all printed materials, including guidelines, given by the Department of Agriculture." [Participant 1 from Davao Oriental]*
>
> *"Because I am old, every start of the cropping season, I read the brochure so I will not forget the content." [Participant 5 from Bohol]*
>
> *"When we received the brochure, we had not started planting, so we still did not need it at that time." [Participant 6 from Pampanga]*

The quotes above show no support for seeing the *'tiklop, tago, and tambak'* observation negatively. A farmer is highly encouraged to keep a folder to store materials (Davao Oriental). A farmer keeping the information ensures that s/he has something to read for guidance when necessary, showing that the material will be referred to in due time (Bohol and Pampanga).

Selection of Content

Farmers were selective in reading the information shown in the brochure. They did not read all the recommendations and steps on land preparation, seedling preparation and management, crop establishment, nutrient and harvest management, and seed purification that were presented in the brochure in one sitting. They only read the information that they needed such as crop establishment, land preparation, nutrient management, and harvest management. They were selective readers. A similar observation was reported in India by Sing and Singh (2014) among livestock farmers. The farmers in their study only read specific sections of a newspaper, i.e., those that related to animal health. The interview excerpts below show how farmers nitpicked on the information that they read from the brochure:

> *"I only read a few and did not continue reading. I read it to know how to prepare the land." [Participant 1 from Quirino]*
>
> *"I read the brochure if I encountered a problem. I read it last cropping season because I had a problem with ungerminated seeds." [Participant 2 from Davao del Sur]*
>
> *"I spent 30 minutes reading about transplanting. It is hard to remember everything about it." [Participant 5 from Masbate]*

This finding highlights the importance of content developers being meticulous in determining the information needs of their intended audience. This is an important yet oftentimes overlooked aspect of content creation.

Going back to Krikelas's Model, the findings suggest that the act of choosing the contents to read or being selective in reading indicates that they were still dependent on their own knowledge or experience for some of their information needs. The following interview excerpts capture this point:

> *"I only read the brochure once because I already have experience related to the contents of the brochure." [Participant 5 from Davao Oriental]*
>
> *"I did not follow the other procedures in the brochure. I rely first on my years of experience." [Participant 3 from Capiz]*

The findings of Naveed and Hassan (2021) among Citrus farmers in Pakistan and Phiri et al. (2019) among rural smallholder farmers in developing countries are similar to this study, which highlights the farmers' overwhelming dependence on personal or prior experience for their information needs. The farmers' own knowledge was their most accessible, prominent, and trusted knowledge. The study by Rahman and Khan (2020) also confirms that farmers rely on personal experience when the nature of the problem or need is familiar or non-critical. Selective reading among farmers is a significant finding of this study, as it reveals that farmers also undergo the same information-seeking behavior process, which depends on the nature of the problem or need, as well as the reliability and adequacy of the available information. Relating this finding to content creation, it is then essential that writers build upon the existing knowledge of their audience, as entirely new information, no matter how useful it may be, will be processed through their own (and sometimes outdated) experiences. Knowledge transitions play a crucial role in facilitating understanding.

This study is novel as it contributes to the limited literature on the information-seeking behavior of rice farmers, particularly in the Philippines. It also extends the application of Krikelas's *Model of Information-Seeking Behavior* to agriculture, particularly among rice farmers. A considerable amount of research has been conducted on the information needs, sources of information, and factors influencing the information-seeking behavior of farmers in general. However, this study provides a new perspective on understanding their information-seeking behavior by examining their interaction with printed IEC materials.

Drawing on the findings of this study, the following recommendations are hereby advanced:

1. Problem-centered communication is key in information packaging for farmers. In problem-centered communication, instead of directly communicating a message on proper crop management practices or recommendations that disregard their accumulated knowledge over time, the messaging will focus on a rice farmer's problem related to a specific crop management recommendation (i.e., a weed problem for proper land preparation). This would enable them to troubleshoot their issues independently. As this espouses ownership of the course of action taken by the farmers themselves, this strategy is sustainable because they themselves experience it and will incorporate it into their knowledge.

2. The timing of distribution of IEC materials and the type of information to prioritize should be paid attention to. The IEC material will be helpful for the intended audience if it contains the necessary information and is distributed at the time they need it.
3. Alternative sources of information must always be accessible and available. It is known that printed materials are limited in their capacity to provide real-time updates and interaction. Communication channel complementation will provide an excellent avenue for effective and efficient information delivery to farmers.
4. IEC materials should be made more durable to withstand years of being kept or piled up. This is important as farmers tend to keep the printed IEC given to them for a long time. The farmers returned to these IECs in the future as necessary.

Conclusion

Farmers' interaction with the brochure was highly need-based. Reading the brochure was infrequent, depending on the time they recognized an urgent farming need that they themselves could not meet. Reading the brochure was also selective, as they only read the information they needed. These findings suggest that farmers sought information only when their current knowledge, the most accessible source of information, was insufficient to meet their needs. The infrequent and selective reading proves the immediate nature of their information needs. This study also viewed the *'tiklop, tago, and tambak'* habit of farmers positively, as farmers do this for future reference, and not as a way to dismiss the information written in the material given to them. The results of this study contribute to the growing body of knowledge on the information-seeking behavior of farmers. Following the findings, it is recommended that problem-centered communication could be used in packaging information for farmers, the timing of distribution of IEC materials and type of information to prioritize should be given much attention, and alternative sources of information that have the capacity to provide real-time receipt of and response to farmers' urgent queries without time and location boundaries should also be made available and accessible. IEC materials should be made more durable to withstand years of being kept or piled up as farmers will return to these IECs in the future as necessary.

Acknowledgment

The authors gratefully acknowledge the farmer-respondents from Capiz, Aklan, Bohol, Masbate, Quirino, Pampanga, Davao Oriental, and Davao del Sur who generously shared their time and experiences. They also acknowledge the assistance of Diadem B. Gonzales-Esmero (PhilRice Central Experiment Station), Girlie A. Carreon and Vanessa A. Tingson (PhilRice Negros), Diana P. Lim and Kimberly D. Sahilan (PhilRice Isabela), Marelie D. Tangog (PhilRice Agusan), and Mervalyn O. Tomas, a former colleague at PhilRice, for their support in data collection.

Literature Cited

Acheampong LD, Nsiah Frimpong B, Adu-Appiah A, Asante BO, Asante MD (2017) Assessing the information-seeking behaviour and utilization of rice farmers in the Ejisu-Juaben municipality of Ashanti Region of Ghana. Agriculture & Food Security ***6***: 1 - 9

Atser GL, Dixon A, Ekeleme F, Hauser S, Fadairo O, Adekoya A, Vanlauwe B, Agada M, Oladokun I, Akpu P, Sanni L, Pypers P, Ampadu-Boakye T, Lauwe BV (2023) The effect of communication media on the uptake of agricultural innovations in selected states of Nigeria. The Journal of Agricultural Education and Extension ***29***(5): 583 - 604

Brhane G, Mammo Y, Negusse G (2017) Sources of information and information-seeking behavior of smallholder farmers in Tanqa Abergelle Wereda, Central Zone of Tigray, Ethiopia. Journal of Agricultural Extension and Rural Development ***9***(4): 47 - 52

Duhan A, Singh S (2017) Sources of agricultural information accessed by farmers in Haryana, India. International Journal of Current Microbiology and Applied Sciences ***6***(12): 1559 - 1565

Farooq S, Muhammad S, Chaudhary KM, Ashraf I (2007) Role of print media in the dissemination of agricultural information among farmers. Pakistan Journal of Agricultural Research Sci ***44***(2): 378 - 380

Ford SA, Babb EM (1989) Farmer sources and uses of information. Agribusiness ***5***(5): 465 - 476

Hosain MM (2008) Use of printed materials by the literate farmers in receiving farm information (Doctoral dissertation). Sher-e Bangla Agricultural University, Dhaka. Retrieved from https://archive.saulibrary.edu.bd/xmlui/bitstream/handle/123456789/1716/27555-00719.pdf?sequence=1&isAllowed=y (acessed July 10, 2025)

Idowu AC, Aromolaran A, Enitan FO, Ayinde A, Masunaga T, Wakatsuki T (2020) Effect of information sources on farmers' adoption of Sawah Eco-Technology in Nigeria. Journal of Agricultural Extension ***24***(1): 64 - 74

Igbinovia MO, Omehia A (2024) The Krikelas' model of information-seeking behaviour: Implications for information service delivery in libraries. Zambia Journal of Library & Information Science (ZAJLIS) ***8***(2): 8 - 14

Kabir KH, Roy D, Sarker MA, Kuri SK (2014) Information-seeking behavior of farmers to ensure sustainable agriculture. European Academic Research *2*(3): 3723 - 3734

Kavithaa NV, Rajkumar NV, Lakshmi CS (2014) Information-seeking behaviour of dairy farmers. International Journal of Science, Environment and Technology *3*(4): 1502 - 1506

Korsching IV PF, Hoban TJ (1990) Relationships between information sources and farmers' conservation perceptions and behavior. Society & Natural Resources *3*(1): 1 - 10

Kughur GP, Ruth MA, Adedeji OA (2018) Factors affecting the use of print media among farmers in the Bwari Area Council of the Federal Capital Territory, Abuja. Eurasian Journal of Agricultural Research *2*(1): 54 - 63

Lwoga ET, Ngulube P, Stilwell C (2010) Information needs and information-seeking behavior of small-scale farmers in Tanzania. Innovation: Journal of Appropriate Librarianship and Information Work in Southern Africa *2010*(40): 82 - 103

Mahindarathne P, Min Q (2019) Factors that influence farmers' information-seeking behaviour: A study of Sri Lankan vegetable farmers. Journal of Information & Knowledge Management *18*(03): 1950037

Memon A, Kumbhar MI, Khushk AM, Mallah MU (2005) Farmers' perception regarding printed material on production technologies of major crops in Sindh. Indus Journal of Biological Sciences *2*(1): 157 - 163

Murage AW, Amudavi DM, Obare G, Chianu J, Midega CA, Pickett JA, Khan ZR (2011) Determining smallholder farmers' preferences for technology dissemination pathways: the case of 'push-pull ' technology in the control of stemborer and Striga weeds in Kenya. International Journal of Pest Management *57*(2): 133 - 145

Mwombe SO, Mugivane FI, Adolwa IS, Nderitu JH (2014) Evaluation of information and communication technology utilization by smallholder banana farmers in Gatanga District, Kenya. The Journal of Agricultural Education and Extension *20*(2): 247 - 261

Naveed MA, Hassan A (2021) Sustaining agriculture with information: an assessment of rural Citrus farmers' information behaviour. Information Development *37*(3): 496 - 510

Nii HR, Tham-Agyekum EK, Ankuyi F, Aidoo DC, Osei JE, Osei C, Bakang JA, Andivi, Roland A (2023) Analysing cocoa farmers' perception on the use of print media for extension delivery in Adansi Asokwa, Ghana. Russian Journal of Agricultural and Socio-Economic Sciences *5*(137): 85 - 97

Njoku JIK (2022) Effectiveness of print media in technology transfer among rural farm households in Imo State, Nigeria. ADAN Journal of Agriculture *3*(1): 8 - 19

Pathak S, Patel MB (2022) Farmers' perception about print media in agricultural information dissemination: A review. Bhartiya Krishi Anusandhan Patrika *37*(4): 339 - 342

Phiri A, Chipeta GT, Chawinga WD (2019) Information behaviour of rural smallholder farmers in some selected developing countries: A literature review. Information Development *35*(5): 831 - 838

Rahman T, Ara S, Khan NA (2020) Agro-information service and information-seeking behaviour of small-scale farmers in rural Bangladesh. Asia-Pacific Journal of Rural Development *30*(1-2): 175 - 194

Rehman F (2010) Development of a strategy to enhance the role of print media in the dissemination of agricultural information among farmers in the Punjab, Pakistan (Doctoral dissertation). Department of Agricultural Extension, University of Agriculture, Faisalabad, Pakistan

Rehman F, Muhammad S, Ashraf I, Hassan S (2011) Factors affecting the effectiveness of print media in the dissemination of agricultural information. Sarhad J. Agric *27*(1): 119 - 124

Redman S, Paul CL (1997) A review of the effectiveness of print material in changing health-related knowledge, attitudes, and behaviour. Health Promotion Journal of Australia: Official Journal of Australian Association of Health Promotion Professionals *7*(2): 91 - 99

Renner M, Taylor-Powell E (2003) Analyzing qualitative data. Programme Development & Evaluation, University of Wisconsin-Extension Cooperative Extension

Sennuga SO, Conway JS, Sennuga MA (2020) Impact of information and communication technologies (ICTS) on agricultural productivity among smallholder farmers: Evidence from Sub-Saharan African communities. International Journal of Agricultural Extension and Rural Development Studies *7*(1): 27 - 43

Sheela KV (2004) Effectiveness of IEC materials on health and nutritional practices of adolescent girls (Doctoral dissertation). Kerala Agricultural University

Stefano, L, Hendriks, SL, Stilwell, C, Morris, CD (2005) Printed information access, preferences, and use by farmers with potential for small-scale organic production in KwaZulu-Natal. Libri—International Journal of Libraries and Information Services *55*: 56 - 66

Tumbo SD, Mwalukasa N, Fue KG, Mlozi MR, Haug R, Sanga C (2018). Exploring information-seeking behavior of farmers in information related to climate change adaptation through ICT (CHAI). International Review of Research in Open and Distributed Learning *19*(3)

SOIL MICROBIAL FUNCTIONAL DIVERSITY STATUS IN RICE MONOCULTURE AND RICE-DUCK PRODUCTION SYSTEMS

Monique C. Pangilinan[1], **Jan Nico A. Lazaro**[2],
Maria Luisa T. Mason[1], and **Jayvee C. Kitma**[2*]

[1]Central Luzon State University, Science City of Muñoz, Nueva Ecija
[2]Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
[*]Corresponding Author: jayveeacruz@gmail.com

Abstract

Soil microbial communities are central to nutrient cycling and crop productivity, particularly in rice-based systems. This study assessed soil microbial functional diversity in rice monoculture and rice–duck production areas and examined their influence on soil fertility. Three rice varieties (NSIC Rc 160, Rc 222, and Rc 402) were evaluated in a completely randomized design. Microbial metabolic activity, functional diversity, and soil chemical properties were measured using BiOLOG® EcoPlates™ and standard soil analyses. Higher average well color development (AWCD) was observed in rice monoculture, with NSIC Rc 402 in the dry season showing the highest value (2.05 nm). Shannon diversity indices (H') ranged from 3.07 to 3.42 across plots, indicating generally high microbial diversity. Rice monoculture exhibited higher soil pH, total N, available P (notably in Rc 160), exchangeable K, and organic carbon during the dry season. In contrast, the rice–duck system showed higher total N in the wet season and improved P, K, and organic carbon in Rc 222 and Rc 402, likely influenced by duck activity and organic inputs. These findings highlight the distinct microbial and soil fertility responses between the two systems and underscore the need for further evaluation of rice–duck integration on microbial diversity, soil health, and yield performance.

Keywords: *BiOLOG EcoPlates, rice-duck production, rice monoculture, soil microbes*

Introduction

Rice (*Oryza sativa* L.) is the main staple food and one of the most widely cultivated crops in the Philippines. However, intensive monocropping—a common practice in many rice-producing areas, has contributed to the degradation of paddy ecosystems, including declining soil fertility, deteriorating water quality, and loss of biodiversity, ultimately reducing long-term system productivity (Bautista & Javier, 2005). Maintaining soil health therefore requires greater attention to soil microbial diversity, which plays a central role in nutrient cycling and plant growth (Kumar & Verma, 2019).

Soil microbial communities are integral to plant nutrition and ecosystem functioning, especially in rice-based systems. Beneficial soil microbes regulate nutrient cycles, support decomposition, and enhance plant productivity. Practices such as organic farming, crop rotation, and reduced tillage have been shown to increase microbial diversity and stimulate the growth of key functional groups, including nitrogen-fixing bacteria and mycorrhizal fungi (Mäder et al., 2002; Altieri, 1999; Van der Heijden et al., 2008).

Crop rotation increases plant litter diversity, enriches soil organic matter, and provides habitat for beneficial microbes such as *Rhizobium* (legume symbiosis), *Pseudomonas* (antibiotic and siderophore producers), *Trichoderma* (biocontrol fungi), and arbuscular mycorrhizal fungi (P uptake and aggregation). It also helps suppress soilborne pathogens including *Fusarium* and *Rhizoctonia*, supporting greater microbial decomposer diversity (Lupwayi et al., 1998; Peralta et al., 2018; Tiemann et al., 2015; Venter et al., 2016).

Reduced tillage maintains stable soil microhabitats and often results in distinct microbial communities with higher fungal abundance (Jiang et al., 2011; Lauber et al., 2008). Six et al. (2006) reported that reduced tillage promotes fungal-dominated systems, particularly Ascomycota (efficient residue decomposers) and Basidiomycota (lignin degraders), due to preserved hyphal networks. These dynamics enhance nutrient cycling and soil aggregation (Kumar et al., 2024).

Organic amendments also influence rice soil bacterial communities by providing diverse carbon sources that stimulate microbial metabolism (Chávez-Romeroa et al., 2016; Daquiado et al., 2016; Hartmann et al., 2015). While gradual shifts in microbial community composition under organic management have been reported (Suzuki et al., 2019), compost additions in rice paddies have been shown to enrich Gram-positive bacteria including Firmicutes, Actinobacteria, and Rhizobiales, although significant increases were observed mainly in Firmicutes (Daquiado et al., 2016).

Nutrient cycling sustains diverse microbial guilds such as N-fixers (*Rhizobiales*), P-solubilizers (*Bacillus, Pseudomonas*), and decomposers (Actinobacteria, saprotrophic fungi), whose functional complementarity strengthens soil health and system resilience (Richardson & Simpson, 2011; Bardgett & van der Putten, 2014). In general, integrated management practices tend to shift communities toward beneficial groups such as Proteobacteria, Actinobacteria, Firmicutes, Ascomycota, and Basidiomycota, with reductions in opportunistic or pathogenic groups such as some Acidobacteria and *Fusarium*. These transitions promote improved nutrient cycling and soil functioning.

Several studies have characterized dominant microbial groups in rice ecosystems. Proteobacteria including *Pseudomonas*, *Burkholderia*, and *Ralstonia* play major roles in carbon and nitrogen cycling under flooded conditions (Edwards et al., 2015). Chloroflexi, including *Anaerolinea*, contribute to anaerobic residue decomposition but may decline under intensive monocropping (Yuan et al., 2018; Li et al., 2021). Acidobacteria commonly persist in low-nutrient, acidic soils and aid in decomposing recalcitrant organic matter (Ahn et al., 2016). In rice–duck systems, Chloroflexi, Proteobacteria, Acidobacteria, and Actinobacteria comprised over 75% of phyla, with Chloroflexi and Proteobacteria remaining abundant, while Actinobacteria (e.g., *Streptomyces*) declined over time (Han et al., 2024).

Microbial responses also vary with seasonal environmental changes. In rice monoculture during the wet season, anaerobic bacteria such as *Clostridium* and methanogens (*Methanobacterium*, *Methanosarcina*) thrive under flooded, reduced-oxygen conditions (Liu & Whitman, 2008). Their abundance typically declines during the dry season as soils become more aerated. Flooded anaerobic soils also favor bacteria and archaea over fungi (Kirk, 2004), while drier conditions encourage fungal decomposers, especially Ascomycota (Phillips et al., 2019).

In rice–duck systems, ducks contribute organic matter inputs and soil disturbance. During the wet season, copiotrophic bacteria such as Firmicutes (e.g., *Bacillus*, *Clostridium*) and Proteobacteria (*Rhizobium*, *Pseudomonas*) increase in response to duck activity (Han, 2004). Methanogens remain active but may be moderated by enhanced soil aeration from duck movement (Conrad, 2007). During the dry season, decomposition of organic inputs stimulates aerobic decomposers such as Actinobacteria, including *Streptomyces*, known for degrading complex polymers (Larney, 2012; Ventura et al., 2007).

Microbes that support improved rice yields through nutrient mobilization and enzymatic activity are often more abundant in fertile soils. *Rhizobium leguminosarum* interactions with rice can enhance nitrogen uptake, grain yield, and biomass (Yanni et al., 1997). Long-term rice cultivation increases soil organic carbon, total N, and microbial abundance but may reduce soil pH (Lu et al., 2016). Integrating fish and livestock also improves soil fertility (Nayak et al., 2024).

Rice–duck systems have been practiced in the Philippines since the 1990s (Cagauan et al., 2000; Villamora et al., 2000; Barroga et al., 2007). They are reported to reduce labor requirements—saving about 13 man-days in weeding, fertilizer use, and pest management—and provide higher net returns than rice monoculture (Barroga et al., 2007). Rice–duck farming also contributes to increased abundance of bacteria, actinomycetes, fungi, and overall microbial communities during rice growth stages. BiOLOG analyses have shown enhanced carbon-utilization profiles, metabolic activity, and functional diversity, particularly at heading (Zhang et al., 2009).

Given the central role of microbial communities in nutrient cycling and soil fertility, assessing microbial functional diversity provides insights into soil health and system sustainability. This study therefore evaluated soil microbial diversity in rice monoculture and rice–duck production systems and examined their influence on soil fertility.

Materials and Methods

Sample Collection for Soil Chemical and Microbial Analysis

Soil samples were collected after cultivation in both rice monoculture and rice–duck production areas during the 2023 dry and wet seasons at the Philippine Rice Research Institute, Central Experiment Station (PhilRice CES), Science City of Muñoz, Nueva Ecija. The rice–duck production system was established in the 2012 dry season at the Palayamanan site, while the rice monoculture system has been maintained at PhilRice since 1985. Crop management practices in both systems, including land preparation, crop establishment, and nutrient and water management, followed the PhilRice PalayCheck System.

The rice–duck production area covered 1,328 m^2 and utilized 137 mallard ducks, which were released daily until the heading stage and re-released after harvest. Fertilizer application rates in the rice–duck production system were 134-35-35-30 NPKS during the 2023 dry season and 97-28-43 N-P_2O_5-K_2O during the wet season, while in the rice monoculture system, rates were 111-42-42 N-P_2O_5-K_2O in the dry season and 90-28-58 N-P_2O_5-K_2O in the wet season.

Samples were obtained within 0 - 20 cm from the surface using an Edelman auger. A 24-inch, diagonally oriented sampling interval between sampling points was employed. Soil samples were placed in clear plastic containers, transferred to the laboratory, and arranged in a completely randomized design (CRD).

Determination of Soil Microbial Diversity Using BiOLOG® EcoPlates™

BiOLOG® EcoPlates™ (Biolog Inc., Hayward, CA, USA) were used to analyze the functional diversity of bacterial communities by measuring their ability to oxidize carbon substrates. An EcoPlate is a 96-well microplate that contains 31 common carbon sources from five compound groups including carbohydrates, carboxylic and ketonic acids, amines and amides, amino acids, and polymers plus a blank well as a control, all replicated thrice to control variation in inoculum densities (Sofo & Ricciuti, 2019). Analysis was conducted at the Department of Agriculture–Crop Biotechnology Center, Science City of Muñoz, Nueva Ecija, Philippines.

Ten grams of fresh soil were weighed into a diluent bottle. One hundred (100) mL of sterilized 0.1% peptone–water solution was added and the mixture was shaken for 30 sec. The supernatant was transferred into a sterile culture dish, and 150 µL per channel were dispensed with a multichannel pipette into each well of the EcoPlate. The plates were incubated at 28°C in a biochemical incubator for seven days. Absorbance at 590 nm was measured on a BiOLOG MicroStation™ every 24 h, and data were collected using BiOLOG MicroLog software version 4.20.05.

Chemical Characterization of Soils

Soil samples were analyzed for total nitrogen (N), available phosphorus (P), exchangeable potassium (K), pH, and organic matter content. Chemical analyses were conducted at the laboratory of the Agronomy, Soils and Plant Physiology Division (ASPPD), PhilRice CES, Maligaya, Science City of Muñoz, Nueva Ecija, Philippines.

Data Analysis

The data gathered included microbial functional diversity parameters derived from BiOLOG® EcoPlates™ such as average well color development (AWCD), substrate richness (S), and Shannon diversity index (H′) and measurements of soil chemical properties (pH, total N, available P, exchangeable K, and total organic carbon). Data were encoded in MS Excel and analyzed using analysis of variance (ANOVA) to determine significant differences among treatments. Treatment means were compared using Tukey's HSD at the 5% level of significance, using the Statistical Tool for Agricultural Research (STAR) version 2.0 software.

Results and Discussion

Microbial Metabolic Activity

Average well color development (AWCD) was used to describe overall color development in BiOLOG plates (Garland and Mills, 1991). The depth of color indicates the ability of microbes to utilize a given carbon source (Lyons and Dobbs, 2012), with higher AWCD values reflecting higher microbial metabolic activity. AWCD values for soil samples are summarized in Table 1.

AWCD was significantly higher in the rice monoculture area, except for NSIC Rc 222 during the dry season, ranging from 0.36–2.05 nm, compared with 0.74–1.25 nm in the rice–duck production area. These results suggest that rice monoculture generally enhanced microbial metabolic activity, likely due to greater inputs of readily available carbon substrates (root exudates, residues, fertilizers) and the dominance of fast-growing microbes able to rapidly utilize them, as reflected in higher AWCD values. Charaslertrangsi et al. (2024) reported that microbial metabolic activities were higher in conventional rice production, although differences were not statistically significant compared with organic farms, and noted that one key factor affecting soil microbial structure is human agricultural practices.

In contrast, the rice–duck production area showed lower AWCD, possibly due to altered soil conditions caused by duck activity or shifts in microbial communities less responsive to Biolog assays. The exception of RP NSIC Rc 222 in the dry season highlights the influence of variety × season interactions, where genotype-specific traits and environmental factors such as soil moisture and oxygenation also shape microbial activity. According to PhilRice (2018), NSIC Rc 222 is a multi-stress-tolerant variety adaptable to rainfed, submerged, and saline conditions due to its efficient root system, tolerance to submergence and salinity, and stress-responsive gene expression that supports stable growth across environments. These traits may partly explain why NSIC Rc 222 stands out among the varieties; however, further trials are needed to determine how NSIC Rc 222 responds beyond these treatments.

Notably, RP NSIC Rc 402 in the dry season exhibited the highest AWCD, suggesting strong root exudation or favorable soil conditions that stimulated microbial carbon metabolism. Although the rice monoculture area had significantly higher mean absorbance values overall, the rice–duck production area still recorded comparable results.

Zhang et al. (2009) reported higher AWCD in rice–duck systems, which contrasts with the lower values observed in this study. They found that rice–duck systems increase microbial community functional diversity and total metabolic activity (e.g., carbon utilization) compared with conventional rice farming. Beyond microbial metabolic activity, other studies have shown that rice–duck and rice–fish systems help reduce overall N losses from fields and improve N use efficiency. Gao et al. (2019) reported that rice–duck farming, particularly with a combination of 70% chemical and 30% organic fertilizer, makes rice production more sustainable by reducing N leakage by 16.9%, increasing grain yield to 10.35 t ha^{-1}, and improving N use efficiency to 43.3% compared with conventional rice farming. Teng et al. (2019) further reported that rice–duck systems integrated with organic farming can reduce N leakage by up to 92.1% compared with conventional rice farming.

In this study, microbial metabolic activity varied among rice varieties and between production systems. In rice monoculture, NSIC Rc 402 (dry season) and NSIC Rc 222 (wet season) recorded higher AWCD values, indicating greater microbial activity likely influenced by varietal traits such as root exudation and rhizosphere interactions. In contrast, the rice–duck production system showed lower but comparable AWCD values, possibly due to soil disturbances caused by ducks that altered microbial communities. NSIC Rc 222 in the rice–duck system demonstrated varietal adaptability to the integrated production system, while NSIC Rc 160 exhibited inconsistent values across both production systems.

Table 1. Average well color development representing relative degree of sole carbon source utilization in two rice production systems. 2023 dry and wet seasons.

Rice Production System	Absorbance Mean Value (nm)	
	Dry Season	Wet Season
Rice-Duck		
RD NSIC Rc 160	1.25 ^{bc}	0.88 ^{bc}
RD NSIC Rc 222	1.23 ^{bc}	1.20 ^{bc}
RD NSIC Rc 402	0.74 ^{cd}	0.92 ^{c}
Rice monoculture		
RP NSIC Rc 160	1.63 ^{ab}	1.91 ^{ab}
RP NSIC Rc 222	0.36 ^{d}	2.04 ^{a}
RP NSIC Rc 402	2.05 ^{a}	1.48 ^{abc}

Different letters in the superscript indicate a significant difference by Tukey's HSD test at $p > 0.05$. Means with the same letter are not significantly different.

Percentage of Substrate Utilization per 96-hr Incubation Time on each Rice Varieties During the Dry and Wet Season

The BiOLOG EcoPlate is composed of 31 different single carbon sources and a control well with parallel configurations on one plate for repeated tests (Ge et al., 2018). These 31 carbon sources can be divided into five (5) categories: carbohydrates, polymers, carboxylic acids, amino acids, amides/ amines and polymers.

Figure 1 shows that microbial communities from the rhizosphere soil of RD NSIC Rc 222 exhibited the highest utilization of carbohydrates while those from RD NSIC Rc 402 showed the lowest. Rhizosphere soil in RD NSIC Rc 160 demonstrated the highest carboxylic acid utilization among the rice varieties, whereas RP NSIC Rc 160 had the lowest reading. For amides/amines, RD NSIC Rc 402 and RP NSIC Rc 160 rhizosphere soils showed the highest utilization while RD NSIC Rc 222 had the lowest. In terms of amino acids, rhizosphere soils collected from plots planted with RD NSIC Rc 402 had the highest utilization, whereas RP NSIC Rc 222 had the lowest percentage. In polymer utilization, rhizosphere soils from plots planted with NSIC Rc 160 exhibited the highest utilization among rice varieties with RD NSIC Rc 160 having the lowest, during the 120-h incubation of carbon sources on BiOLOG EcoPlates.

These differences indicate that the rhizosphere environments of each rice variety support distinct microbial functional potentials, likely influenced by variations in root exudates, nutrient availability, and soil conditions. The degree of oxidation of carbon sources is proportional to the metabolic capacity of the corresponding microbes and can be characterized by AWCD (Garland and Mills, 1991). In addition, the consumption rate of the carbon source is reflected by the reduction of the tetrazolium violet redox dye (Gryta et al., 2014).

The variety of substrates utilized by each organism is used to assess resource niche width, while the extent of shared growth-supporting substrates is used to evaluate niche overlap, contributing to predictions of resource competition among organisms (Wilson and Lindow, 1994; Dundore-Arias et al., 2019; Michalska-Smith et al., 2022).

In terms of functional groups, the highest utilization of carbohydrate carbon sources was observed in rice varieties under the rice–duck production system, where RD NSIC Rc 160, RD NSIC Rc 222, and RD NSIC Rc 402 showed similarly high values in the bar graph, while rice varieties under rice monoculture (RP NSIC Rc 160, RP NSIC Rc 222, and RP NSIC Rc 402) recorded lower values. For carboxylic acids, RD NSIC Rc 160 and RP NSIC Rc 402 had the highest values, followed by RP NSIC Rc 160 and RP NSIC Rc 222 at similar levels, while RD NSIC Rc 222 and RD NSIC Rc 402 had the lowest. For amides/amines, RD NSIC Rc 402 gained the highest value while the remaining varieties clustered at similar levels, except for RD NSIC Rc 160, which was the lowest.

In amino acid utilization, rice varieties under the rice monoculture system showed the highest values compared with those under the rice–duck production system, which exhibited the lowest levels. In polymer utilization, RD NSIC Rc 222 recorded the highest value, followed by RD NSIC Rc 160, while RP NSIC Rc 160, RP NSIC Rc 222, and RP NSIC Rc 402 showed similar levels, and RD NSIC Rc 402 had the lowest.

In natural environments such as soils, microorganisms frequently encounter diverse substrates and may employ varied utilization strategies (Wang et al., 2019). Microorganisms break down carbohydrates into metabolites that can be readily used, making carbohydrates one of the most accessible nutrient sources for soil organisms (Larré-Larrouy et al., 2003). Thus, the observed variation across rice varieties reflects how different rhizosphere conditions influence microbial community function and substrate preference, highlighting the interaction between crop genotype and soil microbial ecology.

Soil Microbial Diversity

The 96-h incubation showed that soil microbial communities across rice varieties could utilize diverse carbon sources, as reflected by the Shannon diversity index (H′) in Table 2. While no significant differences were observed among treatments, the overall H′ ranged 3.07-3.42. This range suggests good microbial diversity in agricultural systems as values above 3 are considered indicative of a good microbial community (Lavelle et al., 2004; Fierer et al., 2007). Higher Shannon index (H′) values were observed in the monoculture rice production area (3.30-3.42) compared with the rice–duck production area (3.11-3.22). NSIC Rc 222 consistently recorded the highest H′ values in both systems and seasons, suggesting a strong varietal influence on microbial diversity. NSIC Rc 160 showed variable results, while NSIC Rc 402 had lower diversity, particularly under rice–duck production. These findings suggest that microbial communities in the rice monoculture area were slightly more diverse than those in the rice–duck production area. The higher Shannon index indicates that microbes in the rice monoculture area may have a broader or more balanced ability to use different carbon sources. Consistent environmental conditions in monoculture rice production may also favor a broader range of microbial communities.

Several studies have reported that incorporating ducks into rice farming can enhance microbial diversity compared with monoculture systems (Liao et al., 2019; Huang et al., 2023). However, the present study observed slightly higher Shannon index values in the rice monoculture area. This contrast may be attributed to differences in site conditions, duration of rice–duck system establishment, management practices, or nutrient inputs, all of which could influence microbial community composition.

Biolog EcoPlates cannot directly identify microbial communities at the species or taxonomic level but are effective in assessing their functional diversity through community-level physiological profiles (CLPP), which reflect the capacity of soil microbes

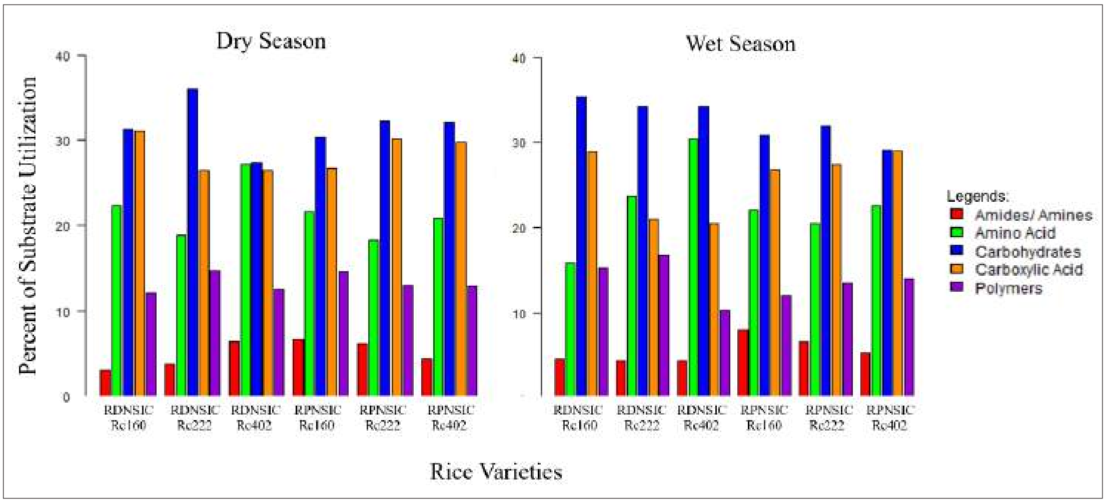


Figure 1. Summary of percent (%) substrate utilization in each treatment namely: RD NSIC Rc 160, RD NSIC Rc 222, RD NSIC402, RP NSIC Rc 160, RP NSIC Rc 222 and RPNSIC Rc 402 in 96-hour incubation time per carbon guild including carbohydrates, carboxylic acid, amides/amines, amino acid and polymers.

to utilize different carbon sources (Garland et al., 1991). CLPP works by tracking how soil microbes use different carbon sources in the Biolog EcoPlates. The organic substrates present in the EcoPlates are utilized by the soil microbial community, leading to a metabolic response. Communities incubated in the EcoPlates yield a characteristic reaction pattern known as a community-level physiological profile or metabolic fingerprint. This fingerprint represents the overall metabolic activity of microbial communities and estimates the degree of microbial functional diversity based on substrate utilization and physiological parameters.

While EcoPlates™ are mainly limited to functional characterization (Preston-Mafham et al., 2002), they have been successfully used to detect shifts in microbial community function under different management and environmental conditions (Classen et al., 2003; Yang et al., 2013).

Table 2. Comparison of metabolic functional diversity index in monoculture rice production (RP) and rice-duck production systems during dry and wet seasons.

Rice Production System	Shannon Index (H′)	
	Dry Season	Wet Season
Rice-Duck		
RD NSIC Rc 160	3.19 ^{bc}	3.18 ^{bc}
RD NSIC Rc 222	3.22 ^{b}	3.20 ^{bc}
RD NSIC Rc 402	3.07 ^{c}	3.11 ^{c}
Rice monoculture		
RP NSIC Rc 160	3.30 ^{ab}	3.38 ^{ab}
RP NSIC Rc 222	3.42 ^{a}	3.41 ^{a}
RP NSIC Rc 402	3.40 ^{ab}	3.32 ^{ab}

Different letters in the superscript indicate a significant difference by Tukey's HSD test at p > 0.05. Means with the same letter are not significantly different.

Soil chemical analysis of different treatments

The results of the soil chemical analysis for different rice varieties in two production systems, conducted after harvest, are presented in Table 3. During the dry season, soil pH in the rice monoculture and rice–duck production areas was comparable. However, during the wet season, rice monoculture had a higher soil pH than the rice–duck production area. This suggests that, during the wet season, soil in rice monoculture fields was slightly more neutral (pH 6.07-6.99) compared with the rice–duck production area, where soil was more acidic (pH 5.79-5.85). Essentially, rice monoculture maintained higher soil pH, while the presence of ducks in rice–duck production likely contributed to soil acidification or prevented pH from rising as much. Ducks stir sediments and add nutrients through droppings, altering paddy water and surface soil pH; field studies have reported lower surface-water pH and altered soil chemistry in rice–duck production (Quan et al., 2008).

According to Ding et al. (2019), wet and dry seasons drive redox changes that commonly alter pH in paddy soils. The wet season often buffers or raises pH relative to drained/aerobic conditions, while the dry season and processes such as nitrification tend to acidify soil (lower pH). These pH shifts strongly influence microbial community composition (bacteria vs fungi), enzyme activities, and biogeochemical processes (nitrification, denitrification, methane production). Lauber et al. (2009) found that soil pH is a major determinant of microbial activity and community composition, aligning with global and local surveys that highlight pH as a primary driver of bacterial diversity and enzyme-mediated C and N cycling. Consistently, bacterial diversity and composition were strongly linked to pH across both surface and deeper soil layers, with previous studies identifying pH as a key predictor of community richness and structure (Lauber et al., 2009; Shen et al., 2013). Even minor shifts of ~1 pH unit can significantly alter dominant bacterial taxa (Kaiser et al., 2016).

Total nitrogen in the rice monoculture area during the dry season ranged 0.13–0.15%, which was higher than in the rice–duck production area (0.08–0.09%). Conversely, in the wet season, the trend reversed: the rice–duck production area had higher N content (0.11–0.13%) than the rice monoculture area (0.09–0.11%). These results suggest that the rice–duck production area retains more N in the wet season, likely due to duck manure and activity, whereas rice monoculture soils have higher N in the dry season, possibly due to reduced soil interactions. Although differences were not statistically significant, seasonal variations in nutrient cycling, water management, and microbial activity appear to drive these patterns.

Zuccarini et al. (2023) reported that N influences soil microbial activity depending on initial conditions and the intensity and duration of inputs: moderate, short-term deposition can stimulate enzyme production, increase microbial biomass, and favor bacteria over fungi, whereas long-term deposition alters soil properties, shifting microbial communities and ecosystem functions.

During the dry season, the highest available P was observed in rice monoculture with NSIC Rc 160 (122.05 ppm), which was higher than in the rice–duck system with the same variety (106.40 ppm). In contrast, for NSIC Rc 222 and NSIC Rc 402, higher available P was recorded in the rice–duck system (107.84 and 117.86 ppm, respectively) compared with monoculture (77.09 and 99.70 ppm, respectively). According to Hua and Zhu (2020), rice–duck treatments can improve P levels, and their study highlighted the effectiveness of using organic fertilizers or incorporating crop straw into farmland for P conservation. In this context, duck manure may have served as an organic fertilizer in rice cultivation, but its effect on P retention cannot be confirmed since values were only measured in ppm and the differences between rice monoculture and rice–duck systems were not significant.

Rice monoculture showed higher available P only for NSIC Rc 160. In contrast, the rice–duck production area had greater P availability for NSIC Rc 222 and Rc 402 during the dry season. This suggests that the effectiveness of each production system may vary depending on the rice variety used. Available P during the dry season (77.09-122.05 ppm) was also higher than during the wet season (15.28-32.24 ppm). This difference could be due to frequent and heavy rainfall in the wet season, which often leads to soil leaching and surface runoff, significantly reducing P availability.

The study revealed a substantial difference in available P between dry and wet seasons. According to Ponnamperuma (1972) and Hossner (1988), during the wet season, prolonged flooding and heavy rainfall induce strong redox fluctuations that promote the formation of fresh Fe/Al (oxyhydr)oxides, which effectively fix phosphorus, while runoff and leaching further reduce available P. In contrast, the dry season brings more aerobic conditions that enhance mineralization of organic P and desorption from soil particles, while reducing moisture-driven P losses, resulting in higher soil-test P values (Shen et al., 2011; Martinengo et al., 2023). Li et al. (2022) added that P fertilization generally has a smaller impact on soil microbial communities compared with N fertilization.

However, Su et al. (2015) found that long-term balanced fertilization, including P, can enhance microbial functional diversity in phosphorus-limited paddy soils, improving nutrient cycling and soil resilience. Similarly, high starter phosphorus fertilization promotes microbial interactions and P turnover in arable soils, increasing microbial community complexity and supporting efficient nutrient cycling (Liu et al., 2024).

Exchangeable potassium was generally higher in the rice monoculture area across all rice varieties and both seasons compared with the rice–duck production area. An exception was observed during the wet season for NSIC Rc 402, where the rice–duck production area recorded a higher value (89.86 ppm) than the rice monoculture area (75.63 ppm). While rice monoculture usually results in higher K levels, the presence of ducks in the rice–duck production area may enhance K availability in certain varieties such as NSIC Rc 402, particularly under wet-season conditions. This suggests that the effect of the production system on K availability may vary depending on the rice variety and growing season.

K^+ ions influence soil carbon-cycling enzymes and microbial electron transport during the reproductive phase, thereby affecting organic matter decomposition (Xi et al., 2023). Additionally, application of potassium fulvate has been found to enhance the relative abundance of beneficial microbial groups, including Ascomycota, Bacillaceae, and Proteobacteria, in continuous cropping systems (Jiao et al., 2024).

During the dry season, the rice monoculture area had higher total organic carbon (TOC) in the soil (1.50–1.72%) compared with the rice–duck production area (0.88–0.92%). A similar pattern was seen in the wet season, where rice monoculture areas generally had higher organic carbon. However, for NSIC Rc 402, the rice–duck production area had more organic carbon (1.39%) than the rice monoculture area (1.24%), indicating that the effect may vary depending on the variety used.

The rice monoculture system showed higher pH, exchangeable K, and TOC, indicating better nutrient retention than the rice–duck production system, which had lower TOC and moderate K levels, likely due to duck activity and organic matter turnover. Among varieties, NSIC Rc 402 maintained the highest exchangeable K (105.10 ppm) and TOC (1.72%), while NSIC Rc 160 showed higher available P (122.05 ppm), suggesting favorable nutrient conditions. NSIC Rc 222 had moderate values but remained stable in both systems, reflecting its adaptability. Both varietal characteristics and production system influenced soil nutrient dynamics, with monoculture favoring nutrient accumulation and rice–duck supporting more balanced nutrient cycling.

Soil chemical characteristics influenced microbial activity and diversity across production systems and rice varieties. Higher N and TOC values in the rice monoculture system, particularly in RP NSIC Rc 402 (TOC = 1.72%) and RP NSIC Rc 222 (N = 0.14%), corresponded with higher AWCD (2.05 and 2.04, respectively) and Shannon index values ($H' = 3.40$ and 3.42, respectively). This indicates that nutrient-rich soils support more active and diverse microbial communities due to improved substrate availability and organic carbon for microbial metabolism.

Conversely, the rice–duck production system showed slightly lower total N and TOC, reflected in lower AWCD and Shannon index values (e.g., RD NSIC Rc 402: AWCD = 0.74; $H' = 3.07$), suggesting limited

Table 3. Soil chemical analysis in two rice production systems each planted with three different rice varieties.

Rice Production System	pH		Total N (%)		Available P (ppm)		Exchangeable K (ppm)		Total Organic Carbon (%)	
	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
Rice-Duck										
RD NSIC Rc 160	6.74	5.79	0.09	0.11	106.40	25.37	50.71	61.20	0.92	1.40
RD NSIC Rc 222	6.79	6.05	0.09	0.11	107.84	26.70	46.46	68.79	0.92	1.35
RD NSIC Rc 402	7.03	5.85	0.08	0.13	117.86	32.24	34.74	89.86	0.88	1.39
Rice monoculture										
RP NSIC Rc 160	6.75	6.07	0.13	0.09	122.05	24.12	71.28	100.98	1.50	2.05
RP NSIC Rc 222	6.52	6.99	0.14	0.11	77.09	20.22	99.08	79.35	1.69	1.38
RP NSIC Rc 402	6.45	6.88	0.15	0.09	99.70	15.28	105.10	75.63	1.72	1.24

RD = Rice + Duck; RP = Rice Production; DS = Dry Season; WS = Wet Season; NSIC= National Seed Industry Council.

microbial activity under reduced nutrient availability. However, moderate increases in exchangeable K and available P under certain rice–duck treatments may still promote microbial functions related to nutrient cycling.

The interaction among production system, rice variety, and soil chemical properties shaped the activity of soil microbial communities. Rice monoculture generally supported higher microbial activity and diversity, as indicated by greater AWCD and Shannon index values associated with higher N and TOC contents. These nutrient-rich conditions enhanced microbial metabolism and utilization of diverse carbon sources. An exception was observed during the dry season, where NSIC Rc 222 in the rice–duck system showed higher AWCD than in monoculture, suggesting a possible varietal response. Future studies are recommended to assess the different exudates released by the roots of various rice varieties that might contribute to microbial community composition in the area.

In contrast, the rice–duck production system showed slightly reduced microbial activity overall, likely due to changes in nutrient dynamics and organic inputs influenced by duck integration. Among rice varieties, NSIC Rc 222 and NSIC Rc 402 maintained relatively higher microbial activity, suggesting that differences in root exudation and rhizosphere environment also contributed to shaping microbial functional diversity.

Soil chemical properties strongly influence microbial diversity and soil health. Neutral pH generally supports higher diversity, while acidic or alkaline conditions reduce it (Luan et al., 2023). Organic matter enhances diversity by providing habitats and substrates, linking carbon content to microbial biomass (Bastida et al., 2021). Nutrient levels, particularly N and P, shape microbial communities, with excess N reducing diversity through acidification (Cheng et al., 2024). The chemical properties of soil play a vital role in influencing crop growth, yield, quality, and market competitiveness. Any degradation of these properties can lead to a decline in soil fertility, reduction of essential nutrients, and consequently, decreased overall productivity (De Paul Obade and Lal, 2016).

Conclusion and Recommendations

This study demonstrated that both rice monoculture and rice–duck production systems support functionally diverse soil microbial communities, as reflected by Shannon diversity index (H′) values above 3.0 across treatments. However, rice monoculture consistently exhibited slightly higher microbial metabolic activity and diversity than rice–duck integration, particularly during the dry season and in NSIC Rc 402 and NSIC Rc 222. These results suggest that the rice–duck system, while maintaining good microbial diversity, may alter microbial composition through increased soil disturbance and nutrient inputs from ducks.

Soil chemical properties further help explain these trends. Rice monoculture systems maintained higher soil pH, organic carbon, available P, and exchangeable K, whereas rice–duck systems enhanced N availability during the wet season. This indicates that each production system has distinct effects on nutrient cycling dynamics, potentially driven by soil redox conditions, organic inputs, and biological activity. The use of BiOLOG EcoPlates™ effectively revealed functional diversity patterns, highlighting differences in carbon substrate utilization between systems and among rice varieties.

A key limitation of this study is that BiOLOG EcoPlates assess functional diversity through community-level physiological profiles (CLPP) but cannot identify microbial communities at the species or taxonomic level. Another gap is the limited emphasis on functional genes and metabolic pathways directly linked to soil fertility as most available studies and tools focus on microbial abundance rather than function. Nevertheless, there are opportunities to enhance microbial diversity in agricultural systems by increasing habitat heterogeneity and supporting varied root exudates that sustain diverse microbial communities.

Both production systems sustain robust microbial communities and soil fertility, but their impacts vary seasonally and by variety. Monoculture offers relatively stable conditions that can support high microbial metabolic activity, while rice–duck systems provide ecological benefits such as enhanced nutrient cycling and integration of animal components.

Future studies should combine functional and molecular analyses (e.g., 16S rRNA sequencing, metagenomics, and functional gene profiling) to better understand shifts in community composition, long-term soil health impacts, and their linkages to crop productivity and environmental sustainability. Such approaches would clarify how specific microbial taxa and functional pathways respond to rice monoculture and rice–duck systems, and how these responses can be leveraged to optimize both productivity and ecosystem services.

Literature Cited

Ahn JH, Lee SA, Kim JM, Kim MS, Song J, Weon HY (2016) Dynamics of bacterial communities in rice field soils as affected by different long-term fertilization practices. Journal of Microbiology ***54***(11): 724 - 731

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment *74*(1-3): 19 - 31

Bardgett RD, Van Der Putten WH (2014) Belowground biodiversity and ecosystem functioning. Nature ***515***(7528): 505 - 511

Barroga RM, Gicana N, Barroga AJ (2007) Socio-Economic evaluation of rice-duck farming system in Bukidnon. Philippine Journal of Veterinary and Animal Sciences ***33***(1)

Bastida F, Eldridge DJ, García C, Peng GK, Bardgett RD, Delgado-Baquerizo M (2021) Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. The ISME Journal ***15***(7): 2081 - 2091

Bautista EU, Javier EF (2005) The evolution of rice production practices (No. 2005-14). PIDS Discussion Paper Series. Retrieved https://pidswebs.pids.gov.ph/CDN/PUBLICATIONS/ris-old-backups/dps/pidsdps0514.pdf (accessed on October 27, 2025)

Cagauan AG, Branckaert RD, Van Hove C (2000) Integrating fish and azolla into rice-duck farming in Asia. Naga, The ICLARM Quarterly ***23***(1): 4 - 10

Charaslertrangsi T, Arunrat N, Sereenonchai S, Wongkamhang PR (2024) Comparison of microbial diversity and metabolic activities in organic and conventional rice farms in Thailand. Microbiology Spectrum ***12***(8): e0307123

Cheng W, Tian W, Wang W, Lv T, Su T, Wu M, Li G (2024) Nutrient availability contributes to structural and functional diversity of microbiome in Xinjiang oilfield. Frontiers in Microbiology ***15***: 1450226

Classen AT, Boyle SI, Haskins KE, Overby ST, Hart SC (2003) Community-level physiological profiles of bacteria and fungi: plate type and incubation temperature influences on contrasting soils. FEMS Microbiology Ecology ***44***(3): 319 - 328

Conrad R (2007) Microbial ecology of methanogens and methanotrophs. Advances in agronomy ***96***: 1 - 63

De Paul Obade V, Lal R (2016) Towards a standard technique for soil quality assessment. Geoderma ***265***: 96 - 102

Ding C, Du S, Ma Y, Li X, Zhang T, Wang X (2019) Changes in the pH of paddy soils after flooding and drainage: modeling and validation. Geoderma ***337***: 511 - 513

Dundore-Arias JP, Felice L, Dill-Macky R, Kinkel LL (2019) Carbon amendments induce shifts in nutrient use, inhibitory, and resistance phenotypes among soilborne streptomyces. Frontiers in Microbiology ***10***: 498

Edwards J, Johnson C, Santos-Medellín C, Lurie E, Podishetty NK, Bhatnagar S, Sundaresan V (2015) Structure, variation, and assembly of the root-associated microbiomes of rice. Proceedings of the National Academy of Sciences ***112***(8): E911-E920

Gao H, Sha Z, Wang F, Fang K, Dai W, Yi X, Cao L (2019) Nitrogen leakage in a rice–duck co-culture system with different fertilizer treatments in China. Science of the total environment ***686***: 555 - 567

Garland JL, Mills AL (1991) Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization. Applied and Environmental Microbiology ***57***(8): 2351 - 2359

Ge Z, Du H, Gao Y, Qiu W (2018) Analysis on metabolic functions of stored rice microbial communities by BiOLOG eco microplates. Frontiers in Microbiology ***9***: 1375

Gryta A, Frąc M, Oszust K (2014) The application of the BiOLOG ecoplate approach in ecotoxicological evaluation of dairy sewage sludge. Applied Biochemistry and Biotechnology ***174***(4): 1434 - 1443

Han N, Yang C, Liu M, Wei C, Mao R, Chen C (2024) Long-term rice-duck farming promotes more complex and stable bacterial communities. Journal of Soils and Sediments ***24***(4): 1739 - 1749

Hartmann M, Frey B, Mayer J, Mäder P, Widmer F (2015) Distinct soil microbial diversity under long-term organic and conventional farming. The ISME journal ***9***(5): 1177 - 1194

Hossner LR, Baker WH (1988) Phosphorus transformations in flooded soils. *In* The Ecology and Management of Wetlands: Ecology of Wetlands (1) (pp. 93 - 306) Springer

Hua K, Zhu B (2020) Phosphorus loss through surface runoff and leaching in response to the long-term application of different organic amendments on sloping croplands. Journal of Soils and Sediments ***20***(9): 1 - 13

Huang J, Li J, Zhou W, Cheng Y, Li J (2023) Effect of different rice transplanting patterns on microbial community in water, sediment, and Procambarus clarkii intestine in rice-crayfish system. Frontiers in Microbiology ***14***: 1233815

Jiao Y, Chen Q, Guo X, Li H, Chen X, Men K (2024) Effect of potassium fulvate on continuous tobacco cropping soils and crop growth. Front. Plant Sci. ***15***: 1457793

Kaiser K, Wemheuer B, Korolkow V, Wemheuer F, Nacke H, Schöning, I, Daniel R (2016) Driving forces of soil bacterial community structure, diversity, and function in temperate grasslands and forests. Scientific reports ***6***(1): 33696

Kirk GJD (2004) *The biogeochemistry of submerged soils*. John Wiley & Sons

Kumar A, Verma JP (2019) The role of microbes to improve crop productivity and soil health: Innovative approaches to socio-ecological sustainability (pp 249 – 265). Ecological Wisdom Inspired Restoration Engineering

Larney FJ, Angers D A (2012) The role of organic amendments in soil reclamation: A review. Canadian Journal of Soil Science ***92***(1): 19 - 38

Larré-Larrouy, MC, Albrecht A, Blanchart E, Chevallier T, Feller C (2003) Carbon and monosaccharides of a tropical Vertisol under pasture and market-gardening: Distribution in primary organo-mineral separates. Geoderma ***117***(1-2): 63 - 79

Lauber CL, Hamady M, Knight R, Fierer N (2009) Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. Appl. Environ. Microbiol ***75***: 5111 - 5120

Li P, Wu G, Li Y, Hu C, Ge L, Zheng X (2022) Long-term rice-crayfish-turtle co-culture maintains high crop yields by improving soil health and increasing soil microbial community stability. Geoderma ***413***: 115745

Li, HY, Wang H, Tao XH, Wang XZ, Jin WZ, Gilbert JA, Zhu YG, Zhang ZJ (2021) Continental-scale paddy soil bacterial community structure, function, and biotic interaction. Msystems ***6***(5): 10 - 128

Liao YM, Huang YTJ, Han NN, Ling Z, Zou CW, Shi DD, Jiang DH (2019) Analysis of population diversity of fungi and bacteria in rice rhizosphere soil under rice-duck farming model. Journal of Southern Agriculture ***50***(1): 59 - 67

Liu S, Li H, Xie X, Chen Y, Lang M, Chen X (2024) Long-term moderate fertilization increases the complexity of soil microbial community and promotes regulation of phosphorus cycling genes to improve the availability of phosphorus in acid soil. Applied Soil Ecology ***194***: 105178

Liu Y, Whitman WB (2008) Metabolic, phylogenetic, and ecological diversity of the methanogenic archaea. Annals of the New York Academy of Sciences ***1125***(1): 171 - 189

Luan L, Jiang Y, Dini-Andreote F, Crowther TW, Li P, Bahram M, Sun B (2023) Integrating pH into the metabolic theory of ecology to predict bacterial diversity in soil. Proceedings of the National Academy of Sciences ***120***(3): e2207832120

Luo X, Fu X, Yang Y, Cai P, Peng S, Chen W, Huang Q (2016) Microbial communities play important roles in modulating paddy soil fertility. Scientific Reports ***6***(1): 20326

Lupwayi NZ, Rice WA, Clayton GW (1998) Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. Soil Biology and Biochemistry ***30***(13): 1733 - 1741

Lyons MM, Dobbs FC (2012) Differential utilization of carbon substrates by aggregate-associated and water-associated heterotrophic bacterial communities. Hydrobiologia ***686***(1): 181 - 193

Mäder P, Fliessbach A, Dubois D, Gunst L, Fried PM, Niggli U (2002) Soil fertility and biodiversity in organic farming. Science ***296***(5573): 1694 - 1697

Martinengo S, Schiavon M, Santoro V, Said-Pullicino D, Romani M, Miniotti EF, Martin M (2023) Assessing phosphorus availability in paddy soils: the importance of integrating soil tests and plant responses. Biology and Fertility of Soils ***59***(4): 391 - 405

Michalska-Smith M, Song Z, Spawn-Lee SA, Hansen ZA, Johnson M, May G, Borer ET, Seabloom EW, Kinkel LL (2022) Network structure of resource use and niche overlap within the endophytic microbiome. The ISME Journal ***16***(2): 435 - 446

Nayak PK, Nayak AK, Panda BB, Senapati A, Panneerselvam P, Kumar A, Kumar U, Tripathi R, Poonam A, Shahid M, Mohapatra SD, Kaviraj M, Kumar U (2024) Rice-based integrated farming system improves the soil quality, bacterial community structure and system productivity under sub-humid tropical condition. Environmental Geochemistry and Health ***46***(2): 65

Philippine Rice Research Institute (2018) Rc 222 boosts yield by 20 cavans. Philippine Rice Research Institute. Retrieved from https://www.philrice.gov.ph/rc-222-boosts-yield-20-cavans/ (accessed September 13, 2024)

Phillips ML, Weber SE, Andrews LV, Aronson EL, Allen MF, Allen EB (2019) Fungal community assembly in soils and roots under plant invasion and nitrogen deposition. Fungal Ecology ***40***: 107 - 117

Ponnamperuma FN (1972) The chemistry of submerged soils. Advances in agronomy ***24***: 29 - 96

Preston-Mafham J, Boddy L, Randerson PF (2002) Analysis of microbial community functional diversity using sole-carbon-source utilization profiles–a critique. FEMS microbiology ecology ***42***(1): 1 - 14

Quan GM, Zhang JE, Chen R, Xu RB (2008) Effects of rice-duck farming on paddy field water environment. Chinese Journal of Applied Ecology/Yingyong Shengtai Xuebao ***19***(9)

Richardson AE, Simpson RJ (2011) Soil microorganisms mediating phosphorus availability update on microbial phosphorus. Plant physiology ***156***(3): 989 - 996

Shen CC, Xiong JB, Zhang HY, Feng YZ, Lin XG, Li XY (2013) Soil pH drives the spatial distribution of bacterial communities along elevation on Changbai Mountain. Soil Biol. Biochem ***57***: 204 - 211

Shen J, Yuan L, Zhang J, Li H, Bai Z, Chen X, Zhang F (2011) Phosphorus dynamics: from soil to plant. Plant physiology ***156***(3): 997 - 1005

Su JQ, Ding LJ, Xue K, Yao HY, Quensen J, Bai SJ, Zhu YG (2015) Long-term balanced fertilization increases the soil microbial functional diversity in a phosphorus-limited paddy soil. Molecular ecology ***24***(1): 136 - 150

Teng Q, Hu X, Luo F, Wang J, Zhang D (2019) Promotion of rice–duck Integrated farming in the water source areas of Shanghai: its positive effects on reducing agricultural diffuse pollution. ***78***: 171

Van der Heijden MGA, Bardgett RD, van Straalen NM (2008) The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology Letters ***11***(3): 296 - 310

Ventura M, Canchaya C, Tauch A, Chandra, G, Fitzgerald GF, Chater KF, van Sinderen D (2007) Genomics of Actinobacteria: tracing the evolutionary history of an ancient phylum. Microbiology and molecular biology reviews ***71***(3): 495 - 548

Villamora MA, Ogaro NO, Guevarra A, Barcala Jr DP, Rupa RM, Mesias R, Bautista A, Besa Z, Partoza N, Payod D, Daroy S (2000) Technology demonstration project on rice-duck farming. PCARRD Highlights `99: Summary proceedings. PCARRD-DOST

Wang X, Xia K, Yang X, Tang C (2019) Growth strategy of microbes on mixed carbon sources. Nature Communications ***10***(1): 1279

Wilson M, Lindow SE (1994) Coexistence among epiphytic bacterial populations mediated through nutritional resource partitioning. Applied and Environmental Microbiology, ***60***(12): 4468 - 4477

Xi S, Chu H, Zhou Z, Li T, Zhang S, Xu X, Pu Y, Wang G, Jia Y, Liu X (2023) Effect of potassium fertilizer on tea yield and quality: A meta-analysis. European Journal of Agronomy ***144***: 126767

Yang Q, Wang X, Shen Y (2013) Comparison of soil microbial community catabolic diversity between rhizosphere and bulk soil induced by tillage or residue retention. Journal of soil science and plant nutrition ***13***(1): 187 - 199

Yanni YG, Rizk RY, Corich V, Squartini A, Ninke K, Philip-Hollingsworth S, Orgambide G, De Bruijn F, Stoltzfus J, Buckley D, Schmidt TM, Mateos PF, Ladha JK, Dazzo FB (1997) Natural endophytic association between *Rhizobium leguminosarum* bv; *trifolii* and rice roots and assessment of its potential to promote rice growth. Plant and Soil ***194***(1/2): 99 - 114

Zhang JE, Xu RB, Quan GM, Xu H, Qin Z (2009) Effects of integrated rice-duck farming on soil microbial quantity and functional diversity. Resources Science ***31***(1): 56 - 62

Zuccarini P, Asensio D, Sardans J, Ogaya R, Liu L, Penuelas J (2023) Effects of nitrogen deposition on soil enzymatic activity and soil microbial community in a Mediterranean holm oak forest. Geoderma ***430***: 116354

FULL PAPER

PREDICTING HYBRID RICE YIELDS THROUGH THE CERES-RICE CROP MODEL

Marilyn M. Yere*, Ailon Oliver V. Capistrano, Juanito M. Maloom, and Nenita V. Desamero

Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
*Corresponding Author: mm.yere@philrice.gov.ph

Abstract

This paper describes the process of calibrating crop-specific genotype coefficients of hybrid rice using the Crop Environment Resource Synthesis (CERES)-Rice model within the Decision Support System for Agrotechnology Transfer (DSSAT) framework. The study aims to predict the performance of hybrid rice and parental genotypes across multiple environments and weather conditions in the Philippines. From parameterization to evaluation statistics, details of the required data inputs are presented. Tests for accuracy were conducted to validate the crop-specific coefficients derived from the calibration process for 14 genotypes: five rice hybrids (Mestizo 1, Mestiso 20, Mestiso 32, Mestiso 55, and Mestiso 73); three maintainer lines (IR58025B, IR79128B, IR68997B); five restorer lines (PR31559-AR32-4-3-2R, IR73013R, SN758, IR34686, TG101M); and one check genotype (NSIC Rc 222), all grown in both irrigated and rainfed environments. Simulation results for maturity duration showed high accuracy, with a normalized root mean square error (nRMSE) of less than 10% among the hybrids, and fair accuracy among most restorer lines (IR73013, IR34686, SN758) and maintainer line IR58025B. Grain yield predictions for most hybrids were near-accurate, with nRMSE values below 10%, except for Mestizo 1, which had a fair score. Most parental lines showed excellent to fair predictability for grain yield, except for maintainer lines IR58025B and IR79128B, which performed poorly (>20% nRMSE) due to typhoon damage during the reproductive stage. Regression analysis indicated the model's sensitivity to climate variability and seasonal changes, with coefficients of determination (R^2) ranging from 0.53 to 0.95 for most genotypes, except for IR34686 and TG101M ($R^2 = 0.32$ and 0.41, respectively). Correlation analysis (r) revealed a strong association between simulated and observed yields for all 14 genotypes. The index of agreement (D), which evaluates model performance by considering random disparities between observed and modeled data, ranged from 0.63 to 0.90, indicating reliable performance for all crop models evaluated. Overall, tests for accuracy, predictability, sensitivity, and correlation all indicate that the calibration of the CERES-Rice model for hybrids and parental genotypes was successful.

Keywords: *CERES-Rice Model, DSSAT, index of agreement (D), nRMSE, sensitivity analysis*

Introduction

At the start of the 21st century, the Philippines began encountering disruptions to rice production attributed to climate change, defined as significant long-term variations in climate patterns due to natural processes or human activities (Hoogenboom et al., 2007). Human-induced changes, such as increased atmospheric CO_2 concentration from burning fossil fuels and deforestation (Fitter & Hay, 2002), have contributed to these disruptions. To address these challenges, strategies should focus on soil carbon sequestration through reduced tillage (Kumari et al., 2011), improving irrigation efficiency through intermittent flooding (Chidthaisong et al., 2018), and promoting balanced fertilization (Benbi & Brar, 2009) to reduce greenhouse gas emissions.

Adaptation options for farmers include adjusting planting and harvest dates to avoid adverse climate conditions and selecting shorter-maturing varieties to allow multiple crops per year (Wolfe et al., 2008). Varieties with higher tolerance to temperature fluctuations can help maintain yields under climate change. Management practices such as fertilizer application, weed control, and pest and disease management must also be adjusted. Warmer temperatures, longer growing seasons, and increased drought intensity necessitate efficient water management and expanded water storage facilities.

Rice is the most extensively grown crop and the staple food in the Philippines, playing a significant political and economic role. Providing around 35% of the average calorie intake, rice is crucial for the population's nutrition, particularly for 60–65% of households in the lowest income quartile (David & Balisacan, 1995). Rice farming is also a primary source of income and employment for about 2.5 million households (Gonzales, 2013) and supports millions of landless farmworkers and tens of thousands of merchants. Given its importance, rice has always been central to the government's food security policies.

Accurate crop yield prediction is vital for policymakers to plan internal food distribution, implement relief measures, manage grain storage, set levy prices, and provide alternative employment in drought-affected areas (Hundal & Kaur, 1996). Crop production estimation can be approached through statistical methods, biophysical models, and remote sensing. Statistical models rely on empirical relationships, such as between grain yield and rainfall (Van & Wolf, 1986). Biophysical crop simulation models integrate knowledge of plant–soil–atmosphere interactions to estimate agricultural production based on weather, soil conditions, and crop management (Hoogenboom et al., 2007). These models help analyze the effects of changes in soil characteristics or weather patterns in ways that field experiments alone cannot achieve. While field experiments are necessary to develop and test crop models, they are limited in scope and location. Crop simulation models can extrapolate experimental results across different times and places.

Conventional rice production studies have largely relied on experience-based agronomic research, often lacking in-depth, system-level analysis. The knowledge-based systems approach, using dynamic simulation models of rice growth and cropping systems, integrates plant growth knowledge from crop physiology, agrometeorology, soil science, and agronomy. Properly validated models can predict rice responses to environmental changes and test alternative management options. Decision Support Systems for Agrotechnology Transfer (DSSAT) combine crop growth models with economic and environmental evaluations, supporting economic analysis and risk assessment.

This study focused on calibrating and evaluating crop-specific coefficients using CERES-based models within the DSSAT system for hybrid rice and its parental lines. By testing these models through simulations, the study further aims to validate and assess their robustness and fitness across different seasons, years, and locations with varying climate and soil conditions, toward predicting hybrid rice yields.

Materials and Methods

This study was conducted within the framework of multi-environment trials (MET) for rice across the Philippines, as the source of data involving registered hybrid rice varieties intended for commercial cultivation, their corresponding parents (maintainers and restorers/pollen parents), and an inbred check, NSIC Rc 222 (Table 1). Growth and phenology data were initially collected from one experimental site in the Science City of Muñoz, Nueva Ecija, during the 2019 dry season (DS). These data were used for parameterization and subsequently uploaded to the DSSAT-Cropping System Model (DSSAT-CSM) for calibration of the crop-specific or genetic coefficients of each experimental genotype, which were later subjected to validation to adjust discrepancies and achieve acceptable model performance. The same type of data was then gathered across MET locations (Ilocos Norte, Isabela, Davao del Sur, and Nueva Ecija) for further validation, which also served as sensitivity analysis.

Parameterization involved inputting directly measured or recorded parameters (crop data, climate variables, soil physical and chemical characteristics, management practices, and inputs) into the model for the 2019 DS at the experimental site (Tables 2 and 3). The crop data included growth variables such as yield and yield components, and phenology data describing the timing of specific growth phases. Calibration adjusted system parameters that are difficult to measure directly or have significant uncertainty, such as crop varietal-specific coefficients. The Generalized Likelihood Uncertainty Estimation (GLUE) program within DSSAT was used to estimate these coefficients. GLUE identifies experiments and treatments in DSSAT data files with relevant measurements for each genotype, enabling the selection of appropriate data for coefficient estimation.

The calibration process involved running 1,000–3,000 simulations, iterating biomass, yield, and phenology data to achieve reliable coefficient

Table 1. Entries for CERES-Rice DSSAT modeling.

NSIC Registry Name	Commercial Name	Maintainer (B)	Restorer (R)/Pollen Parent
NSIC 2014 Rc 368H	Mestiso 55	IR79128B	PR31559-AR32-4-3-2R
NSIC 2011 Rc 250H	Mestiso 32	IR68897B	IR73013R
NSIC 2016 Rc 446H	Mestiso 73	PRUPTG1101**	SN758
PSB 1997 Rc 72H	Mestizo 1	IR58025B	IR34686
NSIC 2009 Rc 204H	Mestiso 20	PRUPTG1101**	TG101M
NSIC Rc 222 (check)	Tubigan 18		

**Two-line (TGMS)-based hybrid, Sterile line (S-line) not included in the trial.

estimates, which were then validated using GLUE (He et al., 2010). For the CERES-Rice model, calibration was performed using 2019 DS data from MET sites. The GLUE method was applied using Bayesian estimation, with Monte Carlo sampling from prior distributions of model coefficients and a Gaussian likelihood function. This process helped identify the best-fitting parameter sets based on observed data.

During calibration, the generic rice genotype IR64 in DSSAT was renamed to reflect the new target genotype. GLUE was then used to estimate the relevant parameters based on the treatments and hybrid genotypes specified in the DSSAT experiment input files. Calibration was guided by actual field observations, specifically biomass and yield measurements, following the methodology of He et al. (2010). Simulation-based calibration was repeated three times to iteratively refine the parameter estimates, aiming to achieve the closest possible match between simulated outputs and observed values.

After calibration, the derived crop-specific coefficients were validated by simulating experiments at specific sites and years, then comparing the simulated outputs such as crop development, production, and soil water dynamics with observed values. Discrepancies were adjusted within reasonable limits (5–10% of the initial value) to achieve acceptable model performance. These simulations were compared with observed yields to assess the accuracy of the crop genetic coefficients. Validation was evaluated by comparing simulated development and growth characteristics with observed values and calculating the root mean square error (RMSE) and normalized RMSE (nRMSE) (Table 10). Simulation quality was classified as excellent (nRMSE < 10%), good (10% ≤ nRMSE < 20%), fair (20% ≤ nRMSE < 30%), or poor (nRMSE ≥ 30%) (Nyang'au et al., 2014). The model evaluation process is detailed in Equation (1):

Equation 1. Formula for RMSE and nRMSE

Where: S – simulated values
M- measured or actual value
N – number of observations

The Root Mean Square Error (RMSE), previously referred to as the root mean square of deviation (RMSD) in earlier research (Probert et al., 1998; Kobayashi & Salam, 2000), is widely used to validate simulation models, including DSSAT (Kobayashi & Salam, 2000; Irmak et al., 2000; Hoogenboom et al., 1989).

Further validation, or sensitivity analysis, was conducted by simulating each genotype across locations and seasons. Predicted yield data were plotted and analyzed against observed yield data using regression analysis to derive the coefficient of determination (R^2), which measures how well the data fit the statistical model. An R^2 of 1 indicates a perfect fit, while an R^2 of 0 signifies no fit. A higher R^2 value indicates a better alignment between yield observations and the model (Gomez & Gomez, 1984). This procedure is detailed in Equation (2):

Equation 2:

$$R^2 = 1 - \left[\sum_{i=1}^{n} (Si - Obi)^2 / \sum_{i=1}^{n} (Obi - Ob)^2\right]$$

A crop model is developed through a detailed and complex process involving several stages, such as understanding basic processes, constructing the model, estimating parameters, and evaluating prediction quality. At various stages of a model's lifecycle, it is essential to examine the model independently, focusing on its behavior rather than its fit to a specific dataset. Sensitivity analysis, along with uncertainty analysis and related methods, is therefore crucial for modelers and users (Monod et al., 2006).

Sensitivity analysis involves quantitatively assessing the variability or uncertainty in the model's components such as parameters, input variables, and equations and deriving an uncertainty distribution for each output variable. This approach helps evaluate the probability that a response exceeds a certain threshold, rather than relying on a single potentially misleading value (Vose, 1996). Specifically, sensitivity analysis aims to determine how the output of a crop model responds to variations in model elements that are subject to uncertainty or variability (Monod et al., 2006).

Regression analysis is a valuable tool for sensitivity and uncertainty analyses, providing a framework to study the influence of all input factors simultaneously. By approximating the crop model under investigation, regression allows the evaluation of the impact of each input factor. Coefficients in the regression model are estimated using least squares, and the quality of the fit is typically assessed by R^2, which indicates the proportion of output variability explained by the model (Monod et al., 2006). R^2 is commonly used as a standard measure for evaluating how well a regression model's predictions align with observed data, representing the proportion of variance in the dependent variable that is explained by the independent variables. However, its use in performance evaluation has been criticized because it does not necessarily reflect prediction accuracy (Fox, 1981; Paruelo et al., 1998).

In contrast, Pearson's sample correlation coefficient (r), which is closely related to R^2, indicates the strength of association between simulated and observed yields, highlighting the dependency between variables.

An alternative measure, the index of agreement (D), is considered superior to both R^2 and r for some purposes. This standardized metric quantifies the degree of prediction error in models and is derived from the ratio of mean square error (MSE) to potential error (Willmott et al., 1985). The index of agreement is particularly valued for its descriptive capabilities, as it is a relative, bounded measure that facilitates cross-comparison between models (de Almeida et al., 2016; Wachholz de Souza et al., 2015; Yebra & Chuvieco, 2009).

The index of agreement (D) ranges between 0 and 1, where a value of 1 signifies a perfect match between model predictions and observed data, while a value of 0 indicates no agreement. It serves as a normalized gauge of prediction error derived from MSE relative to the potential error, and its calculation considers both systematic and random disparities between observed and modeled data. As such, D provides a more comprehensive assessment by accounting for various sources of error and offering insights into the accuracy and reliability of model predictions. The model evaluation process using D is detailed in Equation (3):

Equation 3:

$$D = 1 - \frac{\sum_{i=1}^{n} \quad (Si - Ob)^2)}{\sum_{i=1}^{n} \quad (|Si - Obavg)|Obi - Obavg|)^2)}$$

Forecasting efficiency (EF) is another relative measure of error commonly used in the literature (Loague & Green, 1991; Loague & Freeze, 1985). Like R^2, EF facilitates comparison of model accuracy among different variables because it is unitless. EF equals 1 when model predictions perfectly match observed values ($yi = xi$) and is less than 1 for any realistic simulation. If EF is less than 0, it indicates that the model's predictions are worse than using the mean of the observed values. Unlike R^2—which ranges from 0 to 1 and varies with different linear models (e.g., $y = a + bx$, $y = bx$, or $y = x$)—EF is sensitive to outliers due to its use of a quadratic residual function (Klepper & Rouse, 1991).

The CERES-Rice DSSAT Model

The CERES-Rice model simulates rice growth and yield under different environments and management strategies from transplanting to maturity, based on physiological processes responsive to local weather conditions. Required input data include daily weather (maximum and minimum temperature, rainfall, solar radiation) sourced from nearby AGROMET stations, soil characterization, model-derived genetic coefficients, and crop management information (planting date, seedling age, row and plant spacing, fertilizer and irrigation application rates and dates) per site.

CERES-Rice–based models within DSSAT require a minimum dataset for operation, encompassing site data, daily weather data, soil properties, and crop management practices per site. Key crop management factors include planting date and depth, row spacing, plant population, fertilization, irrigation, residue applications, tillage, and harvest date.

Results and Discussion

The genetic coefficients influencing the duration of vegetative and reproductive growth are presented in Table 8. These include the phenology coefficients P1, P2R, and P5, which represent basic vegetative growth, photoperiod response, and the growing

Table 2. Summary description of 8 rice genetic coefficients (Barik et al., 2012).

Genetic Parameters	Description
P1	Time period (expressed as growing degree days (GDD) in °C above a base temperature of 9 °C from seedling emergence during which the rice plant is not responsive to changes in photoperiod.
P20	Critical photoperiod of the longest day length (in h) at which the development occurs at a maximum rate.
P2R	The extent to which the phasis development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20.
P5	Time period in GDD °C from the beginning of grain filling (3-4 days after flowering) to physiological maturity with a base temperature of 9°C.
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g or main culm dry weight (fewer leaf blades and sheath plus spikes) at anthesis
G2	Single grain weight (g) under ideal conditions, i.e., non-limiting light, water, and nutrients and absence of pests and diseases
G3	Tillering coefficient (scaler value) relative to IR64 genotype under ideal conditions
G4	Temperature tolerance coefficient, usually 1.0 for varieties grown in a normal environment

Table 3. The genetic coefficient of 14 genotypes; calibrated from 2019 DS dataset.

Check variety	Location/Sites	P1	P2R	P5	P20	G1	G2	G3	G4
Hybrids									
PSB Rc 72H (M1)	Isabela	624.4	54.75	772.0	11.65	69.87	0.028	1.191	0.89
NSIC Rc 204H (M20)	Davao del Sur	660.5	143.5	501.6	12.89	72.62	0.03	1.033	0.81
NSIC Rc 250H (M32)	Isabela	680.2	15.4	673.7	12.13	74.78	0.024	0.926	0.86
NSIC Rc 368H (M55)	Nueva Ecija	688.8	211.9	246.4	11.02	73.62	0.026	1.093	0.57
NSIC Rc 446H (M73)	Isabela	670.2	149.4	788.2	12.47	56.34	0.029	0.976	0.84
Parents									
PR31559-AR32-4-3-2R	Nueva Ecija	648.6	185.5	202.6	12.19	86.00	0.025	0.998	0.87
IR73013R	Isabela	270.0	278.5	370.3	11.80	69.30	0.026	0.772	0.86
SN758	Nueva Ecija	562.6	283.8	209.8	12.17	63.02	0.026	1.061	0.64
IR34686	Nueva Ecija	501.2	138.6	500.0	11.98	51.71	0.024	1.156	0.71
TG102M	Nueva Ecija	677.5	205.3	302.0	11.61	70.9	0.021	1.117	0.8
IR68897B	Nueva Ecija	780.3	114.4	427.3	11.41	72.77	0.023	1.054	0.59
IR79128B	Davao	518.3	158.8	599.1	11.12	55.26	0.028	0.782	0.84
IR58025B	Nueva Ecija	488.7	184.4	674.6	11.07	73.14	0.023	0.766	0.86
Check variety									
NSIC Rc 222	Isabela	708.2	60.04	842	11.49	68.36	0.026	1.00	0.58

Table 4. Comparison/validation between the observed and simulated model outputs of selected irrigated genotypes 2018 WS, Science City of Muñoz.

Genotype	Phenology						Grain Yield (kg/ha)			Harvest		Index
	Anthesis (days after seeding)			Maturity (days after seeding)								
Hybrid	Sim	Obs	nRMSE (%)	Sim	Obs	nRMSE (%)	Sim	Obs	nRMSE (%)	Sim	Obs	nRMSE (%)
PSB Rc 72H (M1)	73	87	16.092	120	117	2.56	7543	6328	**19.2**	0.62	0.27	129.62
NSIC Rc 204H (M20)	71	89	20.22	106	119	10.92	7134	7558	5.6	0.63	0.28	125
NSIC Rc 250H (M32)	71	88	19.31	113	115	1.74	7138	5490	30	0.61	0.27	125.9
NSIC Rc 368H (M55)	91	90	1.11	115	125	8	6019	7232	**16.77**	0.58	0.28	107
NSIC Rc 446H (M73)	77	94	18.08	126	129	2.32	6904	7356	6.14	0.54	0.28	92.85
Maintainer Line												
IR68897B	81	85	4.7	113	118	4.23	6490	5925	9.53	0.57	0.3	90
IR58025B	84	85	1.17	127	106	**19.81**	7235	5527	**30.9**	0.64	0.33	93.9
IR79128B	81	85	4.7	120	110	9.09	7151	4611	**55.08**	0.58	0.29	100
Restorer Line												
IR34686	66	103	35.92	104	136	**23.52**	5215	4972	4.88	0.43	0.22	95.45
IR73013R	74	94	21.27	101	122	**17.21**	6469	6880	5.97	0.64	0.29	120.69
PR31559-AR32-4-3-2R	89	90	1.11	113	115	1.74	6416	5478	17.21	0.59	0.37	59.45
SN758	76	96	20.83	98	131	**25.19**	5959	6816	12.57	0.58	0.29	100
TG102M	89	94	5.32	113	126	10.31	6416	6425	0.14	0.59	0.27	118.51
Check Variety												
NSIC Rc 222	70	94	25.53	122	119	2.52	6284	8374	**24.95**	0.49	0.26	88.46

Table 5. Description of the datasets used in the sensitivity analysis in various MET sites.

Dataset Number	Location	Trial Site	Year/Season	Climate Type	Treatment
1	Ilocos Norte	PhilRice Batac, Batac City	2019 WS	1	148-60-60
2	Ilocos Norte	PhilRice Batac, Batac City	2021 WS	1	191-35-65
3	Ilocos Norte	PhilRice Batac, Batac City	2021 DS	1	165-30-60
4	Isabela	PhilRice Isabela, San Mateo	2019 WS	3	126.63-10.66-32.14
5	Isabela	PhilRice Isabela, San Mateo	2019 DS	3	100-60-60
6	Nueva Ecija	PhilRice CES, Muñoz City	2018 WS	1	120-60-30
7	Iloilo	DA-WESVIARC, Iloilo City	2019 WS	3	158.3-15.8-48.9
8	Iloilo	DA-WESVIARC, Iloilo City	2019 WS	3	158-15-49
9	Iloilo	DA-WESVIARC, Iloilo City	2021 DS	3	159-16-31
10	Davao del Sur	SPAMAST, Digos City	2019 WS	4	178.71-8.88-11.74
11	Davao del Sur	SPAMAST, Digos City	2019 DS	4	100-60-60
12	Davao del Sur	SPAMAST, Digos City	2021 DS	4	176-39-42

Table 6. Summary of correlation of determination (R^2), correlation coefficient (r), and an index of agreement (D) after validation of selected hybrids and parents.

Variety/Entry	R^2	r	D
Hybrid			
PSB Rc 72H (M1)	0.79	**0.89**	**0.89**
NSIC Rc 204H (M20)	0.68	**0.83**	0.88
NSIC Rc 250H (M32)	**0.91**	**0.95**	0.80
NSIC Rc 368H (M55)	0.53	0.73	0.82
NSIC Rc 446H (M73)	0.69	**0.83**	0.88
Maintainer Line			
IR68897B	0.63	0.80	0.84
IR58025B	0.53	0.73	0.68
IR 79128B	0.53	0.73	0.85
Restorer line			
IR34686	0.32	0.57	0.76
IR73013R	0.91	0.95	0.90
PR31559-AR32-4-3-2R	0.56	0.74	0.83
SN758	0.49	0.70	0.63
TG102M	0.41	0.64	0.81
Check variety			
NSIC Rc 222	0.53	0.73	0.78

The RMSE values, displayed in the scatter graphs, range from 920 to 1915 (Figures. 1-4).

degree days required from grain filling to maturity, respectively. The growth coefficients G1, G2, G3, and G4 describe potential spikelet number, single grain weight, tillering capacity, and temperature tolerance. These coefficients were derived after calibration of the CERES-Rice model using observed datasets from Nueva Ecija, 2019 dry season (DS) (Table 9).

Model Validation on Phenology

The crop genetic coefficients were validated by simulating potential yield and yield component data for the same test site (Science City of Muñoz, Nueva Ecija) but in a different season (wet season) and year, and comparing these simulations with observed data. The accuracy of the calibration procedure was assessed by comparing simulated development and growth characteristics with observed values and calculating the RMSE and normalized RMSE (nRMSE). Predicted rice yields and growth stages were evaluated based on an acceptable margin of error of 10%.

The comparison between predicted and observed phenology for days to maturity showed that the hybrids performed excellently in simulation, with nRMSE values of less than 10%. Most hybrid parents also demonstrated excellent performance. However, restorer lines IR73013, IR34686, and SN758, as well as maintainer line IR58025B, exhibited less accurate predictions for maturity dates. These lines had higher nRMSE values of 17.2%, 23.5%, 25.2%, and 25.2%, respectively, indicating fair predictability (Table 10).

Model Validation on Yield

Based on the nRMSE values for yield prediction, most hybrids showed an acceptable margin of error, with nRMSE values below 20%. Most parent lines exhibited excellent to good predictability, although the maintainer lines IR58025B and IR79128B performed poorly, with nRMSE values exceeding 20% and simulated yields that overestimated the observed data. Their poor performance may be attributed to Typhoon Ompong, which affected the experimental area with sustained winds of up to 125 mph during the reproductive stage in September 2018 in Muñoz City (Table 10).

Model Validation on Harvest Index

The predictions for harvest index (HI) did not match the observed values for any of the genotypes, which contrasts with the model's performance for grain yield (Table 10). Harvest index is the ratio of grain yield to total aboveground biomass, while crop water productivity refers to grain yield per unit water transpired. Both grain yield and water productivity can be improved by increasing transpiration efficiency or by enhancing HI (Ehlers & Goss, 2003).

In this study, observed HI values for hybrids and parental genotypes were significantly lower than the simulated values. This discrepancy can be attributed to the waterlogged conditions of the MET sites, particularly in continuously flooded areas such as Nueva Ecija and Isabela, which delayed senescence due to extended grain filling. As a result, unused assimilates remained in the straw (Yang & Zhang, 2006), leading to lower HI. Delayed plant senescence, which results in excess non-structural carbohydrates in the straw, has been linked with slower grain filling (Zhu et al., 1988; Mi et al., 2002; Gong et al., 2005).

HI is a variable factor in crop production and can be improved through better water use efficiency (WUE) (Yang & Zhang, 2010). WUE is defined as grain production per unit of water applied (Yang & Zhang, 2010). It can be enhanced by managing irrigation to promote controlled soil drying, such as through alternate wetting and drying (AWD), which can increase grain yield and potentially improve HI.

Sensitivity Analysis

Sensitivity analysis in this study was conducted using a regression approach, by plotting simulated yield against observed yield. The dataset used for this analysis is described in Table 11. The genotypes were evaluated across locations that differ in climate type, year, and season. The CERES-Rice models simulated yield based on site-specific weather, soil conditions, and crop management treatments corresponding to these observed datasets. Simulated yields were then compared with observed yields using regression analysis.

Scatter plots showed that the R^2 (coefficient of determination) values indicated a generally good to near-perfect fit for most genotypes, except for parents IR34686 and TG102M (Table 12). The quality of fit was evaluated by comparing the points to the 1:1 regression line (Figures 1-4).

All genotypes fell within the acceptable range for the index of agreement (D), commonly defined as values greater than 0.5. In this study, D values ranged from 0.6 to 0.9, indicating a high degree of model performance (Table 12). Notably, the restorer line IR73013R exhibited the highest statistical values for R^2, r, and D (0.91, 0.95, and 0.90, respectively), underscoring its exceptional adaptability across environments. Mestizo 1 followed closely. These findings suggest both robustness of the model and adaptability of these genotypes across diverse conditions.

Among the genotypes analyzed, Mestiso 73, Mestiso 32, and IR68897B were the only ones showing good fit in terms of forecasting efficiency (EF), with values of 0.53, 0.61, and 0.61, respectively (Figures 1–2). The other genotypes had lower EF values, likely due to the presence of outliers in their datasets.

Additionally, yield prediction, as illustrated in the scatter plots, varied according to climate type, soil condition, and nutrient management. The observed correlation between simulated and observed yields, across these varying environments, supports the robustness of the CERES-Rice model for hybrid and parental genotypes.

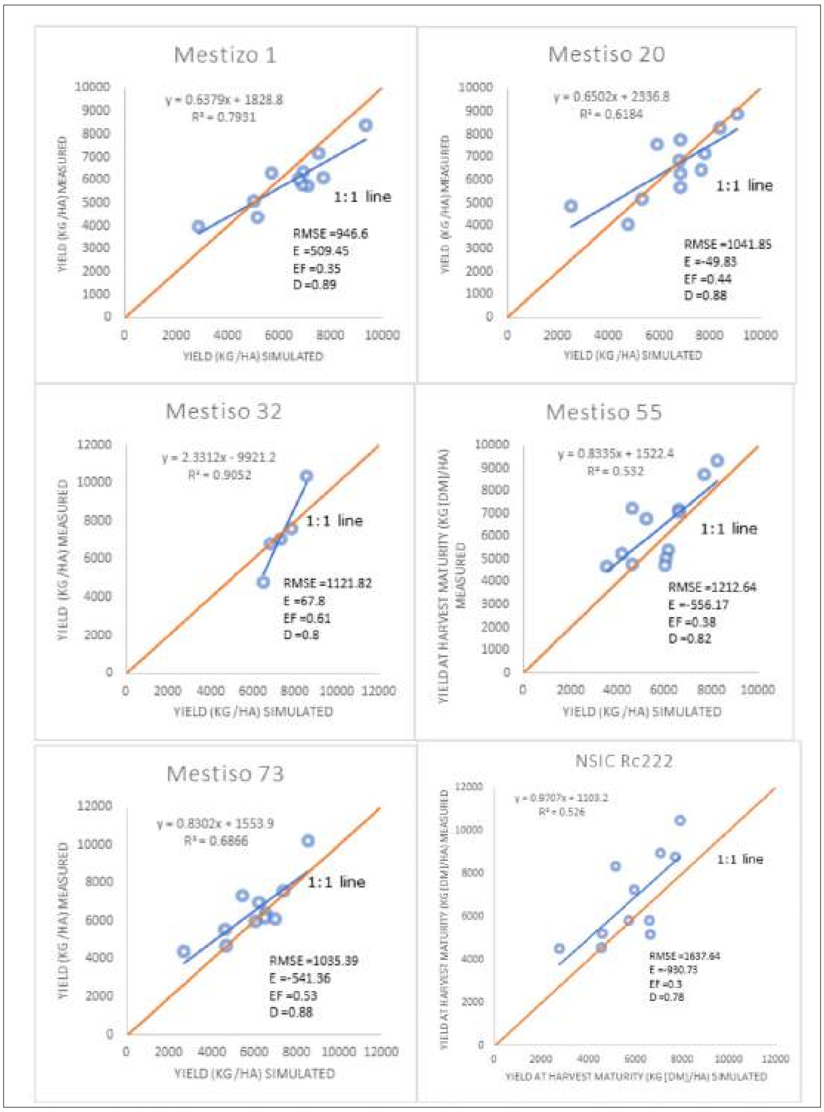


Figure 1a-1f. Scatter plots for the simulated vs. observed yield of the hybrids and check (NSIC Rc222) across MET sites, WS 2018 – WS 2021.

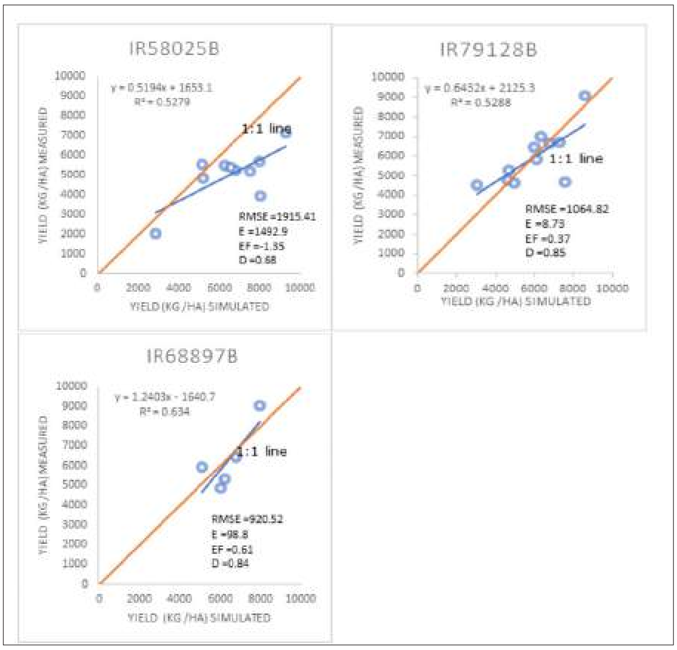


Fig 2a-2c. Scatter plots for the simulated vs. observed yield of the parents (maintainer line) across MET sites, WS 2018 - WS 2021.

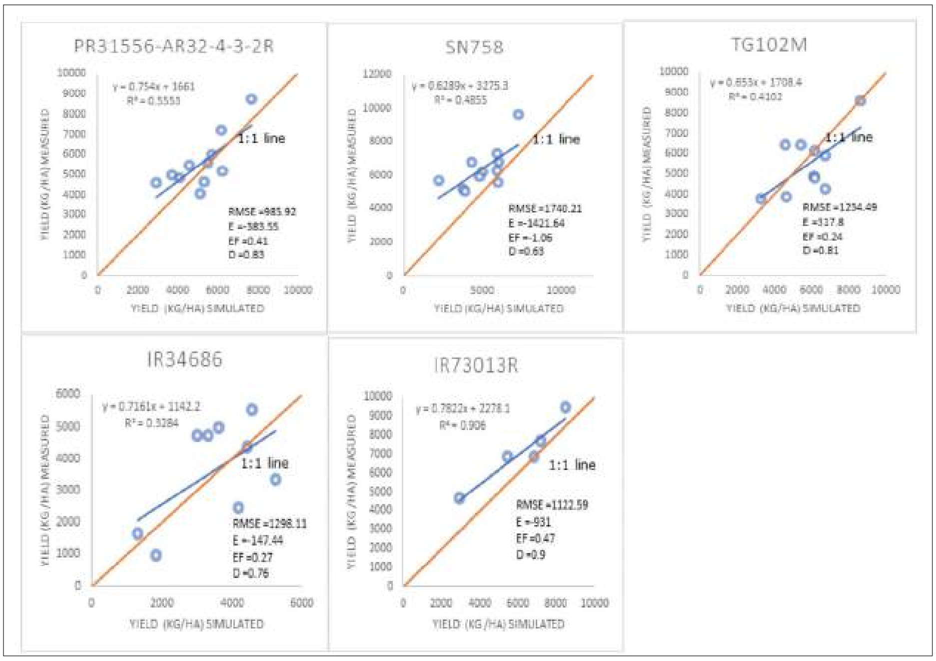


Figure 3a-3e. Scatter plots for the simulated vs. observed yield of the parents (restorer lines) across MET sites, WS 2018 - WS 2021.

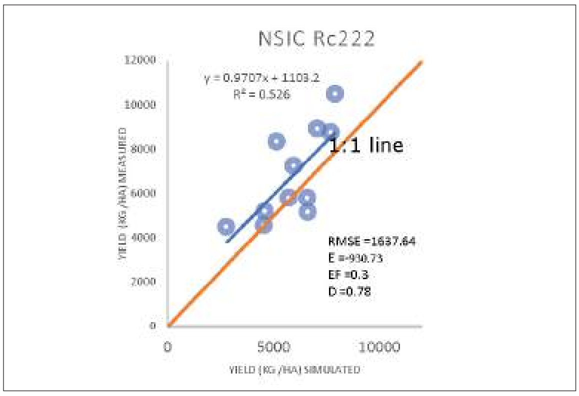


Figure 4. Scatter plot for the simulated vs. observed yield of NSIC Rc222 (check variety), WS 2018-WS 2021.

Conclusion

The validation results of the CERES-Rice models for five hybrids indicate that the models provided excellent predictions for maturity (phenology), with nRMSE values of less than 10%. While most hybrid parents also demonstrated excellent predictive accuracy (nRMSE < 10%), some, particularly the restorer lines IR34686, IR73013R, and SN758 and the maintainer line IR58025B, showed fair performance, with underestimation of maturity dates.

For grain yield predictions, most hybrids achieved excellent accuracy, with nRMSE values below 10%. However, Mestizo 1 exhibited only fair predictability. Most parent lines showed excellent to fair predictability, except for the maintainer lines IR58025B and IR79128B, which showed poor performance (nRMSE > 20%). This poor performance was traceable to the impact of Typhoon Ompong, which affected the experiments during the reproductive stage in September 2018.

Simulated harvest index (HI) did not align well with the observed data for any of the test genotypes, likely due to the waterlogged conditions under which the crops were cultivated. Under such conditions, HI may remain relatively constant, although it can be improved through enhanced water use efficiency (WUE) via controlled or intermittent soil drying (e.g., AWD), which may increase grain yield.

Sensitivity analysis further showed positive outcomes. Regression analysis indicated that the crop models for hybrids and parents, simulated across locations, seasons, and years, were responsive to climate variability and seasonal changes. R^2 values indicated a good to near-perfect fit for most genotypes, except for IR34686 and TG102M. The correlation coefficient (r) showed a strong association between simulated and observed yields for all 14 genotypes, with none falling below 0.5. The index of agreement (D) ranged from 0.63 to 0.90, above the typical acceptability threshold of 0.5, indicating acceptable model performance across all crop models.

However, EF did not always align with D, likely due to EF's sensitivity to outliers. Only three genotypes—Mestiso 73, Mestiso 32, and IR68897B—showed acceptable EF values (0.53, 0.61, and 0.61, respectively).

The calibrated CERES-Rice models, validated and tested for sensitivity across diverse locations and climate conditions, can be considered robust, particularly when evaluated using the index of agreement (D), which effectively captures additive and proportional differences between the means and variances of observed and simulated yields. These crop models are recommended for use in predicting yields in target environments before planting, provided that minimum datasets are properly encoded in the DSSAT-CSM system. The models can serve as valuable decision-support tools for crop genetic improvement and crop management. Further simulations using these crop models in additional multi-location trials across the country are recommended to further refine model fitness and applicability.

Acknowledgment

The authors gratefully acknowledge the financial support provided by the Department of Agriculture - Bureau of Agricultural Research (DA-BAR) for this study, which was implemented by the PhilRice Central Experiment Station and its branch stations in Ilocos Norte, Isabela, and Agusan del Sur. We extend our special appreciation to the collaborating agencies, including DA-WESVIARC in Iloilo and SPAMAST in Digos City, for their vital role in conducting the multi-environment trials (MET) of the cultivars studied. We also especially recognize our colleagues, John Oscar S. Enriquez and Joanne D. Caguiat, for their valuable contributions in leading the conduct of the MET trials and providing data from the experimental stations.

Literature Cited

Barik T, Jena SN, Bastia DK, Behera B (2012) Practical manual on crop simulation modeling. Orissa University of Agriculture and Technology

Benbi DK, Brar JS (2009) A 25-year record of carbon sequestration and soil properties in intensive agriculture. Agronomy for Sustainable Development ***29***(2): 257 - 265

Chidthaisong A, Cha-un N, Rossopa B, Buddaboon C, Kunuthai C, Sriphirom P, Towprayoon S, Tokida T, Padre AT (2018) Evaluating the effects of alternate wetting and drying (AWD) on methane and nitrous oxide emissions from a paddy field in Thailand. Soil Science and Plant Nutrition ***64***(1): 1 - 8

David CC, Balisacan AM (1995) Philippine rice supply demand: Prospects and policy implications. Philippine Institute for Development Studies. Discussion paper series 1995(28)

De Almeida DRA, Nelson BW, Schietti J, Görgens EB, Resende AF, Stark S, Valbuena R (2016) Contrasting fire damage and fire susceptibility between seasonally flooded forest and upland forest in the Central Amazon using portable profiling LiDAR. Remote Sensing of Environment ***184(A)***: 153 - 160

Ehlers W, Goss M (2003) *Water dynamics in plant production.* CABI Publishing

Fitter AH, Hay RKM (2012) *Environmental physiology of plants.* Academic Press

Fox DG (1981) Judging air quality model performance. Bulletin of the American Meteorological Society ***62***: 599 - 609

Gomez KA, Gomez AA (1984) *Statistical procedures for agricultural research* (2nd edition). John Wiley & Sons

Gong Y, Zhang J, Gao J, Lu J, Wang J (2005) Slow export of photoassimilate from stay-green leaves during late grain-filling stage in hybrid winter wheat (*Triticum aestivum* L.). Journal of Agronomy and Crop Science ***191***: 292 - 299

Gonzales L (2013) Global cost and price competitiveness of Philippine rice. FAO regional rice initiative pilot project, Philippines

He J, Porter C, Wilkens P, Marin F, Hu H, Jones JW (2001) Generalized likelihood uncertainty analysis tool for genetic parameter estimation (GLUE Tool. International Center for Soil Fertility and Agricultural Development, International Consortium for Agricultural Systems Application. ***4***: 21 -32

Hoogenboom G, Paul WW, Tsuji GY (1989) International Benchmark Sites Network for Agrotechnology Transfer. In PAN-EARTH Sub-Saharan Africa Workshop Report A129 - A139

Hoogenboom GW, Jones CH, Porter PW, Wilkens KJ, Boote WS (2007). Climate change 2007: Impacts adaptation and vulnerability. IPCC. Contribution of Working Group II to the Third Assessment Report of IPCC

Hundal SS, Kaur P (1996) Climate change and its impact on crop productivity in Punjab, India. Climate Variability and Agriculture

Irmak S, Haman DZ, Bastug R (2000) Determination of crop water stress index for irrigation timing and yield estimation of corn. Agronomy Journal ***92***(6): 1221 - 1227

Klepper O, Rouse DI (1991) A procedure to reduce parameter uncertainty for complex models by comparison with real system output illustrated on a potato growth model. Agricultural Systems ***36***(4): 375 - 395

Kobayashi K, Salam MU (2000) Comparing simulated and measured values using mean squared deviation and its components. Semigroup Forum ***92***(2): 345 - 352

Kumari M, Chakraborty D, Gathala MK, Pathak H, Dwivedi BS, Tomar RK, Garg RN, Singh R, Ladha JK (2011) Soil aggregation and associated organic carbon fractions as affected by tillage in a rice–wheat rotation in North India. Soil Science Society of America Journal ***75***(2): 560 - 567

Loague K, Green RE (1991) Statistical and graphical methods for evaluating solute transport models: Overview and application. (Journal of Contaminant Hydrology) ***7***(1-2): 51 - 73

Loague KM, Freeze RA (1985) A comparison of rainfall-runoff modeling techniques on small upland catchments. Water Resources Research ***21***(2): 229 - 248

Mi G, Tang L, Zhang F, Zhang J (2002) Carbohydrate storage and utilization during grain filling as regulated by nitrogen application in two wheat cultivars. Journal of Plant Nutrition ***25***: 213 - 229

Monod H, Naud C, Makowski D (2006) Uncertainty and sensitivity analysis for crop models. Working with dynamic crop models: Uncertainty and sensitivity analysis for crop models. Elsevie ***4***: 55 - 100

Nyang'au WO, Mati BM, Kalamwa K, Wanjogu RK, Kiplagat LK (2014) Estimating rice yield under changing weather conditions in Kenya using CERES Rice Model. International Journal of Agronomy ***2***: 1 - 12

Paruelo JM, Jobbagy EG, Sala OE, Lauenroth WK, Burke IC (1998) Functional and structural convergence of temperate grassland and shrubland ecosystems. Ecological Applications ***8***(1): 194 - 206

Probert ME, Dimes JP, Keating BA, Dalal RC, Strong WM (1998) APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. Agricultural System ***56***(1): 1 - 28

Van H, Wolf J (1986) Modelling of agricultural production: Weather, soils, and crops. Simulation Monographs. PUDOC

Vose D (1996) *Quantitative risk analysis*. Wiley

Wachholz de Souza CH, Mercante E, Johann JA, Camargo Lamparelli RA, Uribe-Opazo MA (2015) Mapping and discrimination of soya bean and corn crops using spectro-temporal profiles of vegetation indices. International Journal of Remote Sensing ***36*** (7): 1809 - 1824

Willmott CJ, Ackleson SG, Davis RE, Feddema JJ, Klink KM, Legates DR, O'Donnell J, Rowe CM (1985) Statistics for the evaluation and comparison of models. Journal of Geophysical Research Atmosphere ***90***(C5): 8995 - 9005

Yang J, Zhang J (2006) Grain filling of cereals under soil drying. New Phytologist Foundation ***169***(2): 223 - 236

Yang J, Zhang J (2010) Crop management techniques to enhance harvest index in rice. Journal of Experimental Botany ***61***(12): 3177 - 3189

Yebra M, Chuvieco E (2009) Linking ecological information and radiative transfer models to estimate fuel moisture content in the Mediterranean region of Spain: Solving the ill-posed inverse problem. Remote Sensing of Environment ***113***(11): 2403 - 2411

Zhu Q, Cao X, Luo Y (1988) Growth analysis on the process of grain filling in rice. Acta Agronomica Sinica ***14***(3): 182 - 193

RESEARCH NOTE

FIELD EVALUATION OF PHILRICE MULTI-CROP REDUCED - TILL PLANTER FOR MECHANIZED PEANUT SEEDING IN DIVERSIFIED RICE-BASED SYSTEMS

TYRONE C. JUGANAS*, ELMER G. BAUTISTA, RACHELLE MARIE S. MARTIN,
FRANCISCO IGNACIO M. RAMIREZ VIII, RONDIEL ALLAN S. RAMOS, AND KRISTINE SAMOY-PASCUAL*
Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
*Corresponding Author: tyronejuganas@gmail.com and kspascual@philrice.gov.ph

Abstract

Rising rice production costs in the Philippines exacerbated by erratic weather patterns, declining soil fertility, and volatile market prices, underscore the need for crop diversification in rice-based farming systems. Peanut (*Arachis hypogaea*), as a rotational crop, enhances soil fertility through biological nitrogen fixation and provides an additional income stream for farmers. However, the lack of suitable mechanized seeding technologies limits efficient peanut production, particularly for smallholder farmers. This study evaluated the PhilRice Multi-Crop Reduced-Till Planter (MCRTP) for mechanized peanut seeding. A baseline survey indicated common farmer practices, including a seeding rate of 50–60 kg ha^{-1} and a row spacing of 50 cm. Initial calibration revealed kernel damage when standard metering plates were used, prompting the adoption of plastic seed-metering components. Field trials showed that while the machine operated satisfactorily, the seeding rate (35.44 kg ha^{-1}) remained below the target range due to metering plate limitations. Nonetheless, performance testing demonstrated the MCRTP's adaptability for multi-crop use, achieving a field capacity of 0.39 ha hr^{1} (3.11 ha day^{-1}) and a field efficiency of 60.17%, surpassing the 55% benchmark for similar equipment. Further improvements such as optimizing metering plate geometry and adjusting the hopper angle are needed to improve seeding rate accuracy. Future studies should also explore reduced mechanized seeding rates (20–50 kg ha^{-1}) to determine the minimum rate that maintains plant population and yield. Overall, the MCRTP shows strong potential as a practical mechanized seeding solution for peanut establishment in diversified rice-based systems.

Keywords: *crop diversification, high value crops, mechanization, multi-crop reduced-till planter, peanut*

Introduction

Rice remains the primary staple food in the Philippines, sustaining millions of farmers and consumers. However, rice production has become increasingly vulnerable due to fluctuating weather patterns, climatic variability, soil nutrient depletion, and market instability. These factors contribute to declining yields and rising production costs, creating economic pressure on farmers and threatening the country's rice supply.

Crop diversification is recognized as a key strategy for improving resilience in rice-based systems. It enhances ecological stability, spreads risk across different crops, and supports soil health through nutrient cycling (Ijaz et al., 2019). Diversified farms often outcompete monocropped rice systems in terms of net returns, especially in marginal and rainfed areas (Pede et al., 2024). High-value legumes such as peanut (Arachis hypogaea L.) are particularly promising due to their nitrogen-fixing capacity, market demand, and suitability for dry-season planting (Guzman et al., 2011).

Despite its potential, peanut production in the Philippines remains constrained by labor-intensive seeding practices and limited access to mechanized planters (Launio et al., 2018). International studies have developed precision metering technologies for peanut planting, including vacuum and disk systems (Zhao et al., 2022; Guo et al., 2025). Locally, the Philippine Rice Research Institute (PhilRice) has developed affordable multi-purpose planters for rice, corn, and mungbean (Pascual et al., 2022), though these have not yet been evaluated for peanut.

Given the economic and agronomic importance of peanut and the need for cost-efficient mechanization, this study assessed the adaptability and field performance of the PhilRice Multi-Crop Reduced-Till Planter (MCRTP) for peanut seeding. The study aimed to (1) determine the machine's operational performance, (2) evaluate the suitability of existing metering plates for peanut seeds, and (3) identify areas for design improvement to support wider adoption in diversified rice-based systems.

Materials and Methods

Machine Adaptation and Preliminary Assessment

Interest in adapting the MCRTP for peanuts emerged after a visit by the Aramal Tocok FFF-MPC cooperative to PhilRice. Although originally developed for rice and later tested for corn and mungbean, the MCRTP had not previously been evaluated for peanut seeding. A validation activity was conducted in San Fabian, Pangasinan, a site characterized by sandy loam soil—an optimal texture for peanut growth (Collado et al., 2013). A baseline survey documented existing farmer practices, which served as benchmarks during machine calibration.

Machine Testing, Calibration, and Fine-Tuning

Calibration trials were conducted at PhilRice using peanut seeds sourced from the validation site. Rice and corn metering plates were initially tested following Pascual et al. (2022). Plastic metering components were adopted to prevent kernel cracking, with calibration performed across four rows (rows 1, 5, 7, and 9) at 50 cm spacing.

The seeding rate was determined using seed discharge obtained from ten revolutions of the 0.37 m diameter drive wheel (11.6 m travel distance; 2 m effective width). Laboratory calibration was exploratory and served only to refine machine settings prior to field testing.

Following laboratory adjustments, field trials were implemented on two farmer-managed plots (200 m^2 and 450 m^2). Observations included row spacing, seed depth, hill spacing, seeds per hill, percentage of missing hills, seed damage, and distribution uniformity. Farmer feedback on ergonomics, handling, and maneuverability was also recorded.

Machine Fabrication and AMTEC Testing

Modifications to the seed metering plate and depth control mechanism were finalized and fabricated by ACT Machineries, Inc. The MCRTP then underwent standardized performance evaluation at the Agricultural Machinery Testing and Evaluation Center (AMTEC) test site in Cauayan, Isabela (1,550 m^2 test area). In the absence of a Philippine Agricultural Engineering Standard (PAES) specific to peanut seeders, evaluation emphasized uniformity, seed integrity, and reduced soil disturbance.

Technology Deployment

Following evaluation, the MCRTP was deployed to Aramal Tocok FFF-MPC for field use. Cooperative operators were trained on machine operation and maintenance. Performance monitoring and feedback collection continued under real farm conditions.

Data Collection and Analysis

Seeding Rate. Seeding rate was calculated using standard MCRTP computations (Pascual et al., 2022):

$$C = \pi D(10\ \textit{revolutions of the drive wheel}) \qquad (1)$$

D = diameter of the drive wheel

The seeding rate was calculated using the following data:

$$\textit{Seed rate} = \left[\frac{S_w}{C_d\ x\ W_d}\right] \qquad (2)$$

S_w = the total weight of seed released in 10 revolutions of the drive wheel (g)

C_d = divided by the product of drive wheel circumference

W_d = width of the machine (m)

This study did not employ inferential statistics. Results are descriptive, based on observed values from pilot trials intended to establish feasibility and shape follow-up designs.

Results and Discussion

Field Testing and Calibration

San Fabian farmers in Pangasinan typically plant peanuts twice per season using manual methods, with 50 cm row spacing and seeding rates of 50–60 kg ha^{-1}. The soil, a clay loam Alfisol with shrink–swell properties, is common in areas with pronounced wet and dry seasons (Collado et al., 2013).

Initial calibration produced a seeding rate of 25.86 kg ha^{-1}, which is lower than farmer practice but comparable to ranges reported in studies of metering mechanisms for peanut (Prajapati et al., 2020). This suggests functional viability but signals the need for optimization.

Field trials showed satisfactory machine operation, with no missing hills, seed damage, or traction issues. Farmer observations highlighted the effectiveness of the line seeding, furrow opener, and furrow closer. Using the corn seed plate produced a seeding rate of 30.77 kg ha^{-1}, while the rice plate produced an excessive rate of 278 kg ha^{-1} due to its 16 holes spaced at 2.80 cm, compared to 7 holes at 6.50 cm for the corn/mungbean plate. These findings indicate that peanut-specific metering plates are necessary for accurate delivery.

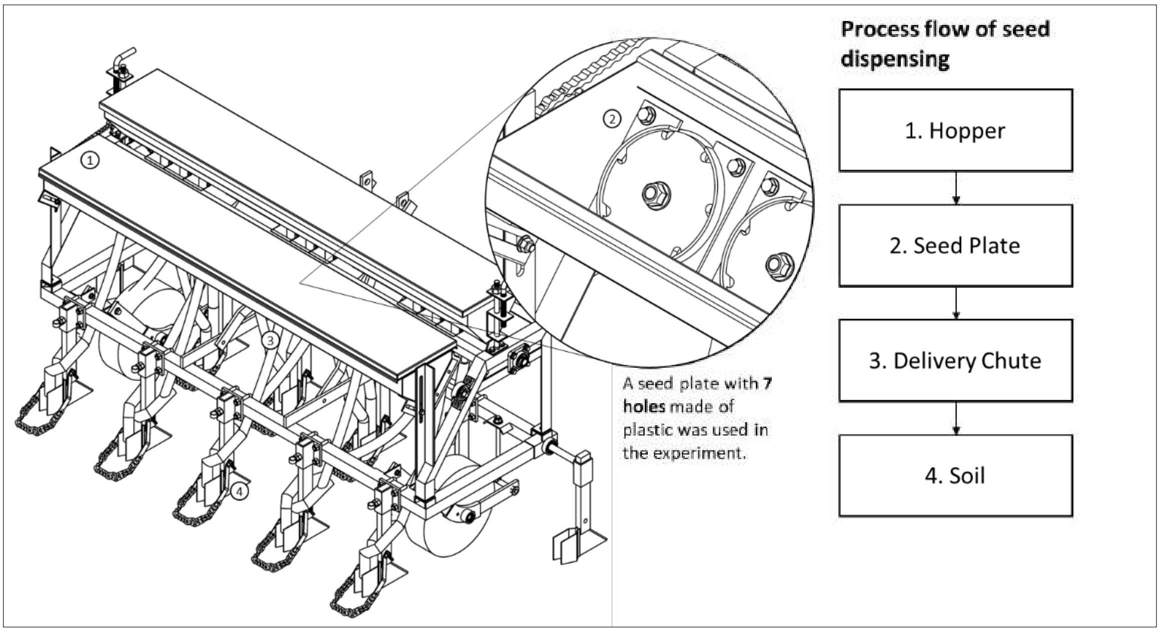
Field Testing Using the Modified MCRTP

AMTEC evaluation confirmed the operational suitability of the MCRTP for mechanized peanut planting. The machine achieved an actual field capacity of 0.39 ha hr^{-1} (3.11 ha day^{-1}) and a field efficiency of 60.17%, exceeding the 55% benchmark for tractor-powered row-crop planters. The achieved seeding rate (35.44 kg ha^{-1}) was 29.12% below the target, but adjusting the metering strip to a 45° angle may increase the rate. Other performance indicators such as row spacing, depth, hill spacing, seed count per hill, seed damage, and missing hills were within acceptable operational ranges (Table 1). These findings demonstrate good adaptability to rice-based cropping systems.

Table 1. Summary of the AMTEC test results for the MCRTP in peanut seeding.

Performance Criteria	Requirement as per PAES 122:2001	AMTEC Test
Actual Field Capacity, ha/hr	0.40[a]	0.39
Delivery Rate, kg/ha	ND[a]	35.44
Uniformity of work	ND[b]	
a. row spacing, mm	ND[b]	311 +/- 3.54
b. depth of seeding, mm	ND[b]	71 +/- 8.08
c. distance between hills, mm	ND[b]	242 +/- 80.68
d. number of seeds per hill	ND[b]	1.00
e. damaged seed, %	ND[b]	0.00
f. missing hill, %	ND[b]	37.60
Field Efficiency, %, minimum	55.00[c]	60.17

Legend:
[a] as specified by the test applicant
[b] not specified by the test applicant
[c] requirement for tractor power-driven with row-crop planter with fertilizer applicator
Note: ND- No Data



A seed plate with **7 holes** made of plastic was used in the experiment.

Figure 1. Isometric drawing of the MCRTP and its seed delivery component.

Figure 2. Field testing of the MCRTP in Cauayan, Isabela.

Table 2. Other observations during the AMTEC test results for the MCRTP in peanut seeding.

Parameter	**Observation / Specification**
General specifications	
Prime mover	34.0 kW ARBOS P504-3 Four-Wheel Tractor
Number of operators	One
Hoppers utilized	5 of 9 available
Field operation and performance	
Travel path	Seeder traveled a relatively straight path when hitched
Turning stability	Stable when lifted via the tractor's three-point linkage
Refilling	Not required during the test operation
Failures/abnormalities	None observed
Adjustability and controls	
Seed discharge rate	Adjusted by replacing the seed plate
Seeding depth	Controlled via the tractor's position control lever
Row spacing	Adjusted by moving the furrow opener assembly laterally
Independent row suspension	Not provided
Construction and safety	
Primary materials	Steel frame; 303/304 stainless steel hoppers; iron/carbon steel furrow opener and wheel
Seed plate	Locally fabricated and replaceable
Ease of handling	Operator could maneuver the machine without issues
Blockages	None occurred during testing
Manufacturing quality	Free from defects, sharp edges, and properly painted
Safety notices	Not provided on the seeder
Remarks	
Fertilizer applicator	Equipped but not tested

Conclusion

Field evaluation of the MCRTP demonstrated that the machine can satisfactorily establish peanut crops within rice-based systems, operating with minimal missing hills, negligible seed damage, and a field efficiency of 60.17%, which exceeds the benchmark for comparable equipment. Although the achieved seeding rates (30.77–35.44 kg ha^{-1}) were lower than the farmer-preferred 50–60 kg ha^{-1}, the machine's consistent seed placement, stable traction, and reliable row formation indicate functional suitability for mechanized peanut establishment. Determining whether these reduced seeding rates are agronomically acceptable now requires yield assessment under field conditions.

The findings support the MCRTP as a viable mechanized option for peanut planting, provided that further refinements—particularly in metering plate geometry and hopper angle—are undertaken to improve seeding rate accuracy. Future research should include multi-site, multi-season trials that jointly evaluate emergence, plant population, yield performance, and cost efficiency to guide recommendations for broader adoption in diversified rice-based systems.

Acknowledgment

The authors extend their profound gratitude to all individuals who significantly contributed to the successful execution and implementation of this study. This includes the researchers, laborers, and technical advisors, whose expertise and efforts were critical in the retrofitting of the MCRTP for peanut seeding. Special acknowledgment is given to the Department of Agriculture – Regional Field Office I (DA-RFO I), Mr. Saturnino Distor, the Aramal Tocok FFF-MPC, and ACT (Machineries & Metalcraft) Inc. for their collaborative engagement. The PhilRice management is also acknowledged for its steadfast support and guidance throughout the project. This study was carried out under the leadership of the REMD-TPG. .

Literature Cited

Agricultural Machinery Testing and Evaluation Center (AMTEC) (2001) Philippine Agricultural Engineering Standard (PAES) ***122***: A93 – A101. Retrieved from https://amtec.uplb.edu.ph/wp-content/uploads/2020/06/PNS-PAES-122-2001-Agricultural-Machinery-Seeder-and-Planter-Specifications.pdf (accessed April 14, 2025)

Collado WB, Monteza RM, Dollentas RT, De Dios JL, Dela Torre JP, Bibar JD, Badayos RB, Soliman AE (2013) Simplified Keys to Soil Series. Philippine Rice Research Institute. Retrieved from https://www.philrice.gov.ph/wp-content/uploads/2015/08/Simplified-Keys-to-Soil-Series-Pangasinan.pdf (accessed January 24, 2025)

de Leon TJP and Manalo, JA IV (2024) Affordances in crop diversification: Three cases from the Philippines. Asian Journal of Agriculture and Rural Development ***14***(2): 34 - 50

Guo P, Sun B, Shang S, Hou J, Wang D, Zhao Z, Elshafie Z, Zheng X, Eltoum F (2025) Effect of Auxiliary Air-Suction Seed-Filling Structure on Seed Discharge Performance of Peanut High-Speed Seed-Metering Machine. Agriculture: ***15***(15): 1678

Guzman RB, Madamba JB, Banzon AT, and Zapata NR (2011) Revitalizing Peanut Farming in Enrile, Cagayan, Philippines ***8***: 47 - 63

Ijaz M, Nawaz A, Ul-Allah S, Rizwan MS, Ullah A, Hussain M, Sher A, Ahmad S (2019) Crop Diversification and Food Security. *In* Hasanuzzaman, M. (ed) Agronomic Crops. Springer, Singapore. Retrieved from https://doi.org/10.1007/978981-32-9151-5_26 (accessed October 2, 2025)

Launio CC, Luis JS, and Angeles YB (2018) Factors influencing adoption of selected peanut protection and production technologies in Northern Luzon, Philippines. Technology in Society, Elsevier ***55***: 56 - 62

Litonjua A, Malabayabas MD, Pascual KS, de Dios JL, Corales RG, Nojor NL, Matia AB, Beltran JC, Manalo, JA, Manalili M, Baltazar M (2024) Crop diversification mitigates climate change impacts. Rice Science for Decision-Makers. ***13***

Pascual KS, Rafael ML, Remocal, AT, and Regalado, MC (2022) DA-PhilRice Multicrop Reduced-till Planter Operational Guidebook for Rice, Corn, and Mungbean. Philippine Rice Research Institute

Pede VO, Mohammed S, Valera HG, Ibrahim M, Antonio, RJ (2024) Livelihood diversification and household welfare among farm households in the Philippines. Agricultural Economics, ***55***(6): 1040 - 1056

Prajapati, M. M., Varshney, A. C., Tiwari, R., & Sharma, S (2020) Performance evaluation of different seed metering mechanisms with dry and soaked groundnut seed. International Journal of Current Microbiology and Applied Sciences ***9***(9): 2681 - 2691

Zhao X, Ran W, Wao J, Bai W and Yang X (2022) Design and experiment of the double-seed hole seeding precision seed metering device for peanuts. International Journal of Agricultural and Biological Engineering, ***15***(3): 107 - 114

RESEARCH NOTE

DETERMINATION OF OPTIMAL ANNEALING TEMPERATURE AND PRIMER SELECTION FOR PCR-BASED DETECTION OF *NIF*H GENE IN NITROGEN-FIXING BACTERIA

Cielo Luz C. Mondejar[1]*, Myan Ace Paola A. Villanueva[2], and Jayvee C. Kitma[2,3]

[1]Philippine Rice Research Institute Cansilayan, Murcia, 6129 Negros Occidental, Philippines
[2]Crop Biotechnology Center, Science City of Muñoz, 3119 Nueva Ecija, Philippines
3 Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
*Corresponding author: clcmondejar@exchange.philrice.gov.ph

Abstract

Efficient detection of the *nifH* gene is essential for characterizing nitrogen-fixing bacteria in agricultural soils, including rice paddies under varying nitrogen (N) conditions. This study aimed to optimize Polymerase Chain Reaction (PCR) conditions, specifically primer selection, annealing temperature, and cycling parameters, for reliable amplification of *nifH* genes in bacterial isolates collected from rice fields with low and sufficient N inputs. Seven primer sets were tested under three annealing temperatures (52.5°C, 55.0°C, and 57.5°C). Amplification success was assessed by agarose gel electrophoresis. Among the temperatures tested, 52.5°C consistently supported successful amplification for most primer sets. Primer 5 (*nifH*-g1-forB/rev) showed specific and reproducible amplification at 52.5°C, whereas the performance of other primers varied across temperature treatments. DNA extracted from isolates collected across sites and nitrogen regimes showed successful *nifH* gene detection. All *nif*-positive samples were further amplified using 16S rDNA primers for validation. The optimized PCR protocol enhances the sensitivity and accuracy of *nif* gene detection. The findings support robust profiling of diazotrophic communities that are important for sustainable agriculture and soil fertility management.

Keywords: *functional gene detection, nifH gene, nitrogen-fixing bacteria, PCR optimization, soil microbriome*

Introduction

The Polymerase Chain Reaction (PCR) is a cornerstone of molecular biology because of its ability to selectively amplify specific DNA sequences. Its reliability and efficiency, however, depend strongly on the optimization of reaction parameters such as annealing temperature, primer concentration, magnesium ion concentration, enzyme type, and cycle number. Inadequate optimization can result in non-specific amplification, low DNA yield, or complete reaction failure, thereby compromising downstream analyses (Dieffenbach & Dveksler, 2003; Kennedy & Oswald, 2011).

Optimization becomes particularly critical when detecting functional genes such as *nif* genes, which encode components of the nitrogenase enzyme complex involved in biological nitrogen fixation. These genes are widely used as molecular markers for studying diazotrophic microorganisms in agricultural soils, rhizospheres, and other ecological niches, and are important indicators for sustainable agriculture and ecosystem nitrogen cycling. Precise amplification of *nif* genes is therefore vital for characterizing nitrogen-fixing microbial communities.

Amplification of *nif* genes presents unique challenges. Sequence variability across bacterial taxa and often low template concentrations in environmental samples demand highly specific and sensitive PCR protocols. Poorly optimized assays may yield inconsistent or non-specific amplification and misrepresent the presence or abundance of *nif*-carrying microbes (Asif et al., 2021). PCR success depends largely on the efficiency and specificity of primer–target interactions and on reaction conditions that support those interactions.

In this study, available amplification protocols were evaluated for primers designed to target *nif* genes. The amplification performance of these primer sequences was assessed to determine their reliability and reproducibility. A systematic approach to PCR optimization tailored to *nif* gene detection is crucial to ensure accurate, reproducible results that support microbial profiling, ecological assessments, and biotechnological applications in agriculture and environmental monitoring. The general objective of this study was to optimize PCR reaction conditions including annealing temperature and primer sets, for specific and efficient detection of *nif* genes in environmental microbial samples; thereby, enhancing the accuracy and reproducibility of nitrogen-fixing bacterial identification.

Materials and Methods

Bacterial Genomic DNA Extraction

Purified bacterial isolates from Burk's agar plates were transferred into test tubes containing Burk's broth and incubated at 37°C overnight to ensure sufficient growth. For DNA extraction, 1000 µL of Burk's broth was placed into sterilized microcentrifuge tubes, and each isolate was inoculated using sterilized sticks. The cultures were incubated overnight at 30°C with shaking, then centrifuged to harvest the cells. Pellets were resuspended in an extraction buffer, vortexed, and incubated at 65°C for 1 h. Potassium acetate was added, and the samples were chilled on ice, then centrifuged. The lysate was transferred to new tubes, and DNA was precipitated using ice-cold isopropanol. After centrifugation, the DNA pellets were washed with 70% ethanol, air-dried, and resuspended in TE buffer. DNA was extracted following the method of Hoorzook and Barnard (2022) with slight modifications and extracted DNA was stored at -20°C (Nguyen et al., 2018).

DNA Quantification and DNA Quality Checking

The concentration and purity of the extracted DNA were measured using a spectrophotometer by recording absorbance at 260 nm and 280 nm based on the protocol by Sambrook et al. (1989). The 260/280 ratio was used to assess protein contamination. The TE buffer was the blank for calibration before measuring each 2 µL DNA sample. To evaluate DNA quality, a 1.5% agarose gel electrophoresis was performed. Agarose was dissolved in a 1X TAE buffer, cooled, and mixed with a nucleic acid stain before being poured into a gel tray. DNA samples were mixed with loading dye, briefly centrifuged, and loaded into the gel wells alongside lambda DNA (50 ng and 100 ng) and a 1 kb ladder. The gel was run for 1 hour and visualized using a gel documentation system.

Polymerase Chain Reaction (PCR) Optimization and Checking of Bands using Agarose Gel Electrophoresis

For PCR optimization, working stocks of DNA were prepared by diluting the extracted DNA to approximately 100 ng/µL. Then, 2 µL of each DNA sample was pipetted into a labeled 96-well PCR plate. The amplification efficiency and specificity of seven (7) primer sets (Table 1), designated Primer 1 through Primer 7, were evaluated, using a standardized annealing temperature of 52.5°C. The seven primer sets were selected based on their reported specificity and successful application on previous studies involving soil microbiomes and nitrogen-fixing bacterial communities associated with rice. Each primer pair targets functionally relevant genes to capture key microbial groups involved in nitrogen cycling. Primer 3 is a 165S rDNA gene primer used as control or check for primers. A negative control labeled "BLANK," containing all PCR reagents except for the DNA template, was included to detect potential contamination or non-specific amplification. A 1-kilobase (kb) DNA ladder was loaded in the leftmost lane of each gel section to serve as a molecular size marker, allowing accurate estimation of the amplified product sizes.

PCR amplification was performed in a total reaction volume of 7.5 µL. Each reaction mixture contained 1X PCR Buffer, 0.5 mM MgCI2, 0.1 mM dNTP, 0.5 uM of each forward and reverse primer, 0.2 u of of Taq DNA Polymerase and adjusted volume to 7.5 ul using water.

After preparing the PCR master mix, it was gently vortexed and briefly centrifuged to collect the contents at the bottom of the tube. The appropriate volume of the PCR mix was then added to each well of the PCR plate containing 2 µL of DNA template. The plate was centrifuged briefly to ensure all contents settled at the bottom.

PCR amplification was performed using a thermal cycler with the following program: an initial denaturation at 95°C for 2 min; 35 cycles of denaturation at 95°C for 15 sec; annealing under three annealing temperatures (52°C, 55°C, and 57°C) for 15 sec; extension at 72°C for 2 min; followed by a final extension at 72°C for 5 min. The reactions were then held at 4°C.

Image Analysis and Statistics

Band intensities were quantified using ImageJ/FIJI by measuring integrated density or mean gray value of each band. For each gel, a blank or empty lane was used to estimate background signal. Band intensity was corrected by subtracting each band's raw gray mean value to gray mean value of estimated background signal (Tomlinson et al. 2024), using the formula: Corrected Band Intensity = Raw Band Intensity – Blank Intensity. Corrected band intensities were then normalized to the reference band (ladder band of the expected product size of the primer used) to correct variability in loading or imaging. Normalized intensity was computed using the formula: Normalized Intensity = Corrected Band Intensity / Ladder Band Intensity. This approach was analogous to the quantitative densitometry used in gel electrophoresis analysis of Vohradský and Pánek (1993). Analysis of variance (ANOVA) was performed to compare mean gray values of bands across isolates, primer sets, and annealing temperatures. A t-test was used to compare the mean gray value of visible bands obtained using *nif* and 16S primers.

Table 1. Primer sequences used for PCR optimization.

Primer Number	Primer Name	Primer Sequences	Molecular Weight	Expected Product Size	References
Primer 1	27F	5′-AGAGTTTGATCMTGGCTCAG-3′	6,160.0	1,500 bp	Screening of nitrogen fixing endophytic bacteria in *Oryza sativa* L. (Hongrittipun et al., 2014)
	1525R	5′-AAGGAGGTGWTCC ARCC-3′	5,232.0		
Primer 2	357F	5′-CTCCTACGAGGCAGG-3′	4,578.0	1,000-1,400 bp	Screening of nitrogen fixing endophytic bacteria in *Oryza sativa* L. (Hongrittipun et al., 2014)
	1392R	5′-ACGGGCGGTGTGTAC-3′	4,649.1		
Primer 3	16SF	5′-AGAGTTTGATCCTGGCTCAG-3′	6,148.0	1,500 bp	Selection of nitrogen fixation and phosphate solubilizing bacteria from cultivating soil samples of Hung Yen province in Vietnam (Ha et al., 2020)
	16SR	5′-TACGGTTACCTTGTTACGACTT-3′	6,691.4		
Primer 4	PPf	5′-GCAAGTCCACCACCTCC-3′	5,060.3	350-400 bp	Molecular characterization of free-living N_2-fixing bacteria isolated from agricultural soils of North Gujarat, India (Patel et al., 2022)
	PPr	5′-TCGCGTGGACCTTGTTG-3′	5,208.4		
Primer 5	nifH-g1-forB	5′-GGTTGTGACCCGAAAGCTGA-3′	6,182.1	359-370 bp	Putative nitrogen-fixing bacteria associated with the rhizosphere and root endosphere of wheat plants grown in an Andisol from southern Chile (Rilling et al., 2018)
	nifH-g1-rev	5′-GCGTACATGGCCATCATCTC-3′	6,053.0		
Primer 6	FGPS6F	5′-GGAGAGTTAGATCTTGGCTCAG-3′	6,830.5	1,500 bp	Isolation, identification and characterization of efficient free-living nitrogen-fixing bacteria from rice rhizosphere ecosystem (Bandeppa et a., 2019)
	FGPS1509R	5′-AAGGAGGGGATCCAGCCGCA-3′	6,201.1		
Primer 7	27F	5′-AGAGTTTGATCCTGGCTCAG-3′	6,148.0	1,500 bp	Isolation and identification of phosphate-solubilizing and nitrogen-fixing bacteria from Lake Ol'Bolossat sediments, Kenya (Wafula & Murunga, 2020)
	1492R	5′-GGTTACCTTGTTACGACTT-3′	5,784.8		

Results and Discussion

*Comparison of nif*H *Gene Amplification Between Different Annealing Temperatures*

DNA templates used in the reactions were extracted from soil-derived bacterial isolates collected from two experimental stations of PhilRice: Central Experiment Station (CES) and PhilRice Negros. Samples labeled SN2, SN5, SN11, SN12, SN13, and SN14 represent DNA from CES grown under sufficient N input. Samples SNN1, SNN3, and SNN5 represent DNA extracted from PhilRice Negros under sufficient N input, whereas LNN1 and LNN8 represent DNA extracted from PhilRice Negros under low N input.

Agarose gel electrophoresis (AGE) results show successful amplification for most primer sets using 52.5°C as annealing temperature (Figure 1). Clear, distinct bands of the expected sizes were observed for Primer 1 (27F & 1525R), Primer 3 (16SF & 16SR), Primer 6 (FGPS6 & FGPS1509), and Primer 7 (27F & 1492R), indicating high specificity and strong amplification efficiency. Primer 5, which targets a region of the *nif*H gene using nifH-g1-forB and

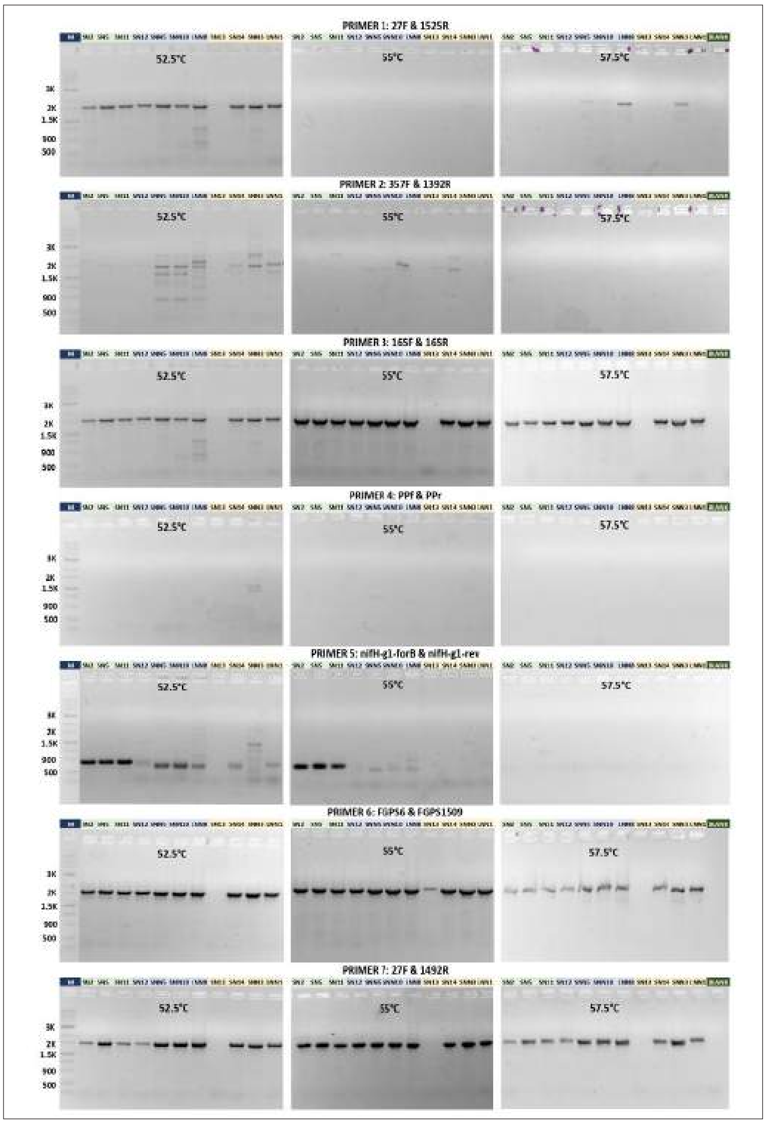


Figure 1. PCR optimization of seven primers using 57.5°C as annealing temperature and a 1 kb ladder as a molecular size marker. *SN samples – PhilRice CES Sufficient N input; LN samples – PhilRice CES low N input. *SNN samples – PhilRice Negros Sufficient N input; LNN samples – PhilRice Negros low N input.

nifH-g1-rev primers, also produced clearly visible amplification products, confirming its effectiveness under the chosen conditions. Notably, all BLANK lanes showed no amplification, confirming that there was no contamination and that non-template-dependent amplification did not occur. Using the same set of 7 primers under higher annealing temperature, AGE results indicate successful amplification for most primer sets at 55°C.

Distinct bands of the expected sizes were consistently observed for Primer 1, Primer 3, Primer 6, and Primer 7, indicating high specificity and efficient amplification. Primer 5 (nifH-g1-forB & nifH-g1-rev) SN2, SN5, and SN11 are the only samples able to yield clear amplification products. For the same seven primer sets under an elevated annealing temperature of 57.5°C, the gel electrophoresis results reveal continued successful amplification for Primer 3 and Primer 7, with clear and specific bands of expected sizes, indicating good amplification performance. Primer 5 (nifH-g1-forB & nifH-g1-rev) yielded no visible PCR bands, suggesting reduced efficiency or specificity at this higher temperature. Similarly, Primer 2 and Primer 4 showed no amplification across all samples, indicating suboptimal performance under these conditions. Importantly, all BLANK lanes remained band-free, confirming the absence of contamination or non-template amplification. These findings suggest that while 57.5°C supports efficient and specific amplification for most primer sets, it may not be optimal for all, particularly those targeting nif genes or less conserved regions.

The analysis of variance of normalized band intensity revealed highly significant effects ($p < 0.01$) of temperature, primer, and isolate. Significant interaction effects ($p < 0.01$) were also observed between temperature and isolate, as well as between primer and isolate. In contrast, the interaction between temperature and primer was not statistically significant.

The normalized mean gray values of bands amplified at three different annealing temperatures (52.5, 55, and 57.5°C) are shown in Figure 2. The highest band intensity was observed at 52.5°C, with a mean gray value of approximately 5.0. Its band intensity is significantly higher than the two annealing temperatures, 55 and 57.5°C, indicating optimal primer annealing and efficient amplification under these conditions. These results highlight the importance of optimizing annealing temperature in PCR protocols, as suboptimal temperatures can lead to reduced yield or weak band intensity, potentially compromising downstream analysis. Overall, 52.5°C appears to be the most suitable annealing temperature for the seven primer sets used in this study, providing the strongest and most consistent amplification signal.

The normalized mean gray values of bands varied significantly among the seven primers tested (Figure 3), indicating differences in amplification efficiency. Primer 3 produced the highest mean gray value (~5.5), significantly greater than all other primers except Primer 7. Primer 5 also showed relatively high band intensity that are significantly different from most other primers. Primer 4 and 2 exhibited the lowest mean gray values, suggesting poor amplification efficiency. Intermediate performance was observed for Primers 1 and 6, indicating moderate amplification capacity. The statistical analysis revealed five distinct groupings, which support the idea that primer selection has a significant effect on band intensity and PCR success. These results emphasize the importance of primer screening during PCR optimization. Primers such as Primer 3 and 5 may be preferred for downstream applications requiring strong and consistent amplification, whereas poorly performing primers may need redesign or further validation.

Comparison of nif*H *Gene Amplification Between Seven Primer Sets

Detecting *nif* genes using an annealing temperature of 52.5°C resulted in visible bands in across samples or isolates (Figure 4). From the PhilRice CES site under sufficient-N input, *nif* gene amplification was detected in samples SN2, SN5, SN10, SN11, SN12, SN14, and SN21. Under low-N input, bands were observed in samples LN7, LN10, LN11, and LN14. At PhilRice Negros, *nif* amplification was observed in samples SNN2, SNN3, SNN5, and SNN7 under sufficient-N input, and in samples LNN3, LNN4, LNN8, and LNN9 under low-N input.

All *nif*-positive samples were subsequently subjected to PCR amplification using 16S rDNA gene primers. Optimal amplification was observed at 52.5°C as annealing temperature (Figure 5), suitable for sequencing for molecular identification. No significant difference between the gray mean values of visible bands amplified using *nifH* and 16S rDNA primers.

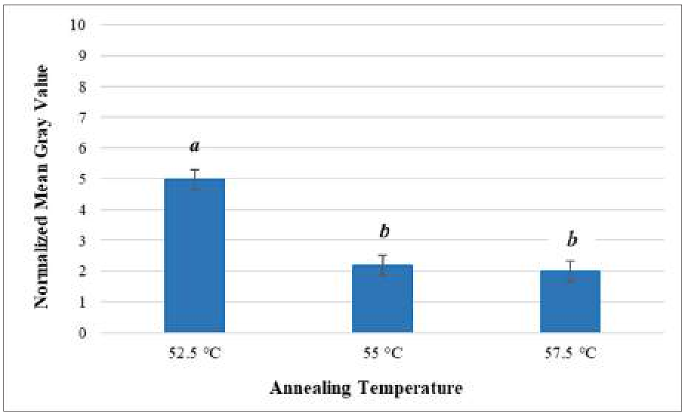


Figure 2. Normalized mean gray values of bands generated using seven primers at annealing temperatures of 52.5, 55, and 57.5 °C.

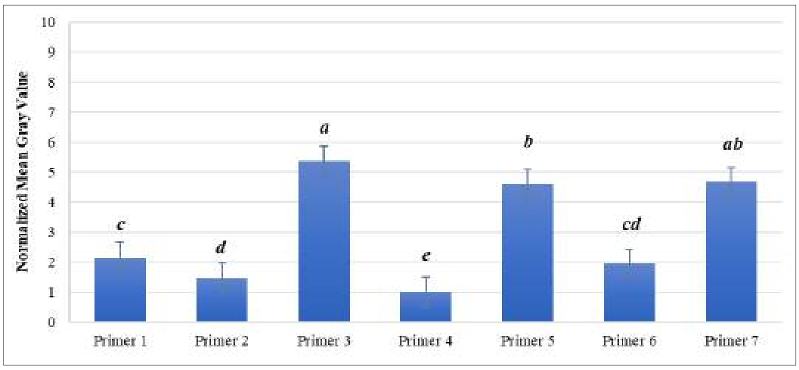


Figure 3. Normalized mean gray values of bands generated across seven primers.

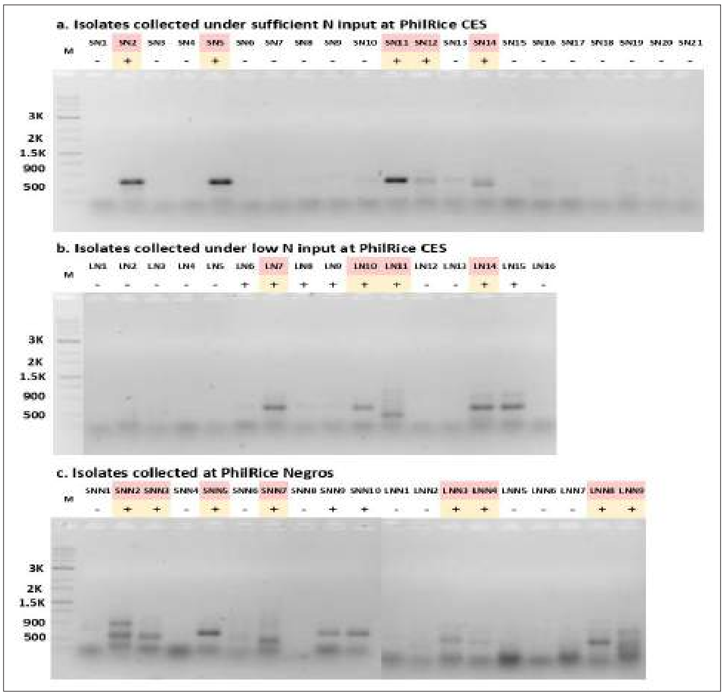


Figure 4. PCR detection of *nif* gene primers using 52.5°C as annealing temperature and a 1 kb ladder as a molecular size marker. *SN samples – PhilRice CES Sufficient N input; LN samples – PhilRice CES low N input. *SNN samples – PhilRice Negros Sufficient N input; LNN samples – PhilRice Negros low N input.

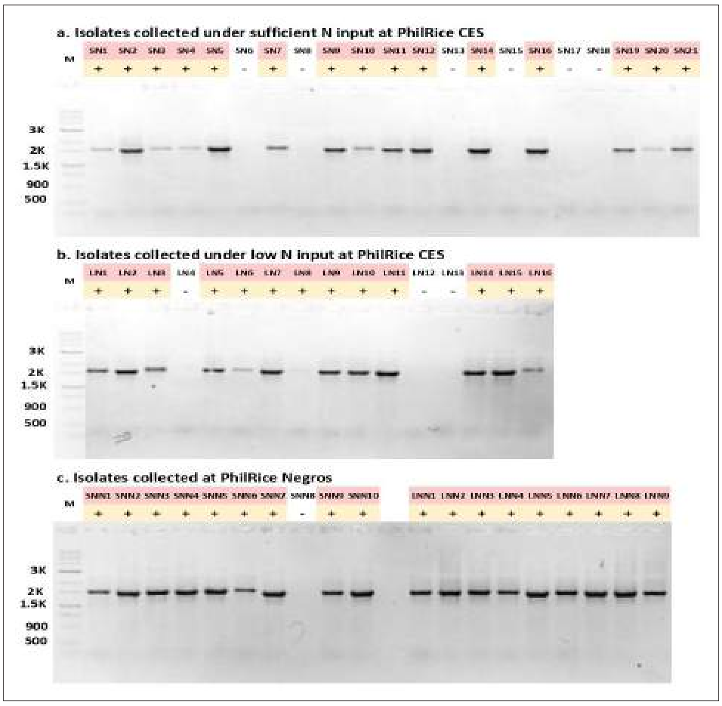


Figure 5. PCR amplification of 16SF and 16SR primers using 52.5°C as annealing temperature and a 1 kb ladder as a molecular size marker. *SN samples – PhilRice CES Sufficient N input; LN samples – PhilRice CES low N input. *SNN samples – PhilRice Negros Sufficient N input; LNN samples – PhilRice Negros low N input.

Conclusion

This study successfully optimized PCR conditions for amplifying the *nifH* gene in nitrogen-fixing bacterial isolates from rice fields with different nitrogen inputs. Among the seven primer sets tested, Primer 5 (*nifH-g1*-forB/rev) consistently demonstrated effective and specific amplification of *nif*H genes, particularly at an annealing temperature of 52.5°C. Optimal amplification was also observed for 16S rRNA primers but need further verification from DNA sequencing. This supports downstream molecular identification of the isolates. Using samples from low and sufficient nitrogen input conditions allows the identification of *nif*-positive isolates across diverse soil environments. This study's successful optimization of PCR conditions enables reliable detection of functional genes and accurate profiling of diazotrophic communities, which are essential for sustainable agriculture.

Literature Cited

Asif S, Khan M, Arshad MW, Shabbir MI (2021) PCR Optimization for Beginners: A Step-by-Step Guide. Research in Molecular Medicine ***9***(2): 81 - 102

Dieffenbach CW, Dveksler GS (2003) *PCR primer: A laboratory manual* (2nd ed.). Cold Spring Harbor Laboratory Press

Hoorzook KB, Barnard TG (2022) Culture independent DNA extraction method for bacterial cells concentrated from water. MethodsX ***9***: 101653

Kennedy S, Oswald N (Eds.) (2011) *PCR troubleshooting and optimization: The essential guide*. Caister Academic Press

Nguyen HH, Park J, Park SJ, Lee CS, Hwang S, Shin YB, Ha TH, Kim M (2018). Long-term stability and integrity of plasmid-based DNA data storage. Polymers (Basel) ***10***(1): 28

Patel PH, Panchal KS, Patel HP (2022) Molecular characterization of free-living N_2 fixing bacteria isolated from agricultural soils of North Gujarat, India. Indian Journal of Agricultural Research ***56*** (6): 689 - 695

Sambrook J, Fritsch EF, Maniatis FT (1989) *Molecular cloning: A laboratory manual*. Cold Spring Harbor Laboratory Press

Tomlinson C, Rajasekaran A, Brochu-Gaudreau K, Dubios C, Farmilo AJ, Gris P, Khatiz A, Matthews A, Piltonen M, Amrani A, Gris D (2024) A convenient analytic method for gel quantification using ImageJ paired with Python or R. PloS One ***19***(11): e0308297

Vohradský J, Pánek J (1993) Quantitative analysis of gel electrophoretograms by image analysis and least squares modeling. Electrophoresis ***14***(1): 601 - 612

RESEARCH NOTE

OUTCOME-BASED MONITORING OF INTEGRATED RICE INTERVENTIONS IN CENTRAL LUZON, PHILIPPINES

Bryan R. Cruz, Irene M. Adion, Emily A. Soriano*, Cristilyn L. Yamzon,
Marilou Y. Manabat, and Rudy Y. Orpiada

Department of Agriculture Regional Field Office III, City of San Fernando, 2000 Pampanga, Philippines
*Corresponding Author: emily.soriano@rfo3.da.gov.ph

Abstract

This study supports the government's goal of transforming Philippine agriculture to improve farmers' welfare through modernization, including digital agriculture and targeted interventions. It applied, but did not develop, an outcome-based Monitoring, Evaluation, and Learning (MEL) framework to assess the effectiveness of Department of Agriculture (DA) programs in Central Luzon, the country's major rice-producing region. A total of 1,460 rice farmers across seven provinces were surveyed during the 2023 wet season using proportionate random sampling from the Registry System for Basic Sectors in Agriculture (RSBSA). Data on Rice Crop Manager Advisory Service (RCMAS) uptake, seed and fertilizer assistance, mechanization access, and training participation were analyzed using descriptive statistics, cost-and-return analysis, correlation, and regression models. Results indicated high coverage of seed and fertilizer assistance, moderate access to machinery and training, and low RCMAS adoption. Hybrid seed use and RCMAS participation were the strongest predictors of yield and income, while ecosystem type and crop establishment influenced profitability. The findings demonstrate the usefulness of digital MEL tools in generating actionable evidence for program improvement and policymaking to strengthen modernization, promote hybrid and digital technologies, and enhance farmer resilience amid rising costs and climate variability.

Keywords: *fertilizer voucher, rice and monitoring, rice crop manager advisory service, seed subsidy*

Introduction

The Department of Agriculture's (DA) OneDA Reform Agenda envisions a modern, innovative, and digitalized agriculture sector that uplifts the welfare and productivity of farmers and fisherfolks (Department of Agriculture, 2022). A key component of this vision is the Rice Crop Manager Advisory Service (RCMAS), a digital platform developed with the International Rice Research Institute (IRRI) in 2013 and turned over to the DA in 2021. Now hosted on a cloud-based server, RCMAS delivers location-specific crop management recommendations that help farmers make more informed decisions (Sharma et al., 2019).

In parallel with digitalization, the DA has intensified support for rice farmers in Central Luzon, the country's rice granary, through major programs such as the RCEF Seed Program, which provides free certified inbred seeds and has helped increase average yields from 3.63 to 4.32 t ha^{-1}. Hybrid seed distribution, demonstration trials, and farmer training have also been expanded to further boost productivity (DA-PhilRice, 2023; Tecson, 2021, 2023). To reduce production costs, fertilizer discount vouchers worth PhP 286 million were distributed to RSBSA-registered farmers in Region III, often bundled with seed interventions (Tecson, 2023). Mechanization has been strengthened through the RCEF Mechanization Program, which has provided tractors, combine harvesters, dryers, and irrigation machinery to cooperatives across Nueva Ecija, Bulacan, and Pampanga (Tecson, 2022; SunStar, 2022; Gavino, 2025). These hardware investments are complemented by training programs led by the Cooperative Development Authority (CDA) and the Agricultural Training Institute (ATI), which have trained hundreds of farmers and cooperative members in machine operation, maintenance, and digital agriculture (CDA, 2022; ATI, 2023).

This study did not evaluate the MEL framework itself. Rather, it used an outcome-based MEL framework as a practical tool to assess how well these DA interventions are performing in Central Luzon. By applying MEL, the study linked data from RCMAS, the RSBSA, and major programs on seeds, fertilizers, mechanization, and training. This enabled a more integrated view of how these interventions interact and contribute to farm productivity, cost efficiency, and income.

Unlike earlier studies that focused on single interventions, this research examines how bundled government support—when delivered together—translates into better farm outcomes. It also shows how digital MEL tools can help decision-makers monitor, evaluate, and refine agricultural programs in near real time. The study's importance lies in providing actionable evidence that supports DA's digital transformation agenda and makes Philippine rice farming more competitive and resilient amid increasing production costs and climate risks.

This work demonstrates that the MEL framework is not the subject of evaluation but a data-driven mechanism for continuous learning and improvement. Through it, policymakers and program managers can monitor technology adoption, gauge subsidy efficiency, and track how effectively services reach farmers—information that is crucial for improving productivity, profitability, and sustainability in the rice sector (Sharma et al., 2019; Cañete & Temanel, 2017; Alam & Effendy, 2017; Rasyid et al., 2016; Arida et al., 2020).

The study aimed to strengthen DA's capacity for data-informed decision-making by operationalizing an outcome-based digital MEL platform that supports farmer competitiveness and income growth. Specifically, it seeks to: (1) summarize results from the 2023 rollout of the MEL approach across selected provinces, covering farmer profiles, RCMAS use, and access to seeds, fertilizers, machinery, and training; (2) assess differences in yield, cost structure, and income across varieties and production systems; and (3) develop practical recommendations to guide the refinement of future DA interventions.

Theoretical–Conceptual Framework

This study is grounded in the Theory of Change and Results Chain approaches, which explain how interventions generate outcomes through a logical sequence of cause and effect (OECD, 2019; IFAD, 2020). These approaches help clarify how agricultural programs create change at the farmer level starting from inputs provided by the government to farmers' adoption of these inputs, and ultimately to improvements in productivity and income.

Guided by these principles, the study used an outcome-based MEL framework as an analytical tool, not as the subject of evaluation. The MEL framework structured the linkage and analysis of data on the Department of Agriculture's interventions under the National Rice Program (NRP) and the Rice Competitiveness Enhancement Fund (RCEF) in Central Luzon. Within this framework, data from RCMAS, the RSBSA, and major DA programs (seed and fertilizer distribution, mechanization, and training) were integrated to capture the relationships between intervention access, farmer adoption, and resulting outcomes

The framework assumes that when farmers gain access to improved seeds, fertilizers, digital advisories, machinery, and capacity-building activities, they are more likely to adopt better farming practices. This, in turn, leads to higher yields, greater cost efficiency, and improved income. The MEL process then provides continuous feedback, allowing DA to refine its programs and policies based on evidence.

By combining the Theory of Change with the MEL approach, the framework clarifies that the study focuses on assessing DA's integrated interventions and their effectiveness, not on evaluating MEL itself. It also emphasizes how digital MEL tools can strengthen evidence-based decision-making and ensure that agricultural modernization efforts translate into tangible benefits for farming communities.

Materials and Methods

Study Area and Sampling Frame

The study was conducted in Region III (Central Luzon), the country's rice granary, which accounts for a major share of national rice output and is a priority area for DA interventions. The seven provinces namely Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac, and Zambales were purposively selected because they represent the full geographic and agro-ecological coverage of DA rice programs and contain the highest concentration of RSBSA-registered farmers. Within these provinces, municipalities above the 75th percentile in terms of RSBSA population (Table 1) were chosen to maximize coverage of areas where interventions such as seed

Table 1. Location and number of respondents for the survey.

Province	Municipality	Number of Respondents Interviewed
Aurora	Dilasag	66
	Casiguran	60
	Maria Aurora	78
Bataan	Dinalupihan	94
	Hermosa	74
	Balanga City	43
Bulacan	San Miguel	97
	San Ildefonso	64
	San Rafael	48
Nueva Ecija	Talavera	104
	Lupao	56
	Guimba	50
Pampanga	Candaba	112
	Arayat	58
	Magalang	32
Tarlac	Victoria	87
	La Paz	66
	Concepcion	60
Zambales	Botolan	119
	Iba	43
	San Marcelino	49

distribution, fertilizer vouchers, mechanization, and training were most intensively implemented. This design captured both program reach and outcome variation across different intervention environments.

A stratified sampling approach was adopted, with provinces and municipalities serving as strata. Farmer-respondents were randomly selected from updated RSBSA lists within each stratum. There were 1,460 respondents surveyed across 21 municipalities, with allocation proportional to provincial farmer population to ensure representativeness. This design balanced geographic diversity with statistical rigor, yielding results that are locally grounded and regionally generalizable.

Study Duration

Data collection was conducted during the 2023 wet season and covered rice farmers who cultivated during the 2022–2023 dry season (September 16, 2022–March 15, 2023), ensuring postharvest recall accuracy.

Sampling Procedure and Recruitment of Respondents

Each province in Central Luzon was assigned a target of 200 respondents, determined using a 90% confidence level and a 6% margin of error. The sampling frame consisted of updated farmer lists from the RSBSA, obtained from the DA–Regional Field Office III (DA-RFO III).

Random sampling was done by assigning each farmer a system-generated random number in Microsoft Excel. Lists were sorted in ascending order, and the top entries corresponding to the required provincial sample size were selected. An additional 20% were identified as alternates to replace non-qualified or unavailable participants. Final validation ensured that only active rice farmers were included.

Respondent recruitment was carried out in close coordination with Municipal Agriculture Offices (MAOs) and LGU agricultural technicians. Selected farmers were informed through text messages, phone calls, or in-person visits by field staff. The purpose of the study was explained, participation was voluntary, and informed consent was obtained before data collection. In areas with limited connectivity, trained enumerators conducted face-to-face interviews under DA-RFO III supervision to ensure complete coverage and data quality.

MEL Data Collection Protocol

Mid-Season Phase: DA-RFO III staff generated updated RSBSA lists and coordinated with MAOs for farmer recruitment and scheduling of interviews.

Post-Harvest Phase: Field data were collected using the RCMAS-linked MEL digital survey tool, which captured information on crop management practices, input utilization, mechanization, and participation in DA training activities.

Data Validation: Completed datasets were reviewed for consistency and completeness. Cleaned data were extracted from the RCMAS server following standard data management protocols developed by the International Rice Research Institute (IRRI).

Feedback and Use: Preliminary results and recommendations were presented to DA-RFO III and the National Rice Program (NRP) to inform planning, policy refinement, and the next cycle of program implementation.

Data Analysis

The study generated different types of data—covering technology adoption, yield performance, production cost, and farm income—each requiring a suitable statistical approach. Continuous variables such as yield and income were examined through regression analysis, while categorical information such as RCMAS adoption, receipt of inputs, and training participation was analyzed using correlation and probability-based methods. Separate models were used because each outcome behaves differently; combining them into a single model could have produced misleading interpretations. This analytical design follows accepted monitoring and evaluation practice and allows each indicator to be assessed appropriately.

A mix of descriptive, correlational, and econometric analyses was applied to address the study objectives and explain the outcomes of the different rice interventions implemented in Central Luzon. Descriptive statistics were used to summarize farmers' socioeconomic profiles, production characteristics, and level of participation in DA programs (Table 2). Profitability indicators such as gross income, net income, and benefit–cost ratio were computed through cost-and-return analysis (Table 3).

To examine the strength of association between key interventions such as RCMAS use, access to certified seed and fertilizer, mechanization, and training and farm performance, Pearson correlation analysis was conducted (Table 4).

To identify the major determinants of productivity and profitability, multiple linear regression analysis was employed. Two separate models were developed: the first estimated factors influencing rice yield (Table 5), while the second examined those affecting net farm income (Table 6). The dependent variables were yield (kg ha^{-1}) and income (PhP ha^{-1}). Explanatory variables included RCMAS adoption, seed and fertilizer assistance, mechanization access, training participation, farm size, and selected farmer attributes (age, education, and farming experience).

The general form of the regression equation was:

$$Y_i=\beta_0+\beta_1 X_{1i}+\beta_2 X_{2i}+\beta_3 X_{3i}+\cdots+\beta_k X_{ki}+\varepsilon_i$$

where:

- Y_i = dependent variable (e.g., yield or income)
- $X_{1i}, X_{2i}, \ldots, X_{ki}$ = explanatory variables (e.g., adoption of RCMAS recommendation, access to seed/fertilizer support, mechanization, training participation, farm size, farmer profile)
- $\beta_0, \beta_1, \ldots, \beta_k$ = parameters to be estimated
- ε_i = error term

where represents either yield or income, are the explanatory variables, is the intercept, are the estimated coefficients, and is the error term.

Model assumptions on linearity, homoscedasticity, and multicollinearity were tested and found acceptable. The regression results, summarized in Tables 5 and 6, indicate the magnitude and significance of each factor's contribution to yield and income.

Results and Discussion

This section presents the results of the 2023 rollout of the outcome-based MEL framework across seven provinces in Central Luzon. Guided by the Theory of Change and Results Chain approaches, the analysis assumes that when farmers have access to seeds, fertilizers, mechanization, training, and digital advisories such as RCMAS, they are more likely to adopt improved practices that enhance productivity, reduce costs, and increase income. The MEL framework was used strictly as an analytical tool to link farmers' participation in interventions with outcomes observed during the wet season.

Literature supports the role of integrated support systems in improving farm performance. Studies in Southeast Asia and the Philippines have shown that productivity gains are strongest when interventions are bundled rather than delivered separately (Alam & Effendy, 2017; Arida et al., 2020). Sharma et al. (2019) reported that RCMAS users who followed site-specific recommendations achieved yield improvements of 10–15%, underscoring the value of digital advisories in precision nutrient management. DA-PhilRice (2023) and Tecson (2021) noted that RCEF-supported distribution of certified and hybrid seeds raised average yields from 3.63 to 4.32 t ha^{-1}, while mechanization and training improved farm efficiency and labor productivity (Rasyid et al., 2016; Cañete & Temanel, 2017). However, few studies have examined how multiple DA interventions interact when viewed through a digital MEL framework—a gap that this study addresses.

Program Coverage and Farmer Participation

There were 1,460 rice farmer-participants from seven Central Luzon provinces. Results showed broad coverage of seed and fertilizer programs, with over 80% of respondents receiving certified or hybrid seeds and 75% availing of fertilizer vouchers. Mechanization support reached about half of the farmers, while 40% participated in DA training programs. RCMAS adoption remained moderate, with roughly one in three farmers having received digital recommendations. This pattern reflects a gradual transition toward digital agriculture, where advisory services complement traditional input and extension programs.

These results are consistent with Sharma et al. (2019), who noted that RCMAS adoption depends on farmers' access to other inputs and local support. The higher participation in "tangible" interventions (seeds, fertilizers, machinery) compared with digital advisories suggests that while farmers readily accept physical assistance, digital tools still require stronger promotion and capacity building.

Relationship Between Interventions and Farm Outcomes

Correlation and regression analyses revealed that hybrid seed use and RCMAS participation were the strongest predictors of both yield and net income. Farmers who used hybrid seeds and followed digital recommendations achieved higher productivity and better cost efficiency than those relying solely on traditional practices, confirming the synergy between improved technologies and information access.

Mechanization, training, and seed receipt alone were not independently significant when isolated from other factors. However, when combined with digital advisories and high-quality seeds, these interventions contributed meaningfully to improved outcomes. This supports the concept of complementarity in agricultural programs where the collective effect of multiple interventions exceeds the sum of their individual impacts (Alam & Effendy, 2017).

Ecosystem type and crop establishment methods also influenced profitability more than yield. Rainfed farmers often incurred higher production costs but achieved comparable or even higher net returns when they adopted early-maturing hybrid varieties. This indicates that profitability is shaped not only by yield but also by efficient resource management, cost-saving practices, and strategic use of technology.

Implications for Policy and Program Improvement

The findings highlight the value of applying a digital MEL framework to monitor and assess agricultural interventions. By integrating data from RCMAS and RSBSA, the MEL approach provides policymakers with concrete evidence on which interventions and combinations deliver the best returns. This can help DA target resources more effectively and prioritize intervention bundles that deliver measurable impact.

For Central Luzon, scaling up hybrid seed adoption, strengthening RCMAS dissemination, and enhancing support for rainfed ecosystems are key strategies to sustain gains in productivity and income. Institutionalizing the MEL framework across programs will also promote evidence-based decision-making, ensuring that modernization efforts under the OneDA Reform Agenda are data-driven and farmer-centered.

Field Information of Farmers in Region 3

Most (90.9%) of the surveyed farmers cultivated rice under irrigated conditions, underscoring the importance of reliable water sources in sustaining productivity, particularly during drought-sensitive growth stages (Mariano et al., 2010). The majority (78.8%) managed farms under 2 ha, with Zambales having the highest proportion (68.25%) of farmers cultivating plots smaller than 1 ha.

Table 2. Field information of farmer - respondents in Region III.

	Frequency	Percentage (%)
Agro-ecosystem		
Irrigated	1,327	90.90
Rainfed	133	9.10
Total	1,460	100.00
Area planted		
Below 1 ha	518	35.46
1 - 1.99 ha	632	43.32
2 - 2.99 ha	217	14.83
3 - 3.99 ha	59	4.07
4 - 4.99 ha	17	1.16
5 ha and above	17	1.16
Total	1,460	100.00
Crop establishment		
Manual transplanting	658	45.04
Manual direct seeding	788	54.00
Mechanical transplanting	7	0.48
Mechanical direct seeding: Drum seeder	7	0.48
Mechanical direct seeding: Precision seeder	0	0
Total	**1,460**	**100.00**

Crop establishment practices varied: 54% adopted direct seeding, especially in Bataan, Bulacan, and Pampanga, due to lower labor requirements; 45.04% practiced manual transplanting, notably in Zambales (84.36%) and Nueva Ecija (81.22%). The gradual shift toward direct-seeded rice (DSR) reflects regional responses to rising labor costs and changing water availability, and is consistent with broader trends toward intensification and diversification (Pandey et al., 2002).

Rice Crop Manager Advisory Service (RCMAS) Recommendation Uptake

Only 20.2% of surveyed farmers received RCMAS recommendations during the dry season, primarily through Agricultural Extension Workers (AEWs) of the Municipal Agriculture Offices. Among these, 90.5% had the recommendations explained and 88.1% received them on time, enabling timely planning.

Recommendations were delivered via paper (45.2%), SMS (30.9%), or both (23.8%). SMS was particularly valued for reminders sent five days before fertilizer application. Among recipients, 85.7% followed the advised fertilizer types (Complete 14-14-14 and Urea 46-0-0). In terms of compliance, 40.5% fully and 50% partially followed the recommended amounts (typically 6–8 bags), while 40.5% fully and 54.76% partially followed the recommended timing (basal, tillering, and panicle initiation stages).

Among those who did not receive RCMAS advice, 96.4% were unaware of the program. Sharma et al. (2019) reported that RCMAS uptake is associated with an additional 640 kg yield and PhP12,496.82 net return ha^{-1}, reinforcing the need for intensified dissemination through DA's local extension channels.

Seed Subsidy/Intervention Use in Region 3

Seed Subsidy Uptake

During the dry season, 93.8% of farmers received seed subsidies recording 78.9% in inbred varieties (e.g., NSIC Rc 512, Rc 508, Rc 480) and 21.1% in hybrids (e.g., NSIC Rc 132H, Rc 176H, Rc 234H). Of these, 91.1% planted the seeds within the same season, while 8.7% did not due to late delivery, mismatched variety preference, or insufficient allocation. Unused seeds were carried over for future planting, milled, exchanged, or shared with other farmers.

The high uptake of certified seeds indicates the effectiveness of the RCEF Seed Program and DA-NRP initiatives to improve access to high-yielding varieties (Bordey, 2023). Continued use of inbred seeds appears to have supported the gradual adoption

Table 3. Rice crop manager advisory services (RCMAS) recommendation uptake.

	Frequency	Percentage (%)
Received RCMAS recommendation		
Yes	295	20.2
No	1165	79.8
	1,460	100.0
Explained RCMAS recommendation		
Yes	267	90.5
No	28	9.5
	295	100.0
Received RCMAS recommendation on-time		
Yes	260	88.1
No	35	11.9
	295	100.0
Planned to follow RCMAS recommendation		
Yes	260	88.1
No	35	11.9
	295	100.0
Format of RCMAS recommendation received		
SMS	91	30.9
Paper	133	45.2
Paper and SMS	70	23.8
	295	100.0
SMS usefulness		
Yes	154	95.6
No	7	4.3
	161	100.0
Follow fertilizer type		
Yes	253	85.7
No	42	14.3
	295	100.0
Follow fertilizer amount		
Yes (partial)	148	50.0
Yes (full)	119	40.5
No	28	9.52
Follow timing of application		
Yes (partial)	162	54.8
Yes (full)	112	38.1
No	21	7.1
	295	100.0
Is there an awareness about RCM, for those who did not receive RCMAS recommendation		
Yes	42	3.6
No	1123	96.4
	1,165	100.0

Table 4. Seed intervention uptake.

	Frequency	Percentage (%)
Seed Receipt		
Yes	1,369	93.8
No	91	6.2
	1,460	100.0
Variety received		
Inbred	1,081	78.9
Hybrid	288	21.1
	1,369	100
Planted the seed received on their own field		
Yes	1,248	91.1
No	119	8.7
	1,369	100.0

of hybrids and newer varieties such as NSIC Rc 506, Rc 508, and Rc 534. This is consistent with the observed increase in national rice production from 12.4 million MT in 2000 to 19.96 million MT in 2021 (de Leon, 2023; Berto, 2023).

Fertilizer Voucher Use

Surveyed farmers (87.7%) reported receiving fertilizer discount vouchers, commonly distributed alongside seed subsidies. The average value was PhP6,300 ha^{-1}, equivalent to roughly two bags and 25 kg of urea, priced between PhP2,500 and PhP2,800 per bag. Most recipients (94.9%) used the vouchers within the same cropping season to purchase fertilizer from accredited suppliers. A small proportion (5.1%) were unable to use their vouchers on time due to late issuance, having already completed fertilization. Some redeemed vouchers in the succeeding season; others awaited revalidation or replacement by local agriculture offices.

Farmers confirmed that the vouchers effectively served as a cost-sharing subsidy to offset sharp fertilizer price increases. However, their impact on total fertilizer use was modest. Urea application slightly declined from 231.6 kg ha^{-1} to 229.6 kg ha^{-1}, and complete fertilizer use decreased from 179.8 to 176.2 kg ha^{-1}. Many farmers compensated by increasing ammonium phosphate use, a relatively more affordable N source. This suggests that while vouchers cushioned rising input costs, they were insufficient to restore previous fertilizer use levels, given price increases of 100–150% compared with prior seasons. As DA emphasized, the scheme's immediate goal was to prevent severe underapplication of urea and safeguard food security (Lagare, 2022).

Table 5. Fertilizer voucher used by farmers in the region.

Received fertilizer voucher	Frequency	Percentage (%)
Yes	1,281	87.7
No	179	12.2
	1,460	100.0
Use of fertilizer subsidy in the intended season		
Yes	1,216	94.9
No	65	5.1
	1,281	**100**

Accessibility to Farm Machineries and Technologies for Rice Crop Production

Farm mechanization in Region III was highest during land preparation (98.5%) and harvesting (96%), where most farmers used tractors, reapers, threshers, or combine harvesters. Mechanization during crop care reached 73.4%, mainly through the use of electric or power sprayers. Crop establishment remained largely manual, with only 4.9% using mechanical transplanters or seeders, indicating limited adoption despite continuous government promotion.

Although mechanization contributes to greater efficiency, timeliness, and labor savings, its direct effect on yield was not statistically significant in this study. Yield remains primarily determined by genetics, environment, and agronomic management (Arida et al., 2020). Nonetheless, mechanization improves indirect drivers of productivity, such as uniform land preparation, timely planting and harvesting, and reduced postharvest losses (Bautista, 2001; Apiors et al., 2016). These benefits translate into improved cost efficiency and profitability even when yield gains are not immediately visible.

Additionally, 78.3% of farmers reported receiving training mostly organized by LGUs, TESDA, DA, DAR, and ATI through Farmers' Field Schools and similar programs. Such capacity-building activities enhance technical competence in machinery operation and maintenance, which is critical for sustaining the long-term benefits of mechanization.

Assess yield performance, cost structures, and income variations across different rice varieties

Rice Yield, Cost of Production, and Income

Cost Structure. During the dry season, average production costs were higher for hybrid rice (PhP47,822.13 ha^{-1}) than for inbred (PhP41,583.91 ha^{-1}), with labor and machinery accounting for the largest share (50.4%), followed by fertilizer (23.8%) and seeds (4.1%). These figures exclude subsidies. Fertilizer, seed, pesticide, and labor were key cost drivers influencing productivity (Alam & Effendy, 2017; Rasyid et al., 2016).

Yield Comparison. Inbred yields mostly ranged from 4.01–5 t ha^{-1} (26.8%), while hybrid yields were generally higher, with 37.2% of hybrid growers exceeding 7 t ha^{-1}, particularly in Tarlac and Nueva Ecija. On average, hybrid varieties yielded 5.2 t ha^{-1}, 19.8% higher than the 4.4 t ha^{-1} average for inbred.

Economic Viability. With subsidies, hybrid rice had a slightly lower break-even price (PhP9.07 kg^{-1}) than inbred (PhP9.45 kg^{-1}). Without subsidies, break-even costs rose to PhP11.18 kg^{-1} (hybrid) and PhP11.24 kg^{-1} (inbred). Although hybrid production costs were higher, greater yield potential offset expenses and improved cost efficiency.

Correlation of DA Interventions to Yield and Net Income

Correlation analysis revealed varying effects of DA interventions. Ecosystem type was not significantly correlated with yield, r (874) = 0.01, $p >$ 0.05, but showed a small negative correlation with net income, r (874) = –.09, $p < .05$, indicating that irrigated farmers earned modestly higher incomes due to greater water reliability and input efficiency (David and Balisacan, 1995; Dawe et al., 2006; Dobermann et al., 2004; Sebastian, 2016). Crop establishment was

Table 6. Comparison of fertilizer used from past to current dry season.

Fertilizer	Traditional Application during the Season (kg)	Actual Application during the Season (kg)	Difference (kg)
	Mean	Mean	Mean
Urea (46-0-0)	231.6	229.6	-2.00
Complete (14-14-14)	179.8	176.2	-3.6
Ammonium sulfate (21-0-0)	143.8	144.2	0.4
Ammonium phosphate (16-20-0)	132.3	137.9	5.6
Muriate of potash (0-0-60)	81.8	81.8	0.0
17-0-17	108.4	108.4	0.0

also not significantly related to yield, r (874) = 0.07, $p > 0.05$, but was positively correlated with net income, r (874) = 0.13, $p < 0.01$, suggesting profitability gains from labor- and cost-saving direct or mechanized methods (Pandey et al., 2002; Arida et al., 2020; Apiors et al., 2016).

RCMAS uptake was negatively correlated with yield, r (874) = –0.10, $p < .05$, and net income, r (874) = –0.16, $p < .01$, with coding (1 = Yes, 2 = No) indicating that adopters achieved higher yields (≈5.5 t/ha vs. 5.0 t/ha) and incomes (PhP 43,717 vs. PhP 28,300/ha), consistent with earlier reports of significant productivity and profitability gains from digital advisories (Sharma et al., 2019; Cañete & Temanel, 2017; Mariano et al., 2010). Seed variety type was positively correlated with both yield, r (874) = 0.14, $p < .01$, and net income, r (874) =0 .22, $p < .01$, with hybrid users outperforming inbred users (≈5.2 vs. 4.4 t/ha; PhP 43,000 vs. PhP 32,000/ha). Despite higher costs, hybrids delivered significantly greater profitability, reinforcing their role as the strongest predictor of performance among DA interventions (Bordey, 2023; de Leon, 2023; Rasyid et al., 2016).

By contrast, farm machinery access, training participation, province of origin, and seed receipt were not significantly correlated with yield or net income ($p > .05$). Their effects appear conditional on other variables, as prior studies confirm that mechanization and training improve efficiency when paired with improved varieties and sufficient inputs (Arida et al., 2020; Apiors et al., 2016).

Conclusion and Recommendations

This study used an outcome-based MEL framework to link DA interventions with yield and income outcomes in Central Luzon. Results showed widespread access to seeds and fertilizer vouchers, moderate use of machinery and training, and relatively limited uptake of RCMAS. Hybrid seed use and RCMAS adoption emerged as the strongest predictors of productivity and profitability, while ecosystem type and crop establishment influenced income more than yield. Other interventions were not significant when analyzed individually but contributed when integrated with improved varieties and digital advisories. These findings highlight the value of digital MEL systems in guiding policy and program refinement. By integrating data from RCMAS, RSBSA, and major rice programs, MEL tools help identify which combinations of interventions deliver the greatest impact. This is particularly relevant under conditions of rising input costs and climate risk, where resources must be targeted more strategically. The study supports evidence-based planning to advance DA's digital transformation agenda and enhance farmer competitiveness. It shows that modernizing Philippine rice farming requires not only physical inputs but also digital tools, complementary support services, and continuous learning through ME.

Based on the evaluation of DA interventions in Central Luzon, the following recommendations are proposed:

1. **Scale up hybrid seed adoption.** Given its strong positive correlations with yield and income, expanding access to hybrid varieties through targeted distribution, demonstration trials, and farmer incentives should remain a priority.

2. **Enhance dissemination and utilization of RCMAS.** Despite its measurable benefits, RCMAS uptake remains limited due to low awareness. Wider promotion through municipal AEWs, integration with voucher systems, and user-friendly delivery formats (SMS, mobile apps) can improve adoption

3. **Integrate interventions for synergistic effects.** Mechanization, training, and fertilizer subsidies were not significant when analyzed individually, but prior studies and this analysis indicate they are more effective when combined with improved seeds and digital advisories. Linking interventions within the MEL framework can maximize efficiency and impact.

4. **Strengthen support for rainfed farmers.** Rainfed ecosystems were associated with lower profitability despite similar yields. Investments in water-saving technologies, climate-resilient varieties, and targeted subsidies are needed to reduce income gaps and enhance resilience.

5. **Institutionalize outcome-based MEL systems.** The digital MEL platform demonstrated its capacity to generate evidence for planning and program adjustment. Embedding it into DA's monitoring and evaluation processes can improve resource allocation, track adoption, and support adaptive policymaking in line with the OneDA Reform Agenda.

Acknowledgment

The authors thank the DA-RFO III Rice Program for funding this study, and express gratitude to IRRI, DA-ATI RTC III, PhilRice, local government units, and farmer collaborators for their invaluable support and participation.

Literature Cited

Agricultural Training Institute (2023) Training programs for rice farmers and extension workers. Retrieved from https://ati.da.gov.ph (accessed June 9, 2024)

Alam MN, Effendy (2017) Identifying factors influencing production and rice farming income with approach of path analysis. American Journal of Agricultural and Biological Sciences ***12***(1): 39 - 43

Apiors EK, Kuwornu JKM, Kwadzo GTM (2016) Effects of mechanization use intensity on the productivity of farms in southern Ghana. Acta Agriculturae Slovenica ***107***(2): 439 - 451

Arida IA, Beltran JC, Antivo MJT, Relado-Sevilla RZ, Malasa RB, Tanzo IR, Bordey FH (2020) Socioeconomic impact of adopting rice combine harvester in the Philippines. Rice-Based Biosystems Journal. Philippines Rice Research Institute *7*: 89 - 108

Bautista EU (2001) Mechanizing rice agriculture in the Philippines. Proceedings of the 13th National Rice R&D Conference. Philippine Rice Research Institute and DA-BAR

Berto C (2023) Agriculture department expands certified inbred seed distribution. PhilRice. Retrieved from https://www.philrice.gov.ph/agriculture-dept-expands-certified-inbred-seed-distribution/ (accessed June 9, 2024)

Bordey FH, Moya PF, Beltran JC, Launio CC, Dawe DC (2023) Can Philippine Rice Compete Globally? *In* Bordey FH, Moya PF, Beltran JC, Dawe CC (Eds.). Competitiveness of Philippine Rice in Asia (pp 141 - 152). Philippine Rice Research Institute

Cooperative Development Authority (2022) CDA Region III Extension Office shares the success of the RCEF mechanization program. Retrieved from https://cda.gov.ph/region-3/december-13-2022-cda-region-iii-extension-office-shares-the-success-of-the-rcef-mechanization-program/ (accessed June 9, 2024)

DA-PhilRice [**Department of Agriculture-Philippine Rice Research Institute**] (2023) RCEF seed program. Rice Competitiveness Enhancement Fund. Retrieved from https://rcef.da.gov.ph/seeds (accessed June 9, 2024)

David CC, Balisacan AM (1995) Philippine rice supply demand: Prospects and policy implications. Philippine Institute for Development Studies. Retrieved from https://www.pids.gov.ph/publication/discussion-papers/philippine-rice-supply-demand-prospects-and-policy-implications (accessed June 9, 2024)

Dawe DC, Moya PF, Casiwan CB (2006) *Why does the Philippines import rice? Meeting the challenge of trade liberalization*. International Rice Research Institute

de Leon JC (2023) Rice that Filipinos grow and eat. Research Paper Series No. 2011-01. Philippine Institute for Development Studies. Retrieved from https://pidswebs.pids.gov.ph/CDN/PUBLICATIONS/pidsrp1101.pdf (accessed June 9, 2024)

Dobermann A, Witt C, Dawe D (Eds.) (2004) *Increasing productivity of intensive rice systems through site-specific nutrient management*. Science Publishers, Inc and International Rice Research Institute

Gavino CN (2025) 194 farmers coops, LGUs in Central Luzon receive farm machinery. Philippine Information Agency. Retrieved from https://pia.gov.ph/news/luzon/cl/194-farmers-coops-lgus-in-central-luzon-receive-farm-machinery/ (accessed June 9, 2024)

Lagare JB (2022) Fertilizer subsidy program gets P4.1 billion additional funding. INQUIRER.net. Retrieved from https://newsinfo.inquirer.net/1683020/fertilizer-subsidy-program-gets-p4-1-b-additional-funding (accessed June 9, 2024)

Mariano MJM, Villano RA, Fleming E (2010) Are irrigated farming ecosystems more productive than rainfed farming systems in rice production in the Philippines? Agricultural Ecosystems and Environment ***139***(4): 603 - 610

Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B (Eds.) (2002) Direct seeding: research issues and opportunities. Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities. International Rice Research Institute

Rasyid A, Kariyasa K, Supriatna Y (2016) Comparative economic analysis of hybrid and inbred rice farming. Jurnal Agro Ekonomi ***34***(2): 95 - 112

Rasyid MN, Setiawan B, Mustadjab MM, Hanani N (2016) Factors that influence rice production and technical efficiency in the context of an integrated crop management field school program. American Journal of Applied Sciences ***13***(11): 1201 - 1204

Sharma S, Panneerselvam P, Castillo R, Manohar S, Raj R, Ravi V, Buresh RJ (2019) Web-based tool for calculating field-specific nutrient management for rice in India. Nutrient Cycling in Agroecosystems ***113***(1): 21 - 33

Sharma S, Singh P, Stuart AM, Singleton GR (2019) Site-specific nutrient management for rice in the Philippines: Calculation of field-specific fertilizer requirements by Rice Crop Manager. Field Crops Research ***239***(2): 56 - 70

SunStar Pampanga (2022) DA awards P24-M agri-interventions to Bulacan farmers. SunStar. Retrieved from https://www.sunstar.com.ph/pampanga/local-news/da-awards-p24-m-agri-interventions-to-bulacan-farmers (accessed June 9, 2024)

Tecson Z (2021) DA steps up rice hybridization program in Central Luzon. Philippine News Agency. Retrieved from https://www.pna.gov.ph/articles/1127263 (accessed June 9, 2024)

Tecson Z (2022) DA distributes farm machinery to Nueva Ecija farmers' groups. Philippine News Agency. Retrieved from https://www.pna.gov.ph/articles/1188821 (accessed June 9, 2024)

Tecson Z (2023) 152K farmers in C. Luzon get certified seeds via RCEF program. Philippine News Agency. Retrieved from https://www.pna.gov.ph/articles/1208516 (accessed June 9, 2024)

RESEARCH NOTE

EXTRACTION AND CHARACTERIZATION OF NANOCELLULOSE FROM COCONUT COIR WITH PRELIMINARY EVIDENCE OF *RHIZOBIUM TROPICI* AND *BACILLUS SAFENSIS* VIABILITY FOR USE AS A CARRIER MATRIX IN NANO-BIOFERTILIZER SYSTEMS

Sarah B. Aquino*, Larjan Kent M. Cuevas, Edrickson C. Remigio,
Ferdie M. Peralta, and Jesusa C. Cabang

Department of Agriculture – Regional Field Office No. 02, Ilagan Soil Laboratory Purok 02,
DA-CVRC Compound, San Felipe, City of Ilagan, 3300 Isabela, Philippines
*Corresponding Author: sarah.aquino@rfo2.da.gov.ph

Abstract

The valorization of agricultural waste offers a sustainable pathway for producing high-value bio-based materials. Coconut coir, a lignocellulosic by-product abundantly generated in the Philippines, remains underutilized and presents disposal challenges. In rice-based farming systems, improving fertilizer efficiency and developing more stable microbial biofertilizers are increasingly important to sustain yield while reducing input costs and nutrient losses. Nanocellulose-based carrier matrices can enhance microbial survival and delivery, with potential applications in rice nutrient management and soil health improvement. This study examined the extraction and characterization of nanocellulose from coconut coir for potential use as a carrier matrix in nano-biofertilizer systems. Three nanocellulose samples were produced through sequential alkaline pretreatment (5% NaOH), bleaching, controlled acid hydrolysis (2M HCl or a mixed H_2SO_4/HCl solution), and ultrasonic dispersion. The suspensions were characterized for particle size, polydispersity, and colloidal stability using dynamic light scattering (DLS) and zeta potential analysis, supported by Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). Among the samples, DA2-SA achieved nanoscale dimensions (83.4 ± 6.7 nm) with strong electrostatic stabilization (−74 mV), while DA3-S1 and DA1-MA exhibited larger particle sizes but maintained robust colloidal stability (up to −97 mV). SEM revealed porous fibrillar networks averaging 10–20 µm, and FTIR spectra confirmed high cellulose purity with dominant O–H and C–O–C functional groups and minimal lignin. Importantly, preliminary microbial viability testing demonstrated that *Rhizobium tropici* (1.2 × 10^{o} CFU/mL) and *Bacillus safensis* (1.4 × 10^{o} CFU/mL) maintained high viable populations when suspended in nanocellulose, providing direct biological evidence of compatibility. These results establish coconut coir-derived nanocellulose as a promising, sustainable carrier matrix for microbial encapsulation in nano-biofertilizer systems, with further validation through replicated trials, long-term viability assays, and cost–benefit analyses recommended for large-scale application.

Keywords: *agro-waste valorization, dual-strain compatibility, encapsulation potential, microbial carrier systems, sustainable bio-inputs*

Introduction

Nanocellulose derived from agricultural waste is gaining attention as a sustainable biomaterial for diverse applications (Dufresne, 2013). Coconut coir, a lignocellulosic by-product abundantly generated in the Philippines, is underutilized despite its potential as a renewable feedstock (Vieira et al., 2024). In rice-based farming systems, soil fertility management remains a key constraint, particularly as rising fertilizer costs and nutrient losses limit productivity and profitability. Microbial biofertilizers have been promoted as complementary inputs in rice production to enhance nutrient cycling, improve soil health, and reduce reliance on synthetic fertilizers, but their field performance remains inconsistent. Biofertilizers are widely commercialized, including some nano-packaged products registered with the Fertilizer and Pesticide Authority, yet the effectiveness of these inoculants depends largely on the carrier material used. Conventional carriers such as peat, alginate, and biochar present trade-offs in cost, availability, and microbial performance (Schoebitz et al., 2013).

Nanocellulose offers large surface area, strong colloidal stability, and abundant hydroxyl groups that may support microbial encapsulation (George & Sabapathi, 2015; Habibi et al., 2010). However, its agricultural application remains underexplored.

This study aimed to extract nanocellulose from coconut coir using sequential chemical and mechanical treatments, characterize its physicochemical and structural properties, and conduct preliminary microbial viability testing with *Rhizobium tropici* and *Bacillus safensis* to evaluate its potential as a sustainable carrier matrix for nano-biofertilizer systems.

Materials and Methods

Description of Test Microorganisms. Rhizobium tropici and *Bacillus safensis* used in this study are indigenous strains previously isolated from the roots of wild tallgrass (*Saccharum spontaneum*) collected within the DA–Cagayan Valley Research Center, City of Ilagan, Isabela, Philippines. Both isolates were confirmed through biochemical and molecular identification and are maintained in the DA–RFO 02 Ilagan Soil Laboratory culture collection. Prior functional assays conducted by the laboratory demonstrated their plant growth–promoting properties, including nitrogen fixation, phosphate solubilization, and potassium mobilization. These validated traits served as the basis for selecting these strains to evaluate the compatibility of nanocellulose as a microbial carrier.

Nanocellulose extraction and treatments. Coconut coir fibers were processed through sequential alkaline pretreatment (5% NaOH), bleaching (1.7% NaClO), acid hydrolysis (2M HCl or HCl/H_2SO_4 mixture), and ultrasonic dispersion. Three treatment variations were prepared: DA3-S1 (sun-dried + mild acid), DA2-SA (strong acid, no drying), and DA1-MA (mild acid, no drying), adapted from established methods (Deepa et al., 2015; Kargarzadeh et al., 2017).

Characterization. Particle size, polydispersity index, and zeta potential were determined by dynamic light scattering (DLS) (Clogston & Patri, 2011). Morphology was observed using scanning electron microscopy (SEM), while functional groups were identified through Fourier-transform infrared spectroscopy (FTIR). All analyses were performed at the CLSU Nanotechnology and R&D Facility following standard protocols; specific equipment models were not disclosed.

Microbial viability assay. The compatibility of nanocellulose with *Rhizobium tropici* and *Bacillus safensis* was evaluated through a standard plate count viability assay following QC procedures used at the DA–RFO 02 Ilagan Soil Laboratory.

1. Preparation of Microbial Cultures

Pure cultures of *R. tropici* and *B. safensis* were grown on Yeast Mannitol Broth (YMB) and Dobereiner's broth (DB), respectively. Cultures were incubated at 28 ± 2 °C for 72 hours to obtain actively growing colonies.

2. Suspension in Nanocellulose

1 mL of microbial inoculum was aseptically transferred into 9 mL of each nanocellulose sample.

3. Incubation Period

The nanocellulose–microbe suspensions were held at room temperature (28 ± 2 °C) for 72 h (3 days) prior to plating.

This incubation duration represents the standard holding time used in microbial viability assessments for biofertilizer carriers.

4. Plate Count Procedure

After 72 hours, tenfold serial dilutions (10^{-1} to 10^{-6}) were prepared using sterile distilled water. 0.1 mL aliquots from each dilution were spread-plated onto Nutrient Agar Media. Plates were incubated at 28 ± 2 °C for 72 h.

5. Enumeration and Threshold Comparison

Colony-forming units (CFU/mL) were calculated using plates with 30–300 colonies. Validity of nanocellulose as a carrier material was assessed against the recommended minimum viability threshold of 10^6 - 10^8 CFU/mL for biofertilizer products (Itelima et al., 2018). Both organisms exceeded the threshold, confirming high compatibility.

Limitations of the Study. This study was conducted as a preliminary process-screening experiment with three treatment variations but without independent batch replication. As such, results were interpreted descriptively and benchmarked against established criteria (e.g., nanoscale <100 nm; > 30 mV) rather than analyzed through inferential statistics. Replicated preparations will be essential in future work to confirm these findings and enable formal hypothesis testing. In addition, advanced analyses such as DLS, zeta potential, SEM, and FTIR were conducted externally at the CLSU Nanotechnology and R&D Facility. While these followed the facility's standard protocols, the exact instrument models and operating parameters were not disclosed to the authors. Consequently, results are reported as provided and interpreted in line with standard benchmarks and published literature. Despite these limitations, the study provides proof-of-concept evidence for the feasibility of producing nanocellulose from coconut coir and its compatibility with microbial biofertilizer applications.

Results and Discussion

Nanocellulose suspensions were successfully produced from coconut coir under all treatments. Particle size analysis showed clear differences as shown in Figure 1. DA2-SA achieved nanoscale dimensions (83.4 ± 6.7 nm), consistent with ISO/TS 20477:2017 for nanocellulose, aligning with typical cellulose nanocrystals (CNC) and nanofibrils (CNF), while DA3-S1 (428.6 ± 37.2 nm) and DA1-MA (1177.5 ± 146.4 nm) remained above 100 nm.

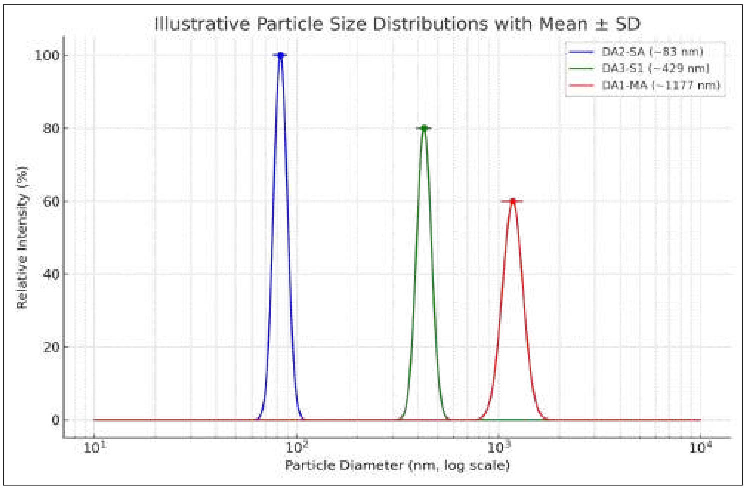


Figure 1. Particle size distribution of nanocellulose samples measured by dynamic light scattering (DLS), showing DA2-SA within the nanoscale range (<100 nm), while DA3-S1 and DA1-MA exhibited larger, more polydisperse distributions.

Polydispersity indices indicated a relatively uniform distribution in DA2-SA, whereas DA3-S1 exhibited greater heterogeneity as presented in Table 1. These results demonstrate that stronger hydrolysis applied to wet-bleached fibers (DA2-SA) promoted finer dispersion, while sun-drying (DA3-S1) or mild acid treatment (DA1-MA) led to partial aggregation and incomplete fibril separation (Deepa et al., 2015; Kargarzadeh et al., 2017).

Zeta Potential and Colloidal Stability

Zeta potential values confirmed robust colloidal stability across treatments as visualized in Figure 2, ranging from −73.7 mV to −96.7 mV, well above the ±30 mV benchmark (Clogston & Patri, 2011). DA3-S1 exhibited the highest stability (−96.7 mV), suggesting a trade-off between nanoscale size (DA2-SA) and electrostatic stabilization (DA3-S1), consistent with trends reported in other lignocellulosic nanocellulose systems (Wu et al., 2019).

Table 1. Polydispersity indices (PI) of nanocellulose samples derived from coconut coir.

Sample	Mean Size (nm)	SD (nm)	PI
DA2-SA	83.4	6.7	— (monodisperse)
DA3-S1	428.6	37.2	1.707
DA1-MA	1177.5	146.4	1.022

Scanning electron microscopy (SEM) revealed porous fibrillar networks averaging 10–20 µm in width as seen in Figure 3. Although fibril bundling

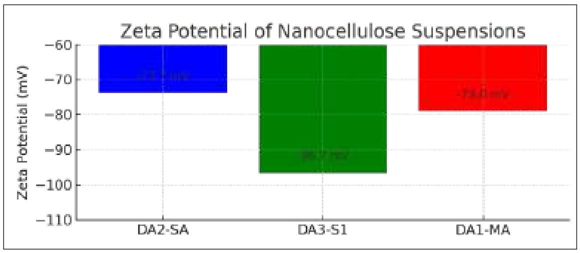
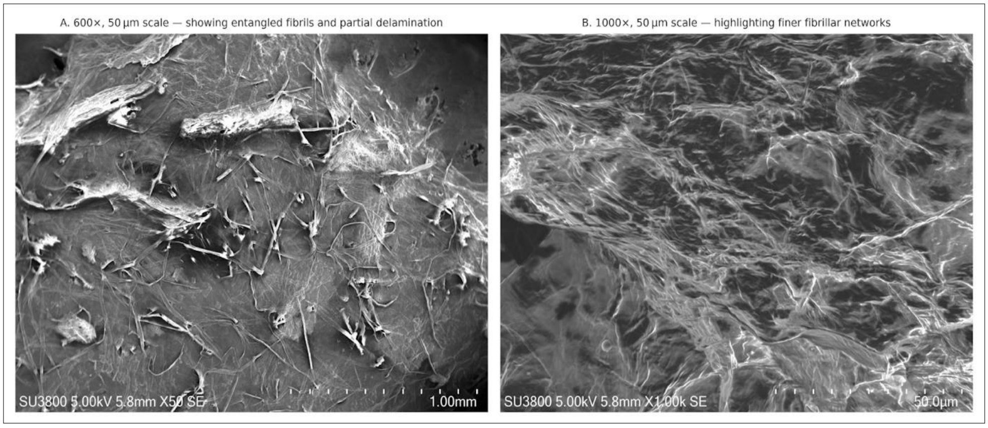


Figure 2. Zeta potential values of nanocellulose suspensions, indicating strong electrostatic stabilization across treatments, all exceeding the ±30 mV stability threshold.


A. 600×, 50 µm scale — showing entangled fibrils and partial delamination

B. 1000×, 50 µm scale — highlighting finer fibrillar networks

Figure 3. Scanning electron micrographs of coconut coir-derived nanocellulose, showing entangled fibrillar networks with partial defibrillation and porous microstructures.

occurred due to drying during sample preparation, the porous structures provide extensive surface area and interconnected microchannels favorable for microbial entrapment and controlled release (George & Sabapathi, 2015).

FTIR spectra confirmed chemical purity with strong O–H, C–H, and C–O–C peaks and minimal lignin signals, supporting suitability for biological applications (Abitbol et al., 2016) as shown in Figure 4.

Preliminary Microbial Viability

Microbial viability was assessed three days (72 h) after suspension of the cultures in nanocellulose, which corresponds to the standard incubation time used for quality control plating at 28 ± 2 °C. Figure 5 and 6 shows the preliminary microbial assays and presents the colony development of *R. tropici* and *B. safensis* after 72-h incubation, indicating that both microorganisms remained highly viable following suspension in nanocellulose. *Rhizobium tropici* and *Bacillus safensis* maintained high viable populations when suspended in nanocellulose, with counts of 1.2×10^{o} CFU/mL and 1.4×10^{o} CFU/mL, respectively. These values exceed the recommended threshold for biofertilizer efficacy (Itelima et al., 2018), providing direct evidence that nanocellulose does not inhibit microbial survival and may serve as an effective encapsulation matrix.

Collectively, these findings establish coconut coir-derived nanocellulose as a promising low-cost carrier with favorable physicochemical stability, structural porosity, and biological compatibility, offering potential for development into nano-biofertilizer systems.

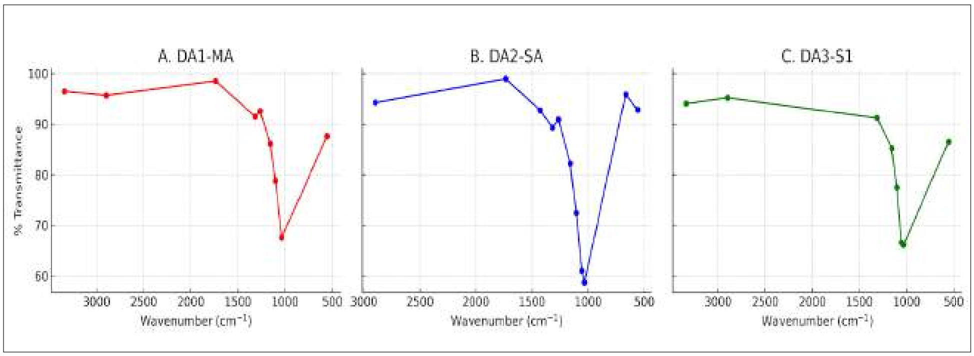


Figure 4. Fourier-transform infrared (FTIR) spectra of nanocellulose samples, showing dominant cellulose functional groups (O–H, C–H, C–O–C) and reduced non-cellulosic peaks, including the absence of carbonyl bands near 1735 cm^{-1}.

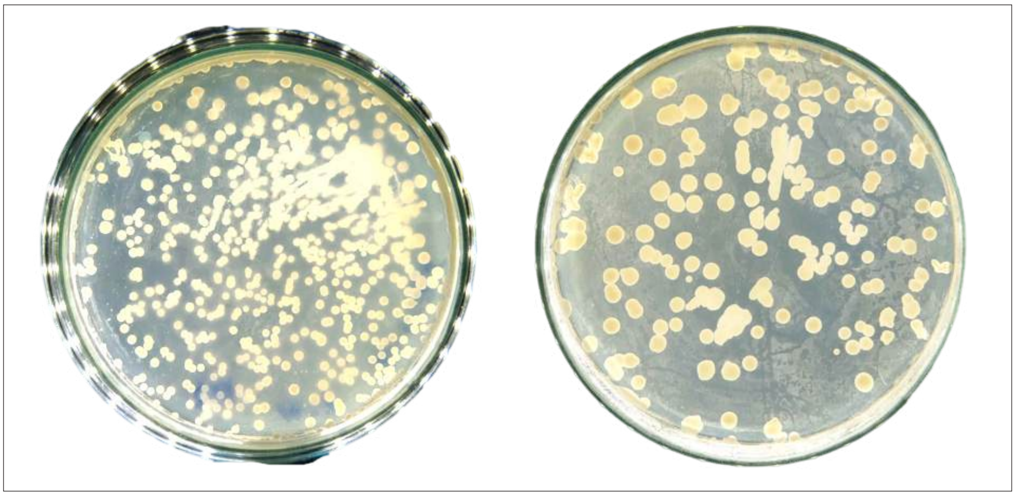


Figure. 5: Quality control plates showing the growth of *Rhizobium tropici* three days after suspension in coconut-coir–derived nanocellulose, confirming high viability and compatibility with the carrier material.

Figure. 6: Quality control plates showing the growth of *Bacillus safensis* three days after suspension in coconut-coir–derived nanocellulose, confirming high viability and compatibility with the carrier material.

Conclusion

Nanocellulose extracted from coconut coir demonstrated favorable physicochemical, structural, and chemical properties and supported the survival of *R. tropici* and *B. safensis* at effective microbial counts. These preliminary findings establish coconut coir-derived nanocellulose as a promising, low-cost carrier matrix for nano-biofertilizer systems. These results also highlight the potential of agro-waste valorization to generate sustainable inputs for climate-smart agriculture

Recommendations

Further studies should include replicated batch preparations, long-term microbial viability assays, soil release dynamics, and cost–benefit analysis to validate scalability and agronomic application. Replicated extractions and field-level validation trials are especially needed to confirm large-scale feasibility.

Acknowledgment

The authors acknowledge the CLSU Nanotechnology R&D Facility for conducting particle size, zeta potential, SEM, and FTIR analyses, and the Department of Agriculture – Regional Field Office No. 02 (DA-RFO 02) under the leadership and guidance of Regional Executive Director Dr. Rose Mary G. Aquino and Regional Technical Director Kay S. Olivas, they are deeply appreciated for their institutional support. Special thanks are also given to Dr. Gerly T. Zulueta, Chief of the DA-Integrated Laboratory Division, and Ms. Fevie Rica Ancheta, Chief of the Regional Soils Laboratory, for their invaluable moral support. Finally, the authors acknowledge DA-Ilagan Soil Laboratory, whose encouragement made an impact to the conduct and completion of this research.

Literature Cited

Abitbol T, Rivkin A, Cao Y, Nevo Y, Abraham E, Ben-Shalom T, Lapidot S, Shoseyov O (2016) Nanocellulose, a tiny fiber with huge applications. Current Opinion in Biotechnology ***39***: 76 - 88

Clogston JD, Patri AK (2011) Zeta Potential Measurement. *In*: McNeil S (eds) Characterization of Nanoparticles Intended for Drug Delivery. Methods in Molecular Biology ***697***: 63 - 70

Deepa B, Abraham E, Cordeiro N, Mozetic M, Mathew AP, Oksman K, Faria M, Thomas S, Pothan LA (2015) Utilization of various lignocellulosic biomass for the production of nanocellulose: A comparative study. Cellulose ***22***(2): 1075 - 1090

Dufresne A (2013) Nanocellulose: A new ageless bionanomaterial. Materials Today ***16***(6): 220 - 227

George J, Sabapathi SN (2015) Cellulose nanocrystals: Synthesis, functional properties, and applications. Nanotechnology, Science and Applications ***8***: 45 - 54

Habibi Y, Lucia LA, Rojas OJ (2010) Cellulose nanocrystals: Chemistry, self-assembly, and applications. Chemical Reviews ***110***(6): 3479 - 3500

ISO (2017) Nanotechnologies—Standard terms and their definition for cellulose nanomaterial (ISO/TS 20477:2017), 1st ed. International Organization for Standardization

Itelima JU, Bang WJ, Onyimba IA, Sila MD, Egbere OJ (2018) Bio-fertilizers as key player in enhancing soil fertility and crop productivity: A review. Direct Research Journal of Agriculture and Food Science ***6***(3): 73 - 83

Kargarzadeh H, Ishak B, Ahmad I, I Abdullah, Dufresne A, Siti B, Zainudin Y, B Rasha, Sheltami RM (2017) Effects of hydrolysis conditions on the morphology, crystallinity, and thermal stability of *Cellulose nanocrystals* extracted from kenaf bast fibers. Cellulose Nanocrystals ***24***(5): 4475 - 4489

Schoebitz M, Lopez MD, Roldán A (2013) Bioencapsulation of microbial inoculants for better soil–plant fertilization: A review. Agronomy for Sustainable Development ***33***(4): 751 - 765

Vieira F, Santana HEP, Jesus M, Santos J, Pires P, Vaz-Velho M, Silva DP, Ruzene DS (2024) Coconut Waste: Discovering sustainable approaches to advance a circular economy. Sustainability ***16***(7): 3066

Wu J, Du X, Yin Z, Xu S, Xu S, Xu S, Zhang Y (2019) Preparation and characterization of cellulose nanofibrils from coconut coir fibers and their reinforcements in biodegradable composite films. Carbohydrate Polymers ***211***: 49 - 56

REVIEW

SOIL MICROBIAL DIVERSITY AND FARMING PRACTICES FOR SUSTAINABLE CROP PRODUCTION

Melody M. Valdez[1], Myan Ace Paola A. Villanueva[2], King Alfred Y. Atinto[3], and Jayvee C. Kitma[3]*

[1]Central Luzon State University, Science City of Muñoz, Nueva Ecija
[2]Department of Agriculture-Crop Biotechnology Center, PhilRice, Science City of Muñoz, Nueva Ecija
[3]Philippine Rice Research Institute, Science City of Muñoz, Nueva Ecija
*Corresponding Author: *jayveeacruz@gmail.com*

Abstract

Soil microorganisms are central to nutrient cycling, soil fertility, plant health, and ecosystem functioning, making them indispensable for sustainable agriculture. This review critically synthesizes current knowledge on how farming practices, including crop rotation, tillage intensity, monocropping, fertilization, organic inputs, and integrated pest management, affect soil microbial diversity and functionality. Evidence from rice-based, corn-legume, and diversified cropping systems indicates that diversified rotations, reduced tillage, and organic inputs enhance microbial abundance, community evenness, and functional redundancy, thereby promoting nutrient cycling, carbon sequestration, disease suppression, and stress resilience. Conversely, continuous monocropping, intensive tillage, and prolonged reliance on synthetic fertilizers consistently reduce microbial abundance and community evenness, leading to the dominance of a narrow range of copiotrophic taxa and a loss of functionality. These shifts are associated with diminished nutrient-use efficiency, reduced soil carbon stabilization, weakened disease-suppressive capacity, and lower resilience to environmental stress. Evidence from long-term experiments and multi-site studies indicates that declines in microbial functional diversity constrain key processes such as nitrogen transformation, organic matter turnover, and pathogen regulation. Although advances in metagenomics, transcriptomics, and functional gene profiling have improved characterization of soil microbial communities, critical gaps remain in linking changes in microbial functional traits to agronomic performance and climate resilience. This review synthesizes findings from long-term field trials, meta-analyses, and comparative cropping-system studies to evaluate how rice-based systems, corn–legume rotations, and diversified cropping systems differentially shape microbial abundance, community evenness, and functional redundancy, and to identify management strategies that consistently support soil ecosystem services and long-term productivity.

Keywords: *agricultural practices, climate, farming patterns, soil health, soil microbial diversity*

Introduction

Soil is a dynamic ecosystem underpinning crop production, providing water, nutrients, and physical support, and hosting diverse microorganisms including bacteria, archaea, fungi, actinomycetes, and protists that drive essential ecological processes such as nutrient cycling, organic matter decomposition, soil aggregations, and pathogen suppression (Gupta et al. 2022; Joos and De Tender, 2022). Healthy microbial communities enhance nutrient-use efficiency, buffer against abiotic stress, and improve plant resilience to pests and diseases.

Agricultural management strongly shapes microbial diversity, abundance, and functional potential. Practices such as crop rotation, organic inputs, cover cropping, and reduced tillage generally foster diverse and stable microbial communities. Conversely, continuous monocropping, soil compaction, and excessive chemical inputs reduce microbial richness, functional redundancy, and ecosystem resilience (Town et al. 2023; Schmidt et al. 2019). Understanding these patterns is crucial for designing microbial-informed management strategies that optimize productivity, soil health, and sustainability.

Factors Influencing Soil Microbial Diversity

Impact of Farming Patterns and Agricultural Practices

Crop Rotation and Diversification. Crop rotation and cropping-system design produce some of the most consistent and management-responsive effects on soil microbial diversity and function across agroecosystems. Across agroecosystems, soil microbial diversity responds strongly to climate zone, crop type, and soil physicochemical conditions. Long-term field studies in subtropical monsoon rice systems of southern China (clay loam, pH 5.5-6.5) and the Philippines consistently show that continuous flooding promotes anaerobic taxa (e.g., methanogens and denitrifiers), while intermittent drying favors aerobic nitrifiers and heterotrophs (Yang et al., 2019; Liu et al., 2024). In temperate maize-soybean systems of the Midwestern United States (Mollisols, neutral pH), microbial diversity is primarily driven by residue quantity and tillage intensity rather than moisture regime (Williams et al., 2023). Meanwhile, semi-arid wheat-maize systems in northern China (silt loam, low SOC) show reduced microbial evenness under intensive fertilization and monocropping due to nutrient-driven dominance of copiotrophic bacteria (Ramirez et al., 2010; Ma et al., 2025). These findings indicate that microbial diversity patterns are context-specific and cannot be generalized across climates or cropping systems.

Crop rotation alters soil microbial communities through resource heterogeneity, redox dynamics, and nutrient legacy effects, with mechanisms varying by cropping system:

Rice-corn and rice-upland rotations (China, Vietnam, Philippines): Alternation between flooded and aerobic phases creates cyclical redox conditions that enrich anaerobic decomposers during rice cultivation and aerobic nitrifiers and phosphate-solubilizers during upland phases, increasing overall functional redundancy relative to continuous rice monoculture (Breidenbach et al., 2017; Yang et al., 2019).

Cereal-legume rotations (corn-soybean, rice-mungbean; Asia and North America): Biological nitrogen fixation by legumes increases soil N availability and stimulates diazotrophs (Rhizobium, Bradyrhizobium, Azospirillum), often resulting in higher *nif*H gene abundance within 1-3 years after legume introduction (Li et al., 2022; Liu et al., 2024).

Vegetable-based and diversified rotations (solanaceous-legume-cucurbit systems; tropical Asia): High root exudate diversity and frequent residue turnover promote copiotrophic and disease-suppressive taxa (*Pseudomonas*, *Bacillus*), increasing microbial evenness but sometimes reducing fungal dominance compared with cereal-based systems (Bertola et al., 2021).

Multi-storey and high-value crop systems (pineapple-vegetable-root crop systems; Southeast Asia): Spatial and temporal niche differentiation enhances microbial richness, particularly AM fungi and Actinobacteria, under moderate fertilization and residue retention (Schmidt et al., 2019).

Dominance of functional groups depends on crop management and soil conditions. Diazotrophs dominate in legume-inclusive rotations under neutral pH (6.0-7.0), moderate SOC (>1.5%), and reduced N fertilizer inputs, while Actinobacteria prevail under cereal monocropping with low residue input and periodic drought stress (Ramirez et al., 2012). Arbuscular mycorrhizal fungi increase under reduced tillage and diversified rotations, particularly in upland systems with low P availability (Hartmann et al., 2015).

Observed increases in microbial Shannon diversity (10-30%) and microbial biomass C (10-40%) are primarily reported in long-term (>5-10 yr) rotation experiments in temperate and subtropical systems, particularly where residue retention and balanced fertilization are practiced (Williams et al., 2023; Liu et al., 2024). These effects are weaker or inconsistent in short-term trials (<3 years) or in highly degraded soils with low organic matter. The key patterns summarized here are presented in Table 1.

Crop rotation and diversification influence not only taxonomic composition but also microbial functional traits and network interactions that regulate ecosystem service delivery. Recent studies demonstrate that microbial functional diversity and the structure of microbial interaction networks are stronger predictors of nutrient cycling, disease suppression, and system resilience than species richness alone (Hartmann et al., 2015; Banerjee et al., 2018). In legume-based and diversified rotations, the enrichment of diazotrophic taxa such as *Rhizobium*, *Bradyrhizobium*, and *Azospirillum* increases nitrogen-fixation potential and strengthens nitrogen-cycling hubs within microbial networks, enhancing functional redundancy and buffering systems against nutrient stress. Conversely, simplified monocropping systems tend to reduce network connectivity and favor fewer functional guilds, making soil processes more vulnerable to disturbance.

Tillage Intensity and Residue Management. Tillage intensity fundamentally regulates soil physical disturbance, organic matter distribution, and microhabitat stability, thereby exerting strong control over soil microbial community composition and function. Conventional tillage, characterized by intensive soil inversion and residue burial, disrupts soil aggregates and fungal hyphal networks, often leading to bacterial-dominated communities, reduced fungal: bacterial ratios, and accelerated organic matter mineralization. While this can temporarily increase nutrient availability, long-term conventional tillage is consistently associated with declines in microbial diversity, reduced carbon stabilization, and weakened soil structural integrity (Six et al., 2006; Cania et al., 2019). In contrast, reduced tillage and no-till systems minimize soil disturbance and maintain surface residues, promoting the persistence of fungal-dominated microbial networks, including arbuscular mycorrhizal fungi (AMF), saprotrophic fungi, and oligotrophic bacterial taxa. Long-term field experiments report 15-40% increases in microbial biomass carbon, higher extracellular enzyme activities involved in carbon and nitrogen cycling,

Table 1. Effects of crop rotation on soil microbial communities across agroecosystems.

Rotation Type / Region	Key Mechanism	Dominant Taxa / Functional Group	Observed Diversity Outcomes
Rice-corn, rice-upland (China, Vietnam, Philippines)	Alternating flooded-aerobic phases create cyclical redox conditions	Anaerobic decomposers during rice; aerobic nitrifiers and phosphate-solubilizers during upland phases	↑ Functional redundancy; ↑ Microbial evenness[1,2]
Cereal-legume (corn-soybean, rice-mungbean; Asia, North America)	Biological N fixation by legumes increases soil N	Diazotrophs (Rhizobium, Bradyrhizobium, Azospirillum); ↑ *nif*H gene abundance[2,3]	↑ Shannon diversity; ↑ Microbial biomass C[2,3]
Vegetable-based / diversified rotations (solanaceous-legume-cucurbit; tropical Asia)	High root exudate diversity & frequent residue turnover	Copiotrophic and disease-suppressive taxa (Pseudomonas, Bacillus); ↓ Fungal dominance[4]	↑ Microbial evenness; moderate ↑ Shannon diversity[4]
Multi-storey / high-value crops (pineapple-vegetable-root; Southeast Asia)	Spatial and temporal niche differentiation; moderate fertilization, residue retention	AM fungi, Actinobacteria[5]	↑ Microbial richness; ↑ Microbial biomass C[5]
Legume-inclusive rotations (general)	Neutral pH, moderate SOC, reduced N inputs	Diazotrophs dominance[6]	↑ Shannon diversity; ↑ Microbial biomass C[6]
Cereal monocropping with low residue / drought-prone	Low residue input, periodic drought	Actinobacteria[6]	↓ Microbial richness; ↓ Microbial evenness[6]
Reduced tillage, diversified upland systems with low P	Niche availability, low P	Arbuscular mycorrhizal fungi[7]	↑ Fungal dominance; ↑ Soil functional stability[7,8]

"↑" indicates increase relative to baseline monoculture or short-term rotation systems.
[1]Breidenbach et al., 2017, [2]Wang et al., 2024, [3]Yang et al., 2019, [4]Peralta et al., 2018, [5]Schmidt et al., 2019, [6]Ramirez et al., 2010, [7]Hartmann et al., 2015, [8]Williams et al., 2023

and greater microbial network complexity under reduced and no-till management compared with conventional plowing, particularly when residues are retained (Steponavičienė et al., 2024; Pittelkow et al., 2015). However, reduced tillage may also favor certain residue-borne pathogens or slow nutrient release in cooler climates, highlighting trade-offs that are highly context dependent.

Residue management practices further modulate tillage effects on microbial diversity. *In-situ* residue retention generally enhances microbial abundance and functional diversity by providing continuous carbon inputs and microclimatic buffering, favoring decomposers such as *Actinobacteria*, *Basidiomycota*, and cellulose-degrading fungi. In contrast, chemical- or urea-assisted residue decomposition can accelerate residue breakdown but may transiently suppress microbial evenness by stimulating copiotrophic bacteria and increasing nitrogen availability, particularly under high application rates. In flooded rice systems, residue incorporation without adequate water or redox management may stimulate methanogenic archaea, whereas surface residue retention under alternate wetting and drying favors a more balanced assemblage of anaerobic and aerobic microbial guilds (Cania et al., 2019; Conrad, 2020).

Overall, evidence from long-term trials indicates that reduced or no-till systems combined with in-situ residue retention and organic amendments consistently support higher microbial diversity, functional redundancy, and ecosystem stability than tillage or residue management applied in isolation. Thus, tillage and residue strategies should be evaluated as integrated management components, with explicit consideration of climate, soil texture, and cropping system.

Tillage intensity and residue management further modulate microbial networks by altering soil structure and carbon availability. Reduced and no-tillage systems preserve fungal hyphal continuity and promote fungal-dominated networks that play a central role in carbon cycling and soil aggregation. Keystone taxa such as *Trichoderma* and saprotrophic Actinobacteria contribute to organic matter decomposition while stabilizing microbial interaction networks under residue-retained systems. In contrast, intensive tillage disrupts microbial connectivity, fragments fungal networks, and reduces the abundance of taxa responsible for pathogen suppression and long-term carbon stabilization (Banerjee et al., 2018).

Fertilization Regimes and Organic Inputs. Fertilization regimes exert strong selective pressure on soil microbial communities by altering nutrient stoichiometry, carbon availability, and soil physicochemical conditions. Pure inorganic fertilizer application, particularly nitrogen supplied as urea or ammonium-based fertilizers, consistently promotes copiotrophic bacterial taxa (e.g., *Proteobacteria*, *Bacteroidetes*) adapted to high nutrient availability, while reducing microbial community evenness and suppressing oligotrophic and slow-growing decomposers such as Acidobacteria and many saprotrophic fungi (Ramirez et al., 2012; Azarbad et al., 2022). Long-term reliance on inorganic N inputs is frequently associated with soil acidification, reduced enzyme diversity, and declines in functional redundancy, thereby narrowing the range of microbial-mediated ecosystem processes. In contrast, organic fertilization systems (e.g., manure, compost, green manure, and cover crop residues) supply chemically complex and heterogeneous carbon substrates that support diverse decomposer communities, including Actinobacteria, saprotrophic fungi (*Ascomycota* and *Basidiomycota*), and phosphorus-solubilizing bacteria. Numerous long-term field studies show that organic inputs increase microbial biomass carbon, extracellular enzyme activities involved in carbon (β-glucosidase, cellulase) and phosphorus cycling (*pho*D), and overall microbial network complexity within 1-3 years of application (Schmidt et al., 2019; Bertola et al., 2021). Integrated nutrient management, combining inorganic fertilizers with organic amendments, consistently emerges as the most resilient strategy across agroecosystems. Meta-analyses and multi-year experiments demonstrate that such systems maintain crop yields while sustaining higher microbial diversity, greater functional gene richness, and more stable microbial networks than mineral-only fertilization (Khmelevtsova et al., 2022; Liu et al., 2024). Microbial community shifts under integrated systems often become detectable within the first 1-2 years, while full restructuring of microbial functional profiles typically requires ≥3-5 years, particularly for nitrogen-cycling guilds and carbon-stabilizing fungi.

The definition of “long-term inorganic nitrogen application” in the literature generally refers to continuous mineral N inputs applied for 5-10 years, with some classical experiments extending beyond 20 years. Long-term inorganic N application (≥5-10 years) in wheat, maize, and rice systems in China and Europe consistently reduces microbial evenness and *nif*H abundance while increasing nitrifier and denitrifier dominance under high N rates (>200 kg N ha^{-1} yr^{-1}) (Ramirez et al., 2010; Azarbad et al., 2022). Organic systems (manure, compost, green manure) promote fungal decomposers and P-mobilizing bacteria, while integrated nutrient management restores microbial balance within 2-5 years after transition from mineral-only regimes (Liu et al., 2024).

Across such time scales, studies consistently report reductions in *nif*H gene abundance, altered *amo*A-driven nitrification dynamics, and increased dominance of denitrifiers under high N rates, effects that are partially reversible when organic inputs are reintroduced or N rates are reduced (Ramirez et al., 2010; Liu et al., 2024). Thus, shifts in fertilization strategy from mineral-only to integrated or organic systems can gradually restore microbial evenness, functional redundancy, and nutrient cycling capacity, although recovery trajectories depend strongly on soil type, climate, and historical management.

Fertilization regimes also shape microbial functional traits and network roles by selectively favoring taxa with specific nutrient acquisition strategies. Organic amendments enhance the abundance of functionally versatile microbial groups, including Bacillus, Pseudomonas, and Acidobacteria, which contribute to enzyme-mediated nutrient mobilization and disease suppression. Integrated nutrient management systems support more complex microbial networks with multiple functional hubs, increasing system stability under fluctuating nutrient inputs. In contrast, long-term mineral-only fertilization often simplifies microbial networks, reduces functional redundancy, and shifts communities toward copiotrophic taxa with limited ecosystem service capacity.

To synthesize how farming practices, influence microbial functional traits, keystone taxa, and interaction networks, Table 2 summarizes dominant microbial groups, their functional attributes, and their roles in supporting soil ecosystem services and crop productivity across major agricultural systems.

Rice-specific Systems (Flooding, AWD, and rotations with upland crops). Rice-based agroecosystems are distinguished by their strong hydrological and redox dynamics, which exert first-order control on soil microbial community structure and function. Prolonged flooding during rice cultivation promotes anaerobic conditions that favor methanogenic archaea (e.g., *Methanobacteriales*, *Methanosarcinales*) and denitrifiers while suppressing aerobic decomposers and nitrifiers. In contrast, drainage phases introduce oxic microsites that stimulate ammonia-oxidizing bacteria and archaea (*Nitrosospira*, *Nitrososphaera*) and enhance aerobic carbon turnover (Conrad, 2007; Breidenbach et al., 2017). Management interventions such as Alternate Wetting and Drying (AWD) deliberately exploit these redox oscillations; multiple field studies and meta-analyses show that AWD consistently reduces methanogen abundance and methane emissions while increasing *amo*A gene abundance and nitrification potential, often improving nitrogen-use efficiency without yield penalties (Yang et al., 2012; Aminurrasyid et al., 2025). Beyond water management, rice systems are increasingly exposed to abiotic stresses that reshape

Table 2. Dominant microbial groups, functional traits, and ecosystem roles across fertilization systems.

Fertilization Regime	Dominant Microbial Groups / Keystone Taxa	Key Functional Traits	Roles in Soil Ecosystem Services and Crop Productivity
Inorganic / mineral-only	Proteobacteria, Bacteroidetes, nitrifiers, denitrifiers (Ramirez, 2010; Azarbad et al., 2022)	Copiotrophic, fast-growing, N-transforming	Rapid nutrient turnover; reduced microbial evenness; simplified networks; decreased functional redundancy
Long-term inorganic N (≥5-10 yr)	Nitrifiers, denitrifiers; reduced diazotrophs (*nif*H+) (Ramirez, 2010; Liu et al., 2024)	High N tolerance; acidification-adapted	Suppressed nitrogen fixation; reduced functional redundancy; altered soil pH and enzyme diversity
Organic (manure, compost, green manure, cover crops)	Actinobacteria; Ascomycota & Basidiomycota fungi; P-solubilizing bacteria (Schmidt et al., 2019; Bertola et al., 2021)	Saprotrophic, slow-growing, nutrient-mobilizing	Enhanced decomposition; increased microbial biomass C; higher enzyme diversity; improved nutrient cycling
Integrated nutrient management (organic + inorganic)	Bacillus; Pseudomonas; Acidobacteria; diverse fungal guilds (Khmelevtsova et al., 2022; Liu et al., 2024)	Functionally versatile; network hubs	Maintains crop yield; restores microbial evenness; high functional redundancy; stable interaction networks
Transition from mineral-only - organic/integrated (1-5 yr)	Increasing saprotrophic fungi & P-solubilizers (Liu et al., 2024)	Adaptable decomposers	Gradual recovery of microbial balance, nutrient cycling, and network complexity
Transition from mineral-only -organic/integrated (1-5 yr)	Increasing saprotrophic fungi & P-solubilizers (Liu et al., 2024)	Adaptable decomposers	Gradual recovery of microbial balance, nutrient cycling, and network complexity

microbial communities. Microbial responses differ across irrigated lowland, rainfed, drought-prone, and saline-prone rice ecosystems. AWD reduces methanogen abundance in irrigated lowlands of China and Southeast Asia, while saline intrusion in coastal rice systems favors halotolerant taxa and suppresses diazotrophs. Triple-cropping systems intensify microbial turnover but may reduce functional redundancy without residue and organic matter inputs (Zhao et al., 2024; Tang et al., 2025). Drought episodes during rice fallow or reproductive stages reduce microbial biomass and suppress denitrification, while favoring drought-tolerant taxa such as Actinobacteria and spore-forming Firmicutes (De Silva et al., 2025). Conversely, saltwater intrusion in coastal rice-growing areas selects for halotolerant and sulfate-reducing microorganisms, alters nitrogen cycling pathways, and can suppress diazotrophic activity, thereby constraining biological nitrogen inputs (Rath et al., 2017). Periodic submergence at sensitive growth stages (e.g., tillering or flowering), as well as increasing soil temperatures under climate warming, further modify microbial respiration rates, methanogenesis, and enzyme kinetics, with measurable consequences for greenhouse gas emissions and nutrient availability (Rajendran et al., 2024; Wang et al., 2021).

Cropping intensity also plays a critical role. Intensive systems with two to three rice crops per year sustain prolonged anaerobic conditions and high residue inputs, often leading to simplified microbial networks dominated by methanogens and facultative anaerobes, alongside declining functional redundancy over time (Liu et al., 2021). In contrast, rotations between rice and upland crops such as maize, peanut, or vegetables periodically reintroduce aerobic phases, increasing microbial richness and promoting functional groups involved in nitrification, phosphorus solubilization, and residue decomposition (Breidenbach et al., 2017; Williams et al., 2023). Empirical studies across Asia consistently report that rice–upland rotations support more balanced N-cycling gene profiles than continuous flooded rice, although outcomes depend on residue retention and fertilization strategies.

Additional rice-specific crop management practices including residue incorporation versus removal, straw decomposition methods, fertilizer placement, and transplanting density further modulate microbial diversity and activity. Straw incorporation under flooded conditions can stimulate methanogenesis if unmanaged, whereas synchronized residue management with AWD or upland rotations mitigates methane production while sustaining microbial biomass and enzymatic activity (Yang et al., 2012; Conrad, 2007). Collectively, these findings demonstrate that rice microbial communities are shaped not by flooding alone but by interacting water, climate, cropping intensity, and residue-management regimes. Review syntheses of rice systems should therefore integrate taxonomic, functional gene, and greenhouse gas measurements across contrasting management and environmental conditions to generate robust, management-relevant conclusions.

Microbial Inoculants, Biofertilizers, and Biocontrol (Evidence and Limits). Microbial inoculants, including plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), and biocontrol agents such as *Bacillus* and *Trichoderma* spp., have demonstrated measurable benefits for crop productivity, nutrient acquisition, and disease suppression under both controlled environments and selected field conditions. Meta-analyses report average yield increases ranging from 5-15% for PGPR and AMF applications, with stronger effects under nutrient-limited or abiotic stress conditions such as drought or low phosphorus availability (Schütz et al., 2017; Li et al., 2022). Biocontrol agents, particularly *Bacillus subtilis* and *Trichoderma harzianum*, have shown consistent suppression of soil-borne pathogens through antibiotic production, induced systemic resistance, and niche competition, contributing to reduced chemical pesticide dependence in rice, vegetable, and cereal systems (Harman et al., 2021; Shrestha et al., 2016). Despite these advantages, large variability in inoculant performance remains a central limitation. Field-scale studies and global syntheses indicate that inoculant survival and efficacy are strongly constrained by soil physicochemical properties, including pH, texture, organic carbon content, and native microbial community composition (Dos Reis et al., 2024; Schmidt et al., 2019). For example, AMF colonization and function decline sharply in acidic soils (pH < 5.5) or under high phosphorus fertilization, while certain PGPR strains become ineffective or antagonistic in highly alkaline or saline environments (Nouwen et al., 2025; Rath et al., 2017). In some cases, introduced strains fail to establish due to competitive exclusion by well-adapted native microbiota, resulting in neutral or even negative impacts on microbial diversity and plant performance.

Temporal dynamics further influence outcomes. Short-term responses (within one growing season) often reflect transient increases in target microbial groups, whereas longer-term establishment (≥2–3 years) depends on repeated applications, compatible crop rotations, and organic matter inputs that stabilize microbial niches (Bertola et al., 2021; Li et al., 2022). Integrated management strategies such as combining inoculants with crop rotation, residue retention, and moderate organic amendments consistently outperform inoculant-only approaches by reducing environmental stress and enhancing microbial persistence. Consequently, microbial products are most effective when deployed as components of microbial-conscious farming systems rather than as stand-alone substitutes for sound soil management. Future research should emphasize standardized multi-site trials, explicit reporting of soil conditions, and long-term assessments to clarify when and where microbial inoculants reliably enhance soil microbial diversity and ecosystem function.

Climate and Environmental Conditions

Environmental and climatic conditions act as overarching modifiers of soil microbial responses to crop management practices, interacting strongly with cropping systems, tillage, fertilization, and residue management. Soil temperature and moisture regulate microbial metabolism, enzyme activity, and community composition, thereby mediating the effects of management interventions on nutrient cycling and soil health. Seasonal fluctuations in moisture availability drive pronounced shifts in microbial assemblages; for example, arbuscular mycorrhizal (AM) fungal communities exhibit distinct wet- and dry-season compositions, reflecting differences in carbon allocation, host phenology, and soil aeration (Dumbrell et al., 2011). Prolonged drought stress can reduce total microbial biomass by 40-80%, constraining organic matter decomposition, aggregate stability, and plant–microbe interactions, while favoring drought-tolerant taxa such as Actinobacteria and spore-forming *Bacillus* spp. that help maintain partial functional redundancy (Manzoni et al., 2012; De Silva et al., 2025). Climate effects are further compounded by crop and soil management. Drying-rewetting cycles common in rainfed and rotational systems alter redox dynamics and nutrient availability, reshaping microbial functional pathways such as nitrification and denitrification (de Vries and Shade, 2013). Elevated temperatures and increased atmospheric CO_2 can stimulate microbial respiration and accelerate carbon turnover, but may also shift communities toward fast-growing copiotrophic taxa, potentially reducing long-term soil carbon stabilization unless counterbalanced by residue retention or organic amendments (Crowther et al., 2016). Moisture stress has been shown to suppress populations of symbiotic nitrogen-fixing bacteria such as *Rhizobium* spp., reducing nodulation efficiency in legume phases of crop rotations (Pena-Cabriales and Alexander, 1979).

Climate effects described here are crop- and system-specific, primarily derived from cultivated agroecosystems rather than forests or grasslands. Drought impacts are strongest in rainfed cereals, whereas temperature effects are most pronounced in flooded rice systems where microbial-mediated greenhouse gas emissions are sensitive to warming (de Vries and Shade, 2013).

Importantly, management strategies can buffer microbial communities against climatic variability. Practices such as crop diversification, cover cropping, reduced tillage, and organic matter inputs increase soil organic carbon and improve soil structure, enhancing moisture retention and thermal buffering. These conditions promote more stable microbial networks capable of sustaining nutrient cycling under climate stress (Schmidt et al., 2019; Williams et al., 2023). Thus, climatic and environmental drivers should be interpreted not as isolated stressors, but as interacting forces that modulate the outcomes of crop management decisions on soil microbial diversity and ecosystem functioning.

Challenges and Knowledge Gaps

Despite substantial advances in soil microbiome research, several critical and unresolved gaps remain that limit the translation of existing knowledge into predictive and management-ready frameworks. While archaea, protists, nematodes, and other soil fauna have been documented in agricultural systems, most studies remain bacteria- and fungi-centric, with non-bacterial groups often underrepresented in routine surveys due to methodological constraints and limited functional annotation (Geisen et al., 2019; Gupta et al., 2022). As a result, their contributions to nutrient cycling, trophic regulation, and microbial network stability in managed agroecosystems are still poorly quantified.

Long-term and multi-site studies have demonstrated that farming practices influence microbial composition; however, few experiments simultaneously link temporal microbial dynamics, functional gene abundance, and crop productivity across seasons and locations (Hartmann et al., 2015; Banerjee et al., 2018). Existing long-term trials often report compositional shifts but stop short of establishing quantitative relationships between microbial functional traits (e.g., *nif*H-, *amo*A-, *pho*D-associated processes) and agronomic outcomes, limiting their utility for decision-making. Although functional gene markers are increasingly measured, their integration into predictive models of yield stability, nutrient-use efficiency, and resilience to climate stress remains limited (Ramirez et al., 2010; Delgado-Baquerizo et al., 2020).

Moreover, while microbial network analyses and soil health indices have been explored independently, their combined application within adaptive management frameworks is still in its infancy. Few studies explicitly integrate microbial interaction networks with soil physicochemical indicators and climate variables to identify keystone taxa or functional thresholds that signal system resilience or vulnerability (Banerjee et al., 2018; de Vries et al., 2018). Addressing these gaps will require coordinated long-term field experiments that combine multi-omics approaches, microbial network analysis, and agronomic performance metrics across diverse cropping systems and environmental gradients. Such integrative efforts are essential to move microbial-conscious agriculture from descriptive understanding toward predictive and operational application. Despite extensive literature, key gaps remain within specific systems: (1) limited multi-year data on microbial recovery after transition from monocropping to rotation in tropical rice systems; (2) insufficient thresholds for functional redundancy under AWD and drought; (2) inconsistent performance of microbial inoculants across soil types and climates. Addressing these gaps requires crop-specific, long-term, multi-location trials integrating microbial functional indicators with agronomic outcomes.

Opportunities for Enhancing Microbial Diversity

- Adopt integrated management: combine diversified rotations, residue retention, reduced tillage, and targeted organic inputs to synergistically support microbial diversity and maintain yields.
- Targeted inoculant use: deploy microbial products where native communities are depleted (e.g., long-term monoculture fields) and evaluate in multi-year trials.
- Standardize reporting: adopt minimum metadata standards (crop history, soil depth, sampling month, management) to allow meta-analyses.
- Policy and extension: translate microbial indicators into farmer-friendly metrics (e.g., soil microbial biomass, basic enzyme assays) and incorporate them into advisory systems.
- Microbial inoculants and biofertilizers: Combinations of Azotobacter, phosphate-solubilizing bacteria, and AM fungi enhance nutrient uptake, root growth, and soil aggregation (Bertola et al. 2021).
- Biocontrol agents: *B. subtilis* and *T. harzianum* suppress pathogens, reducing chemical pesticide reliance (Francis et al. 2020).
- Agronomic practices: Crop rotation, cover cropping, residue retention, reduced tillage, and organic inputs reinforce microbial networks, improving functional diversity and ecosystem services (Town et al. 2023; Williams et al. 2023).

Combining microbial-based technologies with microbial-informed agronomy achieves productivity, sustainability, and resilience to climate variability.

Conclusion

Soil microbial diversity is a core component of agroecosystem resilience. Evidence from multi-site trials and meta-analyses indicates that diversified cropping systems, conservation tillage with residue retention, and organic matter additions consistently support higher microbial richness, functional redundancy, and network stability than monocropping and mineral-only fertilization regimes. Future studies must combine taxonomic and functional profiling with agronomic metrics across multiple years and locations to make the review exhaustive and actionable. Implementing microbial-conscious management at scale hinges on integrating these scientific insights into adaptive management frameworks that account for local soil, climate, and crop contexts.

Literature Cited

Aminurrasyid AHB, Mohd Ikmal A, Nadarajah KK (2025) The rice-microbe nexus: Unlocking productivity through soil science. Rice (New York, N.Y.) ***18***(1): 56

Azarbad H (2022) Conventional vs. organic agriculture-which one promotes better yields and microbial resilience in rapidly changing climates? Frontiers in Microbiology ***13***: 903500

Banerjee S, Schlaeppi K, van der Heijden, MGA. (2018). Keystone taxa as drivers of microbiome structure and functioning. Nature Reviews. Microbiology ***16***(9): 567 - 576

Bertola M, Ferrarini A, Visioli G (2021) Improvement of soil microbial diversity through sustainable agricultural practices and its evaluation by -omics approaches: A perspective for the environment, food quality and human safety. Microorganisms ***9***(7):1400

Breidenbach B, Brenzinger K, Brandt FB, Blaser MB, Conrad R (2017) The effect of crop rotation between wetland rice and upland maize on the microbial communities associated with roots. Plant and Soil ***419***(1 - 2): 435445

Cania B, Vestergaard G, Krauss M, Fliessbach A, Schloter M, Schulz S (2019) A long-term field experiment demonstrates the influence of tillage on the bacterial potential to produce soil structure-stabilizing agents such as exopolysaccharides and lipopolysaccharides. Environmental Microbiome ***14***(1): 1

Conrad R (2020) Importance of hydrogenotrophic, aceticlastic and methylotrophic methanogenesis for methane production in terrestrial, aquatic and other anoxic environments: A mini review. Pedosphere ***30***(1): 25 - 39

Crowther TW, Todd-Brown KEO, Rowe CW, Wieder WR, Carey JC, Machmuller MB, Snoek BL, Fang S, Zhou G, Allison SD, Blair JM, Bridgham SD, Burton AJ, Carrillo Y, Reich PB, Clark JS, Classen AT, Dijkstra FA, Elberling B, Emmett BA, Estiarte M, Frey SD, Guo J, Harte J, Jiang L, Johnson BR, Kröel-Dulay G, Larsen KS, Laudon H, Lavallee JM, Luo Y, Lupascu M, Ma LN, Marhan S, Michelsen A, Mohan J, Niu S, Pendall E, Peñuelas J, Pfeifer-Meister L, Poll C, Reinsch S, Reynolds LL, Schmidt IK, Sistla S, Sokol NW, Templer PH, Treseder KK, Welker JM, Bradford MA (2016) Quantifying global soil carbon losses in response to warming. Nature ***540***(7631): 104 - 108

de Vries FT, Shade A (2013) Controls on soil microbial community stability under climate change. Frontiers in Microbiology ***4***: 265

Delgado-Baquerizo M, Reich PB, Trivedi C, Eldridge DJ, Abades S, Alfaro FD, Bastida F, Berhe AA, Cutler NA, Gallardo A, García-Velázquez L, Hart SC, Hayes PE, He JZ, Hseu ZY, Hu HW, Kirchmair M, Neuhauser S, Pérez CA, Reed SC, Santos F, Sullivan BW, Trivedi P, Wang JT, Weber-Grullon L, Williams MA, Singh BK (2020) Multiple elements of soil biodiversity drive ecosystem functions across biomes. Nature Ecology & Evolution ***4***(2): 210 - 220

De Silva S, Kariyawasasm Hetti Gamage L, Thapa VR (2025) Impact of drought on soil microbial communities. Microorganisms ***13***(7): 1625

dos Reis GA, Martínez-Burgos WJ, Pozzan R, Pastrana Puche Y, Ocán-Torres D, de Queiroz Fonseca Mota P, Rodrigues C, Lima Serra J, Scapini T, Karp SG, Soccol CR (2024) Comprehensive review of microbial inoculants: Agricultural applications, technology trends in patents, and regulatory frameworks. Sustainability ***16***(19): 8720

Dumbrell AJ, Nelson M, Helgason T, Dytham C, Fitter AH (2011) Relative roles of niche and neutral processes in structuring a soil microbial community. The ISME Journal ***4***(3): 337 - 345

Francis F, Jacquemyn H, Delvigne F, Lievens B (2020) From diverse origins to specific targets: Role of microorganisms in indirect pest biological control. Insects ***11(***8): 533

Geisen S, Briones MJI, Gan H, Behan-Pelletier VM, Friman VP, de Groot GA, Hannula SE, Lindo Z, Philippot L, Tiunov AV, Wall DH (2019) A methodological framework to embrace soil biodiversity. Soil Biology & Biochemistry ***136***(107536): 107536

Gupta A, Singh UB, Sahu PK, Paul S, Kumar A, Malviya D, Singh S, Kuppusamy P, Singh P, Paul D, Rai JP, Singh HV, Manna MC, Crusberg TC, Kumar A, Saxena AK (2022) Linking soil microbial diversity to modern agriculture practices: A review. International Journal of Environmental Research and Public Health ***19***(5): 3141

Harman GE, Doni F, Khadka RB, Uphoff N (2021) Endophytic strains of Trichoderma increase plants' photosynthetic capability. Journal of Applied Microbiology ***130***(2): 529 - 546

Hartmann M, Frey B, Mayer J, Mäder P, Widmer F (2015) Distinct soil microbial diversity under long-term organic and conventional farming. The ISME Journal ***9***(5): 1177 - 1194

Joos L, De Tender C (2022) Soil under stress: The importance of soil life and how it is influenced by (micro)plastic pollution. Computational and Structural Biotechnology Journal ***20***: 1554 - 1566

Khmelevtsova LE, Sazykin IS, Azhogina TN, Sazykina MA (2022) Influence of agricultural practices on bacterial community of cultivated soils. Agriculture ***12***(3): 371

Li J, Wang J, Liu H, Macdonald CA, Singh BK (2022) Application of microbial inoculants significantly enhances crop productivity: A meta-analysis of studies from 2010 to 2020. Journal of Sustainable Agriculture and Environment ***1***(3): 216 - 225

Liu B, Ahnemann H, Arlotti D, Huyghebaert B, Cuperus F, Tebbe CC (2024) Impact of diversified cropping systems and fertilization strategies on soil microbial abundance and functional potentials for nitrogen cycling. Science of the Total Environment ***932***: 172954

Ma G, Zhang X, Han X, Kang J, Zhang H, Zhang Y, Lu H, Xie Y, Ma D, Wang C (2025) Nitrogen fertilization effects on soil bacterial communities, nitrogen-cycling genes, and wheat yield across different soil types in the north China plain. Microorganisms ***13***(10): 2382

Manzoni S, Schimel JP, Porporato A (2012) Responses of soil microbial communities to water stress: results from a meta-analysis. Ecology ***93***(4): 930 - 938

Nouwen O, Rineau F, Kohout P, Baldrian P, Eisenhauer N, Beenaerts N, Thijs S, Vangronsveld J, Soudzilovskaia NA (2025) Towards understanding the impact of mycorrhizal fungal environments on the functioning of terrestrial ecosystems. FEMS Microbiology Ecology ***101***(8)

Pena-Cabriales JJ, Alexander M (1979) Survival of *Rhizobium japonicum* and *Rhizobium leguminosarum* in soils undergoing drying. Soil Science Society of America Journal ***43***(5): 962 - 967

Peralta AL, Sun Y, McDaniel MD, Lennon JT (2018) Crop rotational diversity increases disease suppressive capacity of soil microbiomes. Ecosphere ***9***(5): e02235

Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, van Gestel N, Six J, Venterea RT, van Kessel C (2015) Productivity limits and potentials of the principles of conservation agriculture. Nature ***517***(7534): 365 - 368

Rajendran S, Park H, Kim J, Park SJ, Shin D, Lee JH, Song YH, Paek NC, Kim CM (2024) Methane emission from rice fields: Necessity for molecular approach for mitigation. Rice Science ***31***: 159 - 178

Ramirez KS, Lauber CL, Knight R, Bradford MA, Fierer N (2010) Consistent effects of nitrogen fertilization on soil bacterial communities in contrasting systems. Frontiers in Ecology and the Environment ***91***(12): 3463 - 3470

Rath KM, Maheshwari A, Rousk J (2017) The impact of salinity on the microbial response to drying and rewetting in soil. Soil Biology & Biochemistry ***108***: 17 - 26

Schmidt JE, Kent AD, Brisson VL, Gaudin AM (2019) Agricultural management and plant selection interactively affect rhizosphere microbial community structure and nitrogen cycling. Microbiome ***7***(146)

Schütz L, Gattinger A, Meier M, Müller A, Boller T, Mäder P, Mathimaran N (2017) Improving crop yield and nutrient use efficiency via biofertilization-A global meta-analysis. Frontiers in Plant Science ***8***: 2204

Shrestha BK, Karki HS, Groth DE, Jungkhun N, Ham JH (2016) Biological control activities of rice-associated *Bacillus* sp. Strains against sheath blight and bacterial panicle blight of rice. PloS One ***11***(1): e0146764

Six J, Frey SD, Thiet RK, Batten KM (2006) Bacterial and fungal contributions to carbon sequestration in agroecosystems. Soil Science Society of America Journal. Soil Science Society of America ***70***(2): 555 - 569

Steponavičienė V, Žiūraitis G, Rudinskienė A, Jackevičienė K, Bogužas V (2024) Long-term effects of different tillage systems and their impact on soil properties and crop yields. Agronomy ***14***(4): 870

Tang H, Zhou J, Liu N, Huang Y, Liu Q, Altihani FA, Yang B (2025) Response of soil microbial diversity to triple-cropping system in paddy fields in middle reaches of Yangtze River. Plants ***14***(9): 1292

Town JR, Dumonceaux T, Tidemann B, Helgason BL (2023) Crop rotation significantly influences the composition of soil, rhizosphere, and root microbiota in canola (*Brassica napus* L.). Environmental Microbiome ***18***(40)

Wang C, Morrissey EM, Mau RL, Hayer M, Piñeiro J, Mack MC, Marks JC, Bell SL, Miller SN, Schwartz E, Dijkstra P, Koch BJ, Stone BW, Purcell AM, Blazewicz SJ, Hofmockel KS, Pett-Ridge J, Hungate BA (2021) The temperature sensitivity of soil: microbial biodiversity, growth, and carbon mineralization. The ISME Journal ***15***(9): 2738 -2747

Wang Q, Zhou D, Chu C, Zhao Z, Ma M, Wu S (2024) The choice of rice rotation system affects the composition of the soil fungal community and functional traits. Heliyon ***10***(1): e24027

Williams A, Birt HG, Raghavendra A, Dennis P (2023) Cropping system diversification influences soil microbial diversity in subtropical dryland farming systems. Microbial Ecology ***85***(4): 1473 - 1484

Yang S, Peng S, Xu J, Luo Y, Li D (2012) Methane and nitrous oxide emissions from paddy field as affected by water-saving irrigation. Physics and Chemistry of the Earth ***53-54***: 30 - 37

Yang Y, Feng X, Hu Y, Zeng Z (2019) The diazotrophic community in oat rhizosphere: effects of legume intercropping and crop growth stage. Frontiers of Agricultural Science and Engineering ***6***(2): 162

Zhao C, Qiu R, Zhang T, Luo Y, Agathokleous E (2024) Effects of alternate wetting and drying irrigation on methane and nitrous oxide emissions from rice fields: A meta-analysis. Global Change Biology ***30***(12): e17581

CALL FOR PUBLICATION
Rice-based Biosystems Journal

SCOPE

The Rice-based Biosystems Journal encourages publication of original research and review articles that have impact on applied and integrated rice and rice-based cropping systems in a particular ecosystem. The Journal provides information on rice-based researches on soil and crop management, crop protection, crop improvement, grain quality, farm machinery, resource use efficiency, plant biology, nutraceuticals, food value-adding systems, biofertilizers, biopesticides, biomaterials, and system analysis and simulation. It also covers the economics, social, and communication systems that influence the landscape of rice and rice-based cropping systems.

AUTHOR'S GUIDELINES

1. Submission and Acceptance of Manuscripts

Manuscripts are submitted to Rice-based Biosystems Journal: rbbj.philrice@gmail.com. Manuscripts should be formatted as described in the Rice-based Biosystems Journal Author Guidelines and follow the PhilRice style guide. When preparing your file, please use Times New Roman as font type, and 12 as font size for the text. Please do not use Japanese or other Asian fonts. Do not use automated or manual hyphenation. With your submission, you will have to complete, sign, and send the Copyright Transfer Agreement. Authors may provide names of potential reviewers for their manuscript. Authors must inform the editorial assistant of any possible conflict of interest capable of influencing their judgement, and if necessary, a disclaimer will be included. Revised manuscripts must be submitted two weeks after the authors are notified of conditional acceptance pending satisfactory revision. Authors resubmitting manuscripts should follow the same procedures as for submission of new manuscripts. If accepted, papers become the copyright of the journal. Photos and tables must be high resolution scans (JPEG at 300 dpi).

2. Requirements for Manuscripts

2.1. Language

The language of publication is English.

2.2. Format

The first page should contain the name and address of the institute where the work has been done, the title of the paper, name(s) and initial(s) of the author(s), the e-mail address of the corresponding author, and the number of figures and tables.

The main text shall be preceded by an abstract, which is always in English and contains the background for the research undertaken, reference to the material and methods used, as well as main results and conclusions. It should not exceed 220 words. Up to seven 'keywords' should be added. A short version of the title (running title) should also be given.

The main text should be divided into the following sections: Introduction, Materials and Methods, Results and Discussion, Conclusion, Recommendation, Acknowledgment, and Literature Cited. Facts explained by tables or figures need no lengthy explanation in the text. Numerical material should be submitted only after statistical processing.

The manuscript comprises a printout of the text and a list of all figures and tables with their captions and titles on a separate piece of paper. In anticipation of the online edition, we ask that you convey the essential information within the first 60 characters of the captions. Each figure, table, and bibliographic entry must have a reference in the text. The preferred position for the insertion of figures and tables should be marked on the margin of the text of the manuscript. Any corrections requested by the reviewer should already be integrated into the file. The text should be prepared using standard software (Microsoft Word). Please do not include footnotes.

2.3. Length

The manuscript should be typed double spaced with a 4 cm left margin. Manuscripts, including figures and tables, should not exceed 25 printed pages. The publication of shorter papers may be given priority.

2.4. Units, Abbreviations, and Nomenclature

All units and measures must conform to the international standard-system (SI). Botanical genus and species names should be set in italics.

2.5. Illustrations and Tables

The number of tables and figures should be kept to the minimum necessary, and have a maximum of 13 cm in height and 17 cm in width. All figures should include reproducible copies marked with the author's name, short title, and figure number. Figures submitted as electronic file should be saved in PNG instead of JPEG for better quality. Powerpoint and Word graphics are unsuitable for reproduction.

Submit high-contrast photographic materials suitable for reproduction. Images should be of high quality with respect to detail, contrast, and fineness of grain to withstand the inevitable loss of contrast and detail during the printing process.

Scanned figures (usually in JPEG format) should have a resolution of 300 dpi (halftone) or 600 to 1200 dpi (line drawings) in relation to the reproduction size. You may submit figures in color or black and white. Graphs with an x and y axis should not be enclosed in frames; only 2-dimensional representations. Place labels and units.

Captions for the figures should give a precise description of the content and should not be repeated within the figure. Tables should be created with the table function of a word processing program. Spreadsheets are not acceptable.

2.6. References

The literature cited should be arranged alphabetically and contain: the author's surname, first name and middle initial, year of publication, title of paper, name of journal, volume number, and first and last page number of the publication.

Bibliographic references to books or other established publications should contain: author's surname, first name and middle initial, year of publication, and edition, publishing house and place of publication. The name of the author and the date of publication should be included within the text. If more than one publication of the same author appeared in one year, these should be marked by small letters after the year, e.g., 2015a; 2015b. References to publications by more than two authors should be cited as follows: Luna et al. (2015) or (Luna et al., 2015).

3. Copyright

If your paper is accepted, the author identified as the formal corresponding author for the paper will receive an email.

4. Proof Corrections and Offprints

The corresponding author will receive an e-mail with the laid out publication. A working e-mail address must therefore be provided for the corresponding author. Further instructions will be sent with the proof. We will charge for excessive changes made by the author in the proofs, excluding typesetting errors.

5. Submission and Acceptance of Research Notes

A research note is a short discussion on key research findings and advances on a particular theory, study, or methodology that does not sum up to a full research article. The format and guidelines of a research note resembles that of a full-length manuscript except for the number of words, figures and/or tables. A 3000 to 4000-word paper with an abstract and a maximum of 2 figures and/or 2 tables may be submitted as a research note.

6. Submission of Invited Papers

The Editorial Team can invite a member of the Advisory Board and Editorial Board of the Rice-based Biosystems Journal or an expert to submit a paper in line with the theme of the volume to be published. Invited papers may be in the form of a full paper, research note or a review article. A review article gives information on a particular field of study, recent major advances and discoveries, significant gap in the research, current debates, and ideas or recommendations for future advances.

At least one expert on the subject matter will review the invited paper. Instructions for submitting a full paper and research note are in numbers 1-5 of the author guidelines.

6.1 Format

The Abstract consists of 220 words or less that summarizes the topic of the review. The current challenges and perspective on the topic are addressed, with significant conclusion and recommendations.

The Introduction states the purpose of the review. It presents a short background of the nature of the problem and its aspects of being resolved. The limitations of current solution or studies are included.

The Body presents the current studies and major advances or discoveries and impact on the present situation of the problem. Evaluation of studies such as applicability and availability of the methods used to certain areas and situation or statistical significance are elaborated.

The Conclusion summarizes the overall or major impacts and main points of the current studies. Recommendations for future advances of the research on the subject matter are presented.

The Literature Cited follows the instructions in number 2.6 of the author guidelines.

EDITORIAL POLICY

Authors should:

- designate a corresponding author who will be responsible in coordinating issues related to submission and review, including ensuring that all authorship disagreements are resolved appropriately;
- submit original work that has been honestly carried out according to rigorous experimental standards;
- give credit to the work and ideas of others that led to their work or influenced it in some way;
- declare all sources of research funding and support;
- submit manuscripts that are within the scope of the journal by ensuring that they abide by the journal's policies and follow its presentation and submission requirements;
- explain in a cover letter if there are special circumstances when the manuscript deviates in any way from a journal's requirements or if anything is missing and ensure that the manuscripts do not contain plagiarized material or anything that is libelous, defamatory, indecent, obscene or otherwise unlawful, and that nothing infringes the rights of others;
- ensure they have permission from others to cite personal communications and that the extent, content, and context have been approved;
- provide details of related manuscripts they have submitted or have in press elsewhere; and
- check the references cited to ensure that the details are correct.

Authors should not:

- submit the same or a very similar manuscript to more than one journal at the same time, present their work, or use language, in a way that detracts from the work or ideas of others;
- be influenced by the sponsors of their research regarding the analysis and interpretation of their data or in their decision on what to, or not to publish and when to publish;
- divide up the papers inappropriately into smaller ones in an attempt to increase their list of publications;
- be involved in 'ghost' or 'gift' authorship;
- use information privately obtained without direct permission from the individuals from whom it was obtained;
- make exaggerated claims about the novelty or significance of their findings;
- misrepresent or inappropriately enhance their results by any means;
- make significant changes to their manuscript after acceptance without the approval of the editor or journal editorial office; and
- submit a manuscript that has been rejected by one journal to another journal without considering the reviewers' comments, revising the manuscript, and correcting presentational errors.

Reviewers should:

- Maintain the confidentiality of all manuscript content throughout the review process Provide an unbiased evaluation of the scientific papers; and
- Contribute to improving the quality of submitted manuscripts by reviewing them carefully, thoughtfully, and objectively Submit their evaluations on or before the stated deadline. If a delay is unavoidable, they must inform the managing editor promptly.

Reviewers should not:

- Share or copy information from the manuscripts for any purpose;
- Accept an invitation to review a manuscript if the intention is only to gain insights without submitting a completed evaluation form Use any information from the evaluated manuscript for their own research if the manuscript is still under review; and
- Suggest that authors cite their own research papers unless it is genuinely relevant to the work being reviewed.

Plagiarism Policy

- The journal not only promotes and advocates for the original works of its authors but also supports the protection of intellectual property rights. The use of plagiarized content in papers is a violation of research and originality standards. All authors submitting manuscripts to the journal are required to declare the originality of their work, avoid all forms of plagiarism, and adhere to ethical guidelines. If plagiarism is identified during the peer review process, the manuscript will be rejected.

Post-publication and Malpractice Statement

- In the event that plagiarism or misconduct is discovered after publication, the journal reserves the right to take appropriate action to correct any inaccuracies or retract the paper. Requests for corrections by authors to address errors that impact the interpretation of the manuscript after publication are subject to approval by the editor. If a reader identifies a serious error, they are encouraged to contact the authors of the paper directly.

Ethical Guidelines for Authors

- Ensure that the manuscript submitted for review is original, based on research, written by the listed authors, has not been published elsewhere, and is not being submitted simultaneously to other journals.
- Obtain approval from all authors and the research institutions where the study was conducted before submitting the manuscript.
- Ensure that individuals who contributed to the research receive appropriate acknowledgment. Avoid plagiarism and the use of fabricated data. Declare any conflicts of interest. Do not cite unpublished work.

Peer Review Policy

- The journal employs a double-blind peer review process, ensuring that both reviewers and authors remain anonymous to one another. Under this process, the journal invites two experts to evaluate each manuscript. The manuscript will be returned to the authors for revisions based on the referees' comments and suggestions. Revisions will continue until the referees approve the manuscript.
- The editorial board reserves the right to close the review process if authors fail to respond to necessary revisions or if the referees do not recommend the manuscript for publication. The final recommendation of the referees will be considered by the editor in chief when making the decision to publish.

Philippine Rice Research Institute
Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija

BRANCH STATIONS:
DA-PhilRice Batac, MMSU Campus, City of Batac, 2906 Ilocos Norte; Mobile: 0919-944-3016; Email: batac_1.station@mail.philrice.gov.ph
DA-PhilRice Isabela, Malasin, San Mateo, 3318 Isabela; Mobile: 0999-889-3027; Email: isabela.station@mail.philrice.gov.ph; philriceisabela3318@gmail.com
DA-PhilRice Los Baños, UPLB Campus, Los Baños, 4031 Laguna; Tel: (49) 501-1917; Mobile: 0993-631-9175; Email: losbanos.station@mail.philrice.gov.ph
DA-PhilRice Bicol, Batang, Ligao City, 4504 Albay; Tel: (52) 431-0122; 742-0690; 742-0684; Email: bicol.station@mail.philrice.gov.ph
DA-PhilRice Negros, Cansilayan, Murcia, 6129 Negros Occidental; Mobile: 0909-129-3763; Email: negros.station@mail.philrice.gov.ph
DA-PhilRice Agusan, Basilisa, RTRomualdez, 8611 Agusan del Norte; Telefax: (85) 806-0463; Email: agusan.station@mail.philrice.gov.ph
DA-PhilRice Midsayap, Bual Norte, Midsayap, 9410 Cotabato; Mobile: 0938-374-1040; Email: midsayap.station@mail.philrice.gov.ph

SATELLITE STATIONS:
Mindoro: Alacaak, Sta. Cruz, 5105 Occidental Mindoro; Mobile: 0919-495-9371
Samar: UEP Campus, Catarman, 6400 Northern Samar; Mobile: 0921-555-5500; 0948-754-5994; Email: philricesamar@gmail.com
Zamboanga: WMSU Campus, San Ramon, 7000 Zamboanga City; Mobile: 0975-526-0306

DA-PhilRice Field Office, CMU Campus, Sayre Highway, Musuan, Maramag, 8714 Bukidnon; Mobile: 0909-822-9813; Email: philricefocmu.2019@gmail.com
Liaison Office, 3rd Floor, ATI Building, Elliptical Road, Diliman, Quezon City; Mobile: 0928-915-9628

www.philrice.gov.ph
www.pinoyrice.com
☎ **0917-111-7423**
DA-PhilRice
✉ **philrice@philrice.gov.ph**
▶ **PhilRice TV**

CALL FOR PAPERS

The Rice-Based Biosystems Journal is a peer-reviewed online and an open-accessed journal in The University Library of University of the Philippines Diliman, Cagayan State University Library, and recently in Caloocan City Science High School. In 2025, RBBJ received a recognition as one of the indexed journal in Andrew Gonzalez Philippine Citation Index (AGCPI). It is managed by the Philippine Rice Research Institute (PhilRice) through a competent editorial team, reputable advisory and editorial boards, and invited referees. The journal encourages publication of original research and review articles that have impact on and are interconnected with rice and rice-based crops. It publishes rice and rice-based research studies on soil and crop management, crop protection, crop improvement, grain quality, farm machinery, resource use efficiency, plant biology, nutraceuticals, food value-adding systems, biofertilizers, biopesticides, biomaterials, and systems analysis and stimulation. It also covers the economics, social, and communication systems that may influence the landscape of rice and rice-based production. For your submission, you can email your manuscript to rbbj.philrice@gmail.com with subject and file format as: RBBJ_Title_Surname.doc. For more information about the journal, please visit www.philrice.gov.ph/grants/call-publication/.

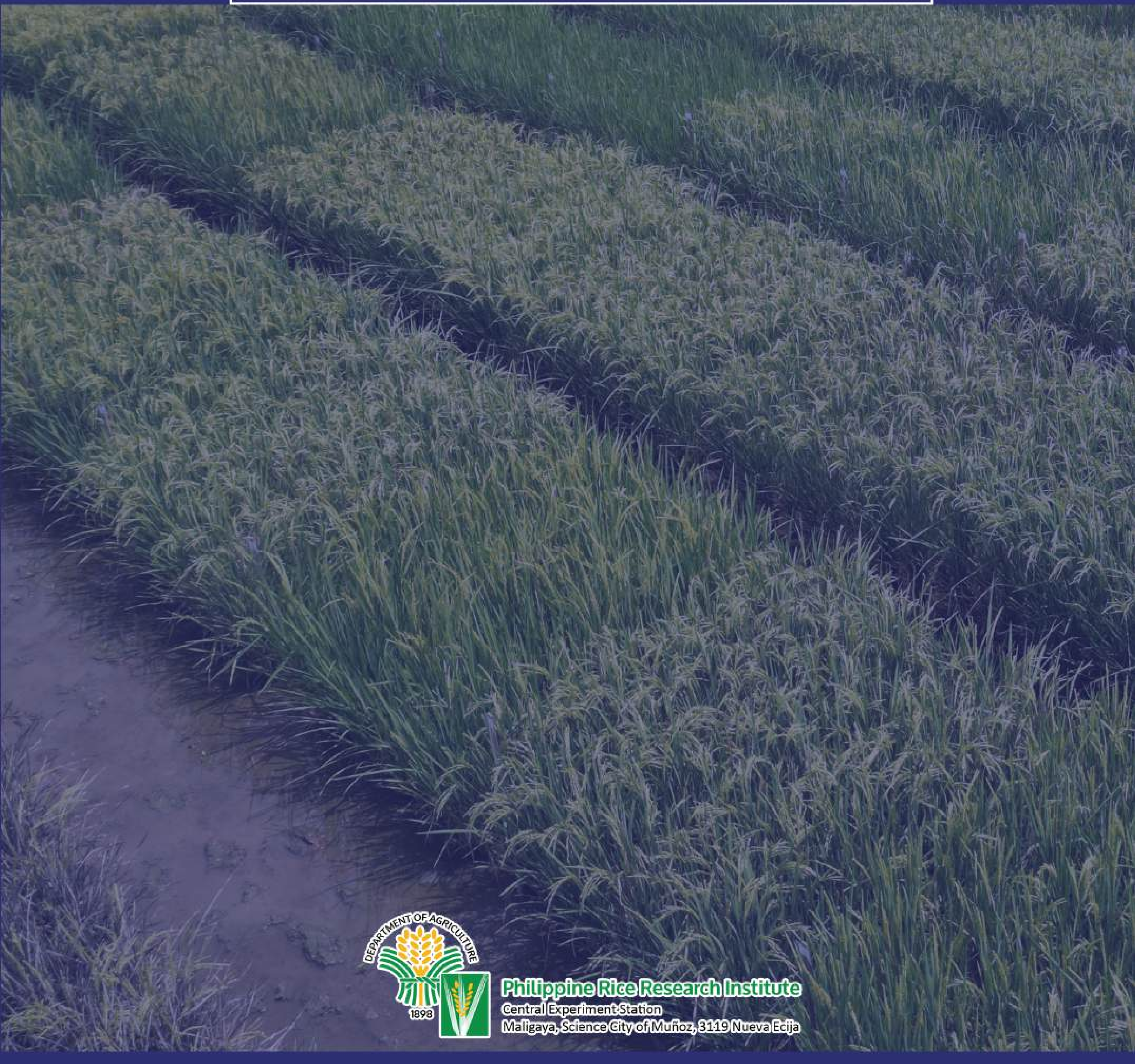
RICE-BASED BIOSYSTEMS JOURNAL

Volume 13 • Issue 1 • February 2025

CALL FOR PAPERS

visit www.philrice.gov.ph/grants/call-publications/

Mailing address:
PhilRice Central Experiment Station
Science City of Muñoz, 3119 Nueva Ecija



Philippine Rice Research Institute
Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija

RBBJ

Volume 12 • Issue 1 • February 2024

RICE-BASED BIOSYSTEMS JOURNAL

Volume 13 ▪ Issue 1 ▪ February 2025

Philippine Rice Research Institute
Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija