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# Differential Response of Three Legume Crops to Integrated Nutrient Management: Synergistic Effects of Reduced Nitrogen and *Bradyrhizobium*-Based Biofertilizer

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**Abstract**

This study investigates the impact of selected soil parameters and integrated fertilizer formulations on the productivity of three legume crops—mung bean, soybean, and cowpea—in order to identify the optimal strategies to maximize yields through reduced nitrogen and bio-augmentation. A five-year experiment composed of 2-year pot trials (2019–2020) and 3-year field trials (2022–2024) was conducted to assess the changes in soil parameters (N, P, K, OM, pH) and yield response of crops with varying amounts (1, 2, 4 kg) of *Bradyrhizobium*-based biofertilizer combined with a 25–50% reduction in mineral N fertilizer. The biofertilizer was composed of locally isolated strains, which were genetically identified in our previous reports as *B. elkanii* NE1-6, NE2-1, *B. diazoefficiens* NE1-65, *Bradyrhizobium* sp. NE1-19, NE1-34, and NE2-3. The results indicated that the amount of K strongly influenced yield increase for soybean ($r = 0.85$, $p < 0.05$) and mung bean ($r = 0.67$, $p < 0.05$), while the amount of N had the greatest influence on cowpea ($r = 0.60$, $p < 0.05$). Soybean yield was maximized with a 50% reduction in N fertilizer (20 kg N) combined with 2–4 kg biofertilizer, while cowpea and mung bean achieved increased yields at 25% reduced N fertilizer combined with 2–4 kg biofertilizer. This study confirms the viability of integrating *Bradyrhizobium*-based biofertilizer with a 25–50% reduction in mineral N fertilizer without yield loss by harnessing the efficient N-fixation ability of the strains in the consortium.

**Keywords:** biofertilizer; *Bradyrhizobium*; integrated nutrient management; legumes; Philippines

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## 1. Introduction

*Bradyrhizobium* has long been used as an effective inoculant for legumes due to its symbiotic relationship with these crops and its high N fixation ability. Its role as a plant-growth-promoting rhizobacterium has been extensively studied, and species from this genus are known to be effective microsymbionts of legumes such as different varieties of soybean [1], cowpea [2], and mung bean [3]. These reports observed yield increases in these

legume crops when using various species and strains of bradyrhizobia and harnessing their ability for biological N fixation and other plant-growth-promoting traits.

In the Philippines, legume production is conventionally applied with chemical fertilizers with a common recommended rate of 40-60-60 kg N-$P_2O_5$-$K_2O$ $ha^{-1}$. The over-use and continued application of synthetic fertilizers are known to cause soil degradation and environmental pollution. In a review article, the impacts of synthetic N and P were found to include significant degradation in soil resources such as acidification, depletion of soil organic matter, nutrient imbalance, and disruption in the communities of beneficial microorganisms [4]. Moreover, the injudicious application of synthetic fertilizers destroys soil biodiversity, thus suppressing the role of N-fixing microorganisms [5]. Thus, it is a common strategy that when N-fixing microorganisms are used as inoculants, the amount of N fertilizer is reduced.

The integrated nutrient management (INM) approach involves the utilization of both inorganic and organic inputs to benefit both the plant and the soil. As bradyrhizobia have plant-growth-promoting traits (PGPTs) and a high N fixation ability, they are the best candidate for use as a complementary organic input or an alternative to decrease the need for mineral N fertilizer as part of sustainable agriculture [6,7]. The use of INM has been reported by several researchers as a viable strategy for sustainable agriculture. In fact, a long-term study reported that the use of INM enhanced soil organic carbon and available NPK, and increased microbial and enzymatic activity [8]. In a report by Kumar et al. [9], the use of PGPRs with partial replacement of inorganic fertilizer enhanced nutrient use efficiency, improved crop growth, and increased the stress tolerance of some vegetable crops. Thus, INM incorporating a reduced percentage of synthetic fertilizers with beneficial microorganisms can boost overall crop growth and restore soil health.

The *Bradyrhizobium*-based biofertilizer used in this study was thoroughly tested on soybeans under laboratory conditions. We can assume that the effectivity of the biofertilizer may be different under actual field conditions. Furthermore, soybean is not a major legume in the Philippines; mung bean and cowpea were therefore used, as they are the most commonly planted food legumes in the country. The ultimate goal of this study is to address some sustainable development goals, particularly those of life on land, by promoting sustainable agriculture practices, and zero hunger, by sustaining crop productivity in an agriculture-based country, in this case the Philippines.

## 2. Materials and Methods

### *2.1. Soil Sampling and Crop Selection*

The soil samples were collected from the common field site of the College of Agriculture, Central Luzon State University (CLSU), Science City of Munoz, Nueva Ecija, Philippines (15.7239° N, 120.9416° E). Sampling followed the standard protocol from the Bureau of Soils and Water Management (BSWM), wherein 10 sub-samples were collected from a 1-ha area at a depth of up to 20 cm, air-dried, pulverized, and quartered until a 1 kg composite soil was obtained, which was sent for analysis to the Regional Soils Laboratory (RSL) in San Fernando, Pampanga. The soil used in the pot experiments was obtained from the same field. The experiments were conducted only during dry seasons using soybean (PSB-SY2), cowpea (BPI-Cp3), and mung bean (NSIC Mg14), since other vegetables are planted in the area during the wet season. These varieties were chosen for their local supply and commercial availability.

### *2.2. Information on the Biofertilizer Used*

The bacterial isolates used for the biofertilizer in this study were all isolated and genetically identified in a previous study [10]. They were deposited at the DNA Data-

bank of Japan (http://www.ddbj.nig.ac.jp/ accessed on 10 May 2026) with the following accession numbers: *B. elkanii* NE1-6 (LC367070), NE2-1 (LC367073), *B. diazoefficiens* NE1-65 (LC367072), *Bradyrhizobium* sp. NE1-19 (LC415435), NE1-34 (LC367071), and NE2-3 (LC367074). These strains were used in our previous reports cited above, in which they were applied as a single inoculant to soybean and were found to be efficient. However, this is the first time that these strains were applied to mung bean and cowpea in a combination formulation as a biofertilizer.

### *2.3. Formulation of the Biofertilizer*

Each of the six strains was cultured separately in Yeast-Mannitol broth (YMB) at consistent agitation (120 rpm) in the dark until the bacterial density of each strain was at $1 \times 10^8$ cfu $mL^{-1}$, as measured through a spectrophotometer using 600 nm. Then, 1 mL from each culture (a total of 6 mL) was added to an Erlenmeyer flask containing 94 mL of YMB. The flask was agitated with the same condition for 5 days with sufficient turbidity and inoculated on a carrier material at a rate of 10% by weight basis.

The carrier material was a 250 g sterilized compost containing 30% moisture content which was then incubated for another 5 days inside a dark room. The bacterial population was counted and, after confirmation that at least $1 \times 10^8$ cfu $g^{-1}$ was present, it was used as a solid biofertilizer. The biofertilizer was packaged into a 250 g pack using a polypropylene plastic bag. It has a soil-like smell and 2 mm particle size. It was black in color, which is characteristic of a fully decomposed carbon-rich material. Based on the analysis, the biofertilizer contained 0.93% N, 0.69% $P_2O_5$, 0.96% $K_2O$, and 25.01% OM. The pH was 9.03. The biofertilizer used was given the name *Brady*-fert, because all the species belong to the genus *Bradyrhizobium*. Brady-fert is not yet a commercial product, as it is not yet registered with the Fertilizer and Pesticide Authority of the Philippines.

### *2.4. Treatment and Experimental Design for Pot Experiment*

The pot experiment was conducted under a protected structure during the dry season (February to May) and was arranged in a Completely Randomized Design with 4 replications. The treatments used were as follows: T1—full recommended rate of inorganic fertilizer based on soil test results (40-40-60 N-$P_2O_5$-$K_2O$ kg $ha^{-1}$); T2—30-40-60 + 1 kg Brady-fert, T3—30-40-60 + 2 kg Brady-fert; T4—30-40-60 + 4 kg Brady-fert; T5—20-40-60 + 1 kg Brady-fert; T6—20-40-60 + 2 kg Brady-fert; T7—20-40-60 + 4 kg Brady-fert. The inorganic fertilizers used in the INM combination for all the treatments were 46-0-0 (Urea), 0-18-0 (Ordinary Superphosphate), and 0-0-60 (Muriate of Potash). The rate of the full inorganic fertilizers used were based on the fertilizer recommendation as a result of soil analysis, and was 40-40-60 N-$P_2O_5$-$K_2O$ kg $ha^{-1}$. From this recommended amount, the amount of N was decreased by 75%, 50%, and 25%, and 1, 2, and 4 kg of the Brady-fert was added, respectively. The decrease in the amount of the inorganic fertilizer was based on the nationwide standard for the Adaptive Balanced Fertilization Strategy (ABFS) of the BSWM. The rates of the Brady-fert were based on the popular national recommended application rate for commercial biofertilizers. These treatment combinations were conceptualized in order to address one of the ultimate objectives for the development of this scheme: to reduce the cost of fertilizer inputs.

Each 7 kg capacity plastic pot contained 7 kg homogenized soil in which 4 seeds were initially planted; these were then thinned after 1 week to retain only 1 seedling. For the treatment application, the recommended rate of Brady-fert was applied only once as a soil drench during planting, while the inorganic fertilizers were applied twice as follows: 50% N, 100% P, and 50% K were applied at 10 days after seed emergence (DAE), and the

remaining N and K was applied at 21 DAE. The pots were maintained to be weed free with sufficient irrigation, which was similar for all treatments.

Harvesting of cowpea and mung bean commenced at 90–95 days after sowing (DAS), when the leaves began to drop and the pods turned brown and dried up. Soybean was harvested 78 days after seed emergence and then dried. Data were collected on seed yield (t $ha^{-1}$) and soil parameters (N, P, K, pH, OM). For the pot experiment, the yield per pot (kg $pot^{-1}$) was converted into t $ha^{-1}$ by using the weight of the soil used for each pot (7 kg) and the corresponding weight of the soil in a 1-hectare furrow slice, which is approximately 2,000,000 kg.

After the first pot trial, a second was conducted using the same set of soil samples in which the same treatments were employed for the same crop varieties. This was done to validate the results from the first trial. Due to the pandemic of 2020–2021, no experiment was conducted in 2021.

### 2.5. Treatment and Experimental Design for Field Experiment

During the dry season of 2022–2024, field experiments with a Randomized Complete Block Design of 7 treatments and 3 replications were conducted using the same crop varieties at the Ramon Magsaysay-Center for Agricultural Resources and Environment Studies (RM-CARES, 15.7364° N, 120.9261° E) at CLSU. Each plot measured 2 m × 10 m and was cemented on all four sides so that the size of each plot was fixed. The planting distance was 0.5 m × 0.5 m, and since plots were of limited size, all the plants were used as samples.

The treatments employed for the field experiments were similar to those in the pot experiments. This was done in order to verify the results under actual non-homogenized soil conditions without the limitation of the containment of the pot. Care and maintenance of the crop followed conventional manual weeding and irrigation whenever necessary, in a similar manner for all plots. Data gathered included the yield during harvesting and other soil parameters, as the focus was to determine the viability of the INM approach in reducing dependence on inorganic fertilizers.

The NPK of the soil samples used for the field experiments were initially analyzed for fertilizer recommendation using a soil test kit. The same soil sampling procedure was used, in which a portion was sent to the RSL to analyze N, P, K, OM, and pH. The soil samples were re-tested in 2023 and 2024 and were analyzed at CLSU.

### 2.6. Data Analysis

All replicated data were subjected to analysis of variance (ANOVA) using the R software (version 4.2.3), and mean comparisons were performed using Tukey's honestly significant difference (HSD) test at a 95% confidence level.

## 3. Results

### 3.1. Crop Response to Combined Fertilizer Application on Pot Experiment

The data below (Figure 1) shows the influence of integrated nutrient management (INM) on the average seed yield of the three legumes. For cowpea, the highest seed yield was attained with the 25% reduction in N fertilizer combined with 4 kg Brady-fert, which was significantly higher than that under the full NPK fertilizer. The lowest yield was obtained from the 50% reduction in N fertilizer combined with 1 kg Brady-fert; however, this was significantly increased with the addition of 2 and 4 kg Brady-fert. The same trend is observed with 25% reduction in N fertilizer, with the lowest yield being found on plots with application of only 1 kg Brady-fert, and with significant improvement upon the addition of 2 and 4 kg Brady-fert. This pattern is observed with both cowpea and soybean,

indicating that for this first pot trial, adding 4 kg Brady-fert with 50% reduction and 2–4 kg Brady-fert with 25% reduction in N fertilizer showed an increased yield compared to the full application of NPK.

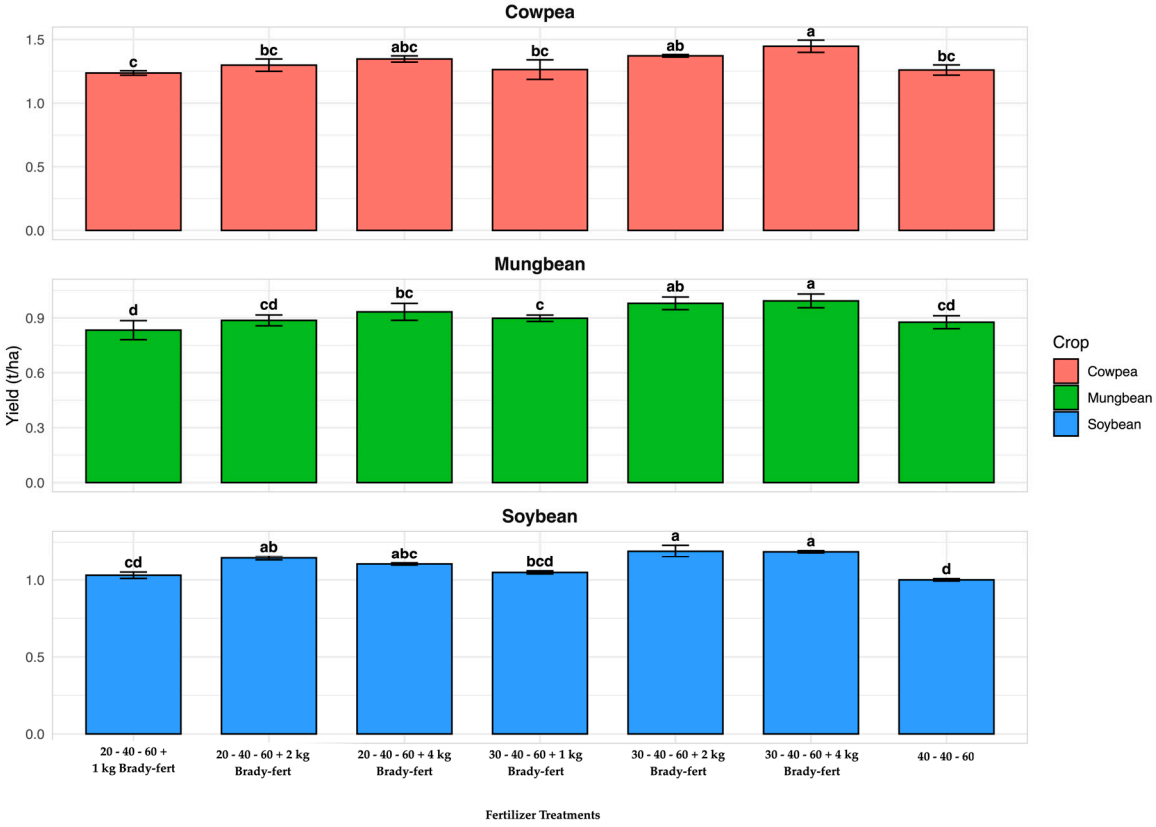


**Figure 1.** Influence of integrated nutrient management using 25–50% reduction in N fertilizer and 1–4 kg of *Bradyrhizobium*-based biofertilizer (Brady-fert) on the average seed yield of 3 legumes (cowpea, mung bean, soybean) planted in pots during the dry seasons of 2019 and 2020. Error bars: Mean ± SE; Letters on top of error bars indicate significant differences by Tukey HSD ($p < 0.05$).

### *3.2. Crop Response to Combined Fertilizer Application on 3-Year Field Experiment*

Figure 2 shows the 3-year field trial using the same treatments as above in order to test the influence of INM approaches compared to the application of full NPK fertilizer on the yield of cowpea, mung bean, and soybean. Consistent with the result of the pot trials, the combination of 25–50% reduction in N fertilizer combined with 4 kg Brady-fert showed the highest yield for three consecutive years, regardless of the crop. In 2022 and 2024, no significant differences among the treatments were observed; however, the highest yields for the three crops were obtained from the 25% reduction in N fertilizer and 4 kg Brady-fert treatments, with the lowest yield consistently observed from the full NPK fertilizer without any Brady-fert. In 2023, significant differences were observed between the three crops, wherein the highest yield increase was found with a 50% reduction in N fertilizer and 4 kg Brady-fert.

### *3.3. Correlation Between Soil Parameters and Yield*

In order to determine the influence of the INM approach on the yield of the three legumes and soil parameters, a comparative regression analysis (Figure 3) was performed and the changes in soil condition over time (Figure 4) were described. When comparing the influence of N, P, K, pH, and organic matter (OM) on the yield of the mung bean, cowpea, and soybean during the 3-year field experiment, the trend showed a positive

influence in the order of organic matter, pH, P, K, and N. Across the soil gradients, distinct yield results were observed wherein cowpea consistently achieved the highest productivity pf between 1.1 and 1.3 t ha$^{-1}$. Soybean showed a moderate yield, with the lowest yield performance observed for mung bean, rarely exceeding 1.1 t ha$^{-1}$ even with improving soil conditions. This suggests that, while an improvement in soil condition plays a vital role in yield increase, the optimal yield is also a function of the genetic potential of the crop.

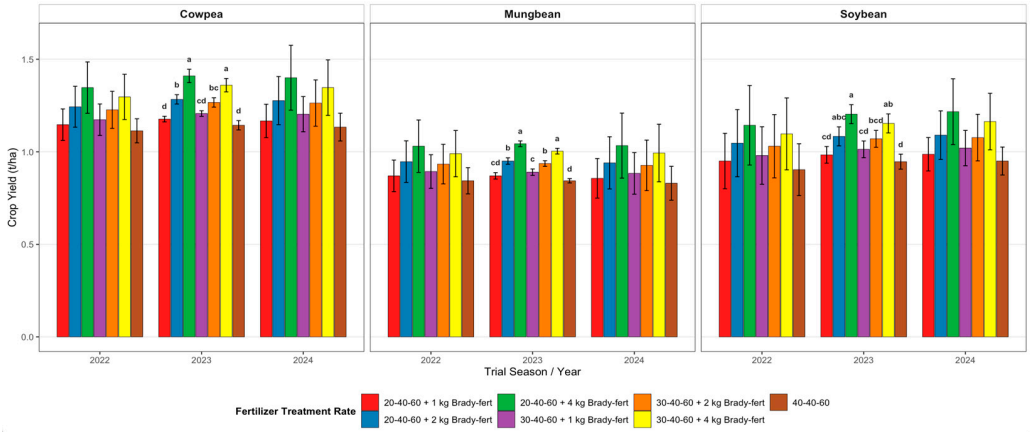


**Figure 2.** Influence of integrated nutrient management using 25–50% reduction in N fertilizer and 1–4 kg of *Bradyrhizobium*-based biofertilizer (Brady-fert) on the seed yield of cowpea (*Vigna unguiculata*), mung bean (*Vigna radiata*), and soybean (*Glycine max*) for 3 consecutive years (2022–2024) under actual field conditions. Bars denote annual trial means; error flags indicate ± SD; letters show Tukey's HSD groupings (only shown where ANOVA $p < 0.05$).

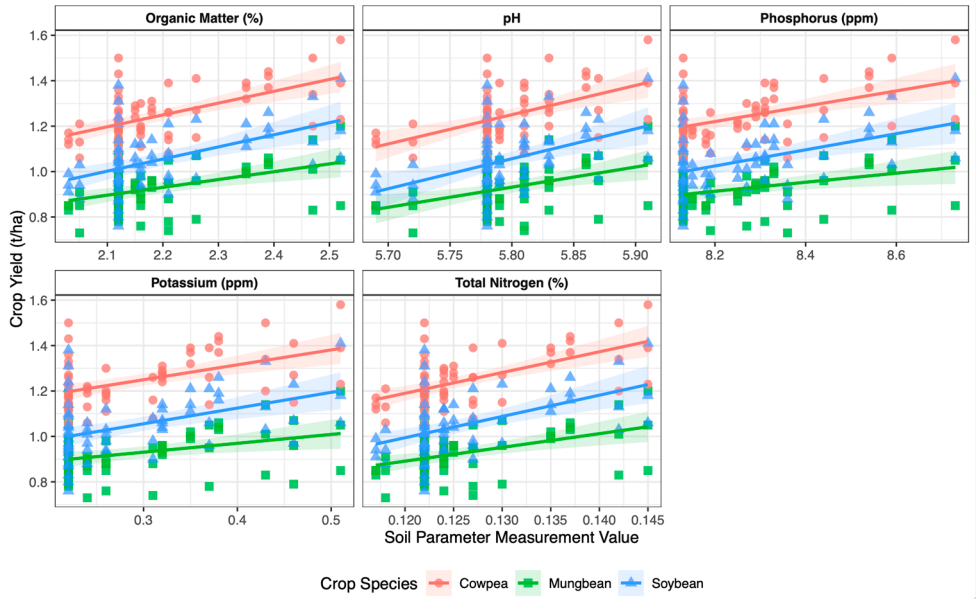


**Figure 3.** Comparative regression analysis between yield data and soil parameters during the 3-year field experiment (2022–2024), as influenced by the combined application of reduced inorganic and *Bradyhrizobium*-based (Brady-fert) biofertilizer on 3 legume crops. The points indicate the number of observations over the 3-year period.

The changes in selected soil parameters shown in Figure 4 show an overall improvement in soil condition when Brady-fert was added along with 25–50% reduction in N fertilizer. The pH of the soil showed the highest change from an initial of 5.78 to 5.91 with 20-40-60 kg ha$^{-1}$ NPK (50% reduction in N) and 4 kg Brady-fert. Similarly, the OM, N, P, and K contents also increased slightly over time with the same treatment.

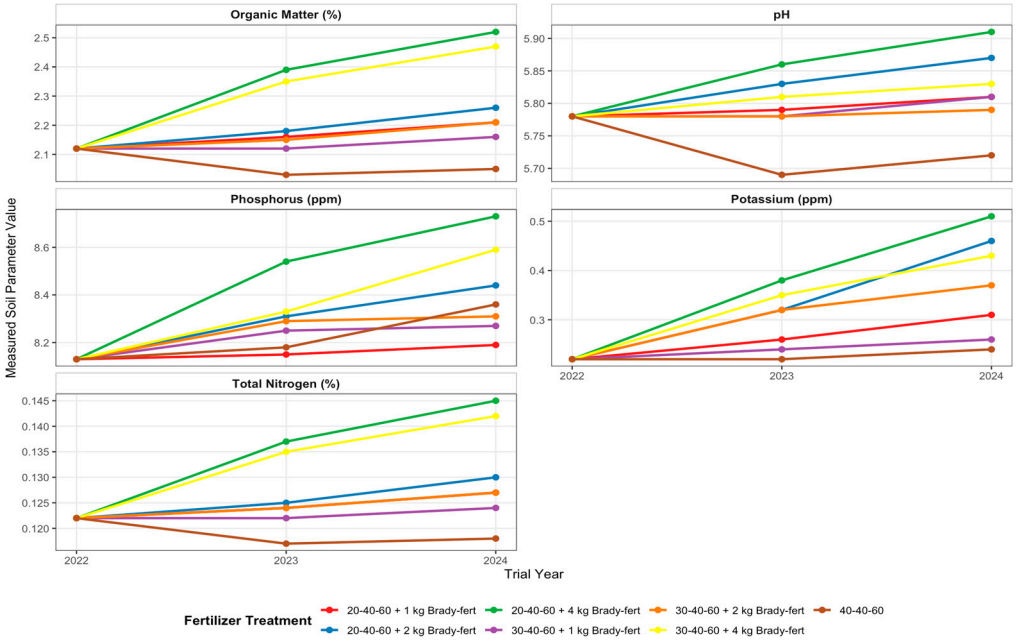


**Figure 4.** Dynamics in soil chemical properties during the 3-year field experiment (2022–2024) as influenced by the combined application of reduced inorganic and *Bradyhrizobium*-based (Brady-fert) biofertilizer. The lack of red line in Total N is due to same values with that of the orange line.

## 4. Discussion

*Bradyrhizobium* species have long been established as efficient N-fixers, particularly when in a symbiotic relationship with leguminous crops. In this study, we further established that the use of *Bradyrhizobium* strains in a mixed-inoculant formulation as a biofertilizer can decrease the need for mineral N fertilizer. The Brady-fert used in this study is composed of six strains of *Bradyrhizobium* indigenous to the Philippines [11]. In the past, these were used individually in single inoculations for different cultivars of soybean and showed efficient N fixation abilities [12]. This report addressed the following questions: (1) is the formulated biofertilizer also effective with other legumes; (2) is the biofertilizer effective in the field or only in the lab; and (3) does the biofertilizer have any influence on soil parameters?

For both the pot and field experiments, it is evident that among the three crops, cowpea showed the highest improvement in terms of yield. Soybean responded better when the amount of mineral N fertilizer was reduced by 50% rather than 25%. Among the three crops, mung bean had the least yield increase, but it followed a similar trend as cowpea, wherein a 25% reduction in the amount of mineral N fertilizer combined with either 2 or 4 kg Brady-fert obtained a significantly increased yield compared to the full NPK fertilizer. This indicates that, as leguminous crops, the N-fixers present in the Brady-fert may have played a big role in supplying the required N of the crops despite the 25–50% reductions.

In a study by [13], the inoculation of different *Bradyrhizobium* isolates to five cowpea varieties resulted in an overall increase in growth, biomass accumulation, and nodule performance. This report had a follow up study [14] wherein four varieties of cowpea were inoculated with *Bradyrhizobium* strain CP-24 and the yield increased by 28.47% compared to the uninoculated plant. Aside from this, *Bradyrhizobium* inoculation also increased the other growth parameters such as nodule number, effective nodules, leaf area, root dry weight, leaf area index, root length, pod length, and aboveground biomass yield, indicating the superior influence of inoculated over uninoculated plants. Meanwhile, it was reported that in Ethiopia, a tropical country, highly efficient N-fixers from the genus *Bradyrhizobium*

were effective symbionts of cowpea [15], supporting our finding that cowpea is highly responsive or sensitive to inoculation with *Bradyrhizobium*-based biofertilizer.

Our results also indicate that mung bean is positively influenced with the application of 25%-reduced N fertilizer added with 2–4 kg Brady-fert. Although the effect on mung bean was not as strong as with cowpea, the yield increases in both the pot and field experiments over time point to the positive effect of the INM approach. In Southern Ethiopia, it was found that the combined application of chemical fertilizer and bio-slurry composed of rhizobia significantly improved the overall growth and yield of mung bean [16]. In support of this, a study revealed that inoculation of mung bean with *Bradyrhizobium* at different levels of N produced the most significant highest yield when mineral N fertilizer was only applied at 40 kg $ha^{-1}$ [17]. In our study, 30 kg N produced the highest yield for mung bean combined with 2–4 kg Brady-fert. Favero et al. [18] also found that in tropical soils, *Bradyrhizobium* is the only rhizobial inhabitant of mung beans, suggesting that *Bradyrhizobium* has high compatibility with mung bean for inoculation studies in the tropics. This explains the compatibility of adding Brady-fert in combination with reduced-N fertilizer for mung bean production.

This study showed that, with a higher reduction in N fertilizer (50%) combined with 2–4 kg Brady-fert, a significant increase in soybean yield is obtained over time. This indicates that, among the three legumes tested, soybean is the most compatible with Brady-fert and does not need high amounts of mineral N fertilizer to attain optimal yield. A study comparing soybean inoculated with *Bradyrhizobium* under organic and conventional farming systems showed that growth and yield was increased in organic farms [19], suggesting that bradyrhizobia works well in soil without the application of mineral fertilizers. Similarly, a report stated that inoculating soybean with *Bradyrhizobium* significantly increased the relative symbiotic effectiveness under controlled conditions by at least 80% [20]. Contrary to these results, another study applying *Bradyrhizobium* inoculum in different forms to soybean under field conditions found no consistent increase in yield over a 2-year period [21]. The authors suggested that this result may be due to several factors, including the very low N content of the soil, the acidic soil condition (5.9–6.4), the microbial strains used (compatibility), and the presence of excessive moisture during the growing period. It has been reported that too much moisture can significantly affect the nodulation in legumes even with inoculation, such that increased moisture stimulates anaerobic processes that may produce phytotoxins, a by-product from anaerobic microorganisms in the soil that negatively impacts the root system [22]. On the same note, drought can significantly decrease the beneficial effect of *Bradyrhizobium* inoculation in legumes such that it can inhibit the exchange of signaling molecules that are involved in the communication between the legume host plant and the rhizobia [23]. Thus, the soybean–*Bradyrhizobium* symbiosis is indeed an interesting and complex relationship, although the success of inoculation varies across geographic locations [24] and with other soil properties, such as flooding, which we have reported previously.

Aside from yield improvement, this study also revealed the potential impact of the INM approach on soil parameters. The correlation and regression analysis trends, including the observation of soil chemical properties dynamics, indicated a positive impact of Brady-fert on overall soil conditions. The consistent increase in the levels of soil parameters, particularly for K, can be attributed to the Brady-fert applied in addition to the 25–50% reduction in N fertilizer. The effect of inoculating *Bradyrhizobium* in combination with other beneficial microorganisms was reported to increase the amount of nitrogenase activity and soil nitrogen content [25]. Another report revealed that, while inoculation of soybean with bradyrhizobia did not significantly increase the soil pH, OM, N, or C:N ratio, it was able to significantly influence the increase in total and available P [26]. In contrast, it was recently

reported that soil parameters significantly improved with the combined application of *Bradyrhizobium* and biochar. For instance, the soil pH increased from 5.77 to 6.20, N rose from 0.12% to 0.19%, available P increased from 32.4 to 45.3 ppm, available K increased by 18.2%, and the OM increased by 27.7% [27]. As discussed and cited above, the incorporation of *Bradyrhizobium* with organic inputs significantly improved the levels of soil OM, N, P, K, and even the soil pH. The data obtained in this present study indicated the valuable contribution of reducing inorganic fertilizer application, particularly N, with the addition of efficient bradyrhizobia, to lessen its impact on soil quality.

However, the improvement in soil properties is not solely attributed to the addition of Brady-fert. The reduction in the amounts of chemical fertilizers by 25 to 50% played an important role in the gradual improvement of the soil condition over a span of 3 years. It was observed that with the application of decreased chemical fertilizers combined with organic fertilizer to corn, the soil properties (EC, SOC, Total N, nitrate N, available P, available K) and microbial diversity significantly improved [28]. Another study applied an integration of 90% chemical fertilizer with 100% organic fertilizer and found that the N, P, and K uptake increased significantly by 29.2%, 29.0%, and 56.5%, respectively. Aside from this, the nutrient use efficiency for these primary macroelements increased by 30.4%, 21.1%, and 47.7% for N, P, and K, respectively [29]. This result is somewhat similar to the trend that was observed in our study, with K being the macroelement that was positively influenced most by the INM approaches.

Despite the increasing reports on the positive impact of INM for sustainable crop production, not only on improving crop yields, but more importantly on soil health restoration, there is still a lack of long-term scientific data across various geographical locations and different farming practices. In this report, a 2-year pot and a 3-year field experiment using three crops consistently and positively provided scientific evidence on the beneficial effects of INM for the soil and for the crop. A report on the harmful effect of long-term and over-application of N fertilizer found out that it can lead to an overall degradation of soil quality while affecting the adsorption and accumulation of soil pollutants such as polycyclic aromatic hydrocarbons [30]. Aside from this, the over-use of N fertilizer pollutes not only the soil but also the groundwater from where potable water is pumped, impacting human health. Therefore, it is necessary that the INM approach be given due recognition in every crop production systems for the benefit of food security, environmental protection, and agricultural sustainability. The use of INM practices also showed a reduction in methane emissions by 1.355% compared to conventional farming systems, with crop yields improving from 1.3% to 66.5% in various systems [31]. This scientific evidence merits policy recommendations on the wide implementation of INM for agricultural systems.

In summary, this study demonstrates the strong positive influence of integrating *Bradyrhizobium*-based biofertilizer at a 4 kg $ha^{-1}$ rate with a 25–50% reduction in mineral N. Since the Brady-fert used in this study is composed of locally isolated strains, its application to local conditions is optimized. Thus, this report provided additional evidence that reducing the amount of mineral N application by 25–50% with the addition of bradyrhizobia will not cause a decrease in yield; rather, a consistent yield increase over time along with a consistent improvement in soil condition was observed. Through the utilization of this INM approach, legume production can be aligned with sustainable development goals with a focus on environmental protection, food security, and poverty reduction.

## 5. Conclusions

Although many studies have already reported the use of bradyrhizobia as an efficient N-fixer, and its use to reduce the need for mineral fertilizers with legumes is well-established, the six indigenous bradyrhizobia strains in this study have not been reported

as a consortium for these three (3) legumes. These locally isolated bradyrhizobia have only been used as a single inoculant on soybean in our previous reports, and this is the first time that these six strains have been used as a consortium, developed into a biofertilizer, and applied to field planted with these three legumes. It is known that the success of inoculation depends largely on the compatibility with host plants and local agro-environmental gradients, among other various factors. As the use of biofertilizers slowly becomes a popular way to lessen the impact of the rising cost of mineral fertilizers, there is a need to develop biofertilizers from locally isolated microorganisms. Thus, reports like this will further solidify the evidence that biofertilizers, particularly those that are locally isolated and produced, are a sustainable strategy not only for achieving the yield potential of crops but also for improving soil conditions. Though many reports on biofertilizers are available, only several have been conducted as multi-year trials.

This study highlights the gradual but consistent positive impact of using the INM approach to improve crop yield and soil condition. The synergistic benefits of integrating *Bradyrhizobium*-based biofertilizer with reduced N mineral fertilizer show that it can sustain the yield of the three leguminous crops while simultaneously enhancing soil chemical properties. Future prospects include the potential use of this Brady-fert not only for legumes but for non-leguminous crops in an INM strategy. As the world faces the challenges of declining crop productivity resulting from soil degradation aggravated by climate change and the rising cost of fertilizers, alternative technologies like this are beneficial. We have established that legume production will be sustainable with a 25–50% reduction in N fertilizer combined with 2–4 kg Brady-fert.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| PGPR | Plant-Growth-Promoting Rhizobacteria |
| RM-CARES | Ramon Magsaysay-Center for Agricultural Resources and Environment Studies |
| CLSU | Central Luzon State University |
| DA | Department of Agriculture |

| | |
|---|---|
| DAE | Days After seed Emergence |
| RSL | Regional Soils Laboratory |
| DDBJ | DNA Databank of Japan |
| PGPT | Plant-Growth-Promoting Trait |
| NPK | Nitrogen-Phosphorus-Potassium |
| INM | Integrated Nutrient Management |

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