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Evaluation of polyhalite fertilizer in varying levels and combination with chemical fertilizers on the growth and yield performance of lowland rice (*Oryza sativa* L.) in the Philippines

Rocamora, P. M., Buladaco, M. S. II*, Bugia, S. A. C., Bunquin, M. A. B. and Sanchez, P. B.

Division of Soil Science, Agricultural Systems Institute, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna, Philippines.

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Abstract The results showed location- and season-specific variations. The growth and yield parameters improved with increasing rates of NPK applied, irrespective of the potassium source. During the dry season, grain yields varied among treatments and locations. In Oriental Mindoro, the highest yield was achieved by T4 (50% NP + 50% MOP) at 10.12 tons ha^{-1}, while the T1 (Control) produced 9.63 tons ha^{-1}. In Laguna, T10 (100% NP + 80% MOP + 20% POLY4) and T9 (100% NP + 60% MOP + 40% POLY4) recorded the highest yields at 7.76 and 7.60 tons ha^{-1}, respectively, compared to T1 with 4.46 tons ha^{-1}. In Nueva Ecija, T7 (100% NP + 100% POLY4) and T3 (100% NP + 100% MOP) produced the highest yields of 7.39 and 7.37 tons ha^{-1}, respectively, while T1 yielded 4.81 tons ha^{-1}. During the wet season, in Oriental Mindoro, T7 yielded 10.06 tons ha^{-1}, with T8 (100% NP + 40% MOP + 60% POLY4), T9, and T10 closely following (9.54, 9.49, and 9.48 tons ha^{-1}), all outperforming T1 (7.77 tons ha^{-1}). In Laguna, T8 recorded the highest yield at 8.85 tons ha^{-1}, followed by T7 (8.26 tons ha^{-1}), while T1 produced only 4.89 tons ha^{-1}. In Nueva Ecija, T8 and T7 achieved the highest yields at 9.26 and 9.17 tons ha^{-1}, respectively, significantly higher than T1 (8.30 tons ha^{-1}).

Keywords: Polyhalite, POLY4, Lowland rice

Introduction

Rice (*Oryza sativa* L.) is a staple crop that feeds more than half of the world's population, making it one of the most critical commodities in global food security (Confalonieri and Bocchi, 2005; Oladosu *et al.,* 2014). About 90% of the global rice is produced and consumed in Asia (Bandumula, 2017). The global average yield of rice in 2019 was 4.7 tons ha^{-1} and could steadily increase by approximately 1% annually (Awika, 2011; Grain Central, 2018). In the tropics, rice yields can reach around 7-8 tons ha^{-1} during the dry season and 5-6 tons ha-

*Corresponding Author: Buladaco, M. S. II; **Email:** msbuladaco@up.edu.ph

[1]during the wet season, though a large variation in the national, regional and seasonal averages are expected to be obtained annually. The irrigated and rainfed lowland rice systems make up approximately 80% of the global harvested rice area and contribute 92% of the total rice production worldwide (Singh and Singh, 2017). The Philippines, a rice-producing nation, is heavily reliant on the crop to sustain its growing population. In the Philippines, more than 4.5 million hectares of agricultural land are utilized for rice production. Irrigated rice areas in the country constitute approximately 70% of the total rice area which produced more than 75% of the total volume of rice supply in 2019, where this amount was equivalent to more than 14.4 million tons of palay (PSA, 2019). However, the country's rice production has often faced challenges, including stagnant yields, declining soil fertility, and the increasing cost of chemical fertilizers. These issues emphasize the need for innovative agricultural practices to enhance productivity and maintain soil health. One such promising avenue is the utilization of alternative fertilizers which has recently garnered significant attention in the agricultural research community.

Potassium (K) fertilization is crucial in enhancing rice yield and maintaining soil fertility. It significantly increases rice yield across different studies. For instance, in a wetland ecosystem in Bangladesh, potassium application increased rice yield from 5.19 t ha^{-1} to 6.86 t ha^{-1}, with optimal doses ranging from 78 to 93 kg ha^{-1} (Islam and Muttaleb, 2016). Similarly, in a rice-oilseed rape cropping system, potassium fertilization improved rice yield by 4.2–8.9% (Ye *et al.,* 2020). In another study, a potassium application rate of 120 kg ha^{-1} resulted in a 16.59% yield increase compared to no potassium application (Jiang *et al.,* 2019). An estimated rice grain yield of 4-8 tons ha^{-1} requires about 56-112 kg K from the soil and is becoming a limiting factor, especially in the paddy soils devoted to lowland rice production (Yang *et al.,* 2003). Commonly, the amount of K nutrients applied in the soil during a crop season meets only 20-30% of the plant growth requirement (Du *et al.,* 2017). Despite the benefits of potassium fertilization on yield, maintaining a positive soil potassium balance remains a challenge. Studies indicate that even with potassium application, negative potassium balances are common, suggesting that current application rates may not be sufficient to sustain long-term soil fertility (Islam and Muttaleb, 2016; Zhang *et al.,* 2010). This results in K deficiency which can lead to reduced water retention, decreased root development, as well as low tolerance of plants to moisture stress and diseases.

Polyhalite, marketed under the trade name POLY4, is a natural mineral containing K. POLY4 fertilizer (0-0-14, 14% K_2O, 19% S, 6% MgO, and 17% CaO) is a slow-release fertilizer which is obtained from polyhalite evaporite mineral ($K_2Ca_2Mg(SO_4)_4.2H_2O$). It is a soluble fertilizer with low chloride content, as compared to the conventional muriate of potash (MOP). Several studies have demonstrated polyhalite's potential to improve the growth and yield of various crops, including coffee (González-Osorio *et al.,* 2023), corn (Pavuluri *et al.,* 2017), tomato (Da Costa Mello *et al.,* 2018), sugarcane (Bhatt *et al.,* 2024) and wheat (Kumar *et al.,* 2023). However, its efficacy in lowland rice production, particularly in tropical regions such as the Philippines, remains underexplored. This study assessed the effectiveness of POLY4 as an alternative K source for rice cultivation across three locations in the Philippines, with a focus on its effects on growth indicators (plant height, tiller count, and chlorophyll content) and yield components (straw weight, filled grain weight, and grain yield).

Materials and methods

Time and place of study

The study was conducted in three different locations: 1. Calapan, Oriental Mindoro, 2. Santo Domingo, Nueva Ecija, and 3. Los Baños, Laguna with varying climatic conditions and soil types. The study was conducted for one cropping year, consisting of the wet (WS) and dry (DS) seasons of 2019-2020. The first season started during the WS from July-November 2019 in Laguna and Nueva Ecija while the second season was during the DS from November 2019-February 2020 in Laguna, and December 2019-May 2020 in Nueva Ecija. For Mindoro, the first season was during the dry season from November 2019-March 2020 in Mindoro, while the second season was during the wet season from July-November 2020.

The first study site was at Calapan. It is a coastal component city in the province of Oriental Mindoro located at 13° 24' North latitude and 121° 11' East longitude. The soil type found in the study area is San Manuel silt loam, classified as fine loamy, mixed, isohyperthermic Fluventic Eutropepts (Carating *et al.,* 2014). The second study site is located at Santo Domingo. It is a municipality located at 15° 35' North latitude and 120° 53' East longitude in the landlocked province of Nueva Ecija. The soil type found in the study area is Maligaya sandy loam, classified as an Ustic Epiaquerts (Carating *et al.,* 2014). Lastly, the third site is at Los Baños, Laguna. It is a landlocked municipality in the Philippines, located at 14° 11' North latitude and 121° 13' East longitude. The municipality features a Lipa soil series, classified as a fine clayey isohyperthermic family of Typic Eutropepts (Carating *et al.,* 2014). The important soil characteristics are detailed in Table 1.

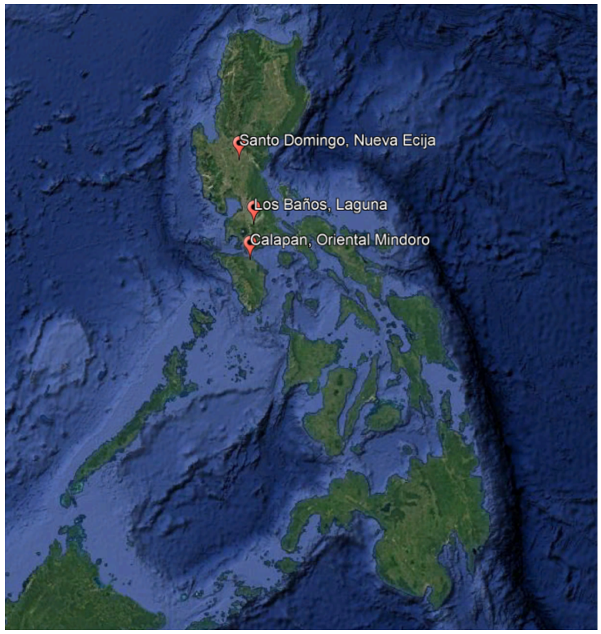

Figure 1. Location of study areas

Table 1. Soil characteristics of the study areas

Parameters	Site 1: Calapan, Oriental Mindoro	Site 2: Santo Domingo, Nueva Ecija	Site 3: Los Baños, Laguna
Soil Series	San Manuel	Maligaya	Lipa
Texture	Silt loam	Sandy loam	Clay loam
pH	6.25	5.43	5.53
OM, %	2.72	1.93	2.58
Total N, %	0.14	0.10	0.11
Available P, ppm	24.13	5.28	13.69
Exchangeable K, $cmol_c\ kg^{-1}$	0.96	0.45	1.86
CEC, $cmol_c\ kg^{-1}$	23.50	17.81	30.61

Field experimental design

The rice variety planted was NSIC Rc238. Dapog seedlings, young rice plants grown in raised seedbeds, were transplanted 11-15 days after sowing. Two to three (2-3) dapog seedlings were transplanted per hill at 20 x 20 cm spacing. Molluscicide application was done before and after transplanting to minimize losses from the golden apple snail. Herbicide was also applied 10 days after transplanting (DAT). The experimental plots were separated by small bunds and dikes (20-25 cm) to minimize the risk of contamination between treatments. The treatments were laid out in a randomized complete block design (RCBD) with four replications. The study had ten treatments, with varying combinations of inorganic fertilizers and proportions of different potassium sources (Table 2).

Table 2. Treatment codes and descriptions of the fertilizer combinations used in the study to determine the effect of POLY4 fertilizers on the growth and yield of lowland rice

Treatment code	Treatment description*
T1	Control (no fertilizer application)
T2	0% NP (no fertilizer) + RRK (100% POLY4)
T3	100% RRNPK (100% MOP)
T4	50% RRNPK (50% MOP)
T5	50% RRNPK (50% POLY4)
T6	100% RRNP (no K fertilizer)
T7	RRNP + RRK (100% POLY4)
T8	RRNP + RRK (40% MOP, 60% POLY4)
T9	RRNP + RRK (60% MOP, 40% POLY4)
T10	RRNP + RRK (80% MOP, 20% POLY4)

*RR=Recommended rate. MOP=Muriate of potash.

The recommended rate (RR), 150-60-90 kg N-P_2O_5-K_2O ha^{-1} was determined based on the initial soil analysis conducted at the Analytical Services Laboratory (ASL) of the Division of Soil Science (DSS-ASI, CAFS-UPLB). The chemical fertilizers used for the study were urea (46-0-0), single superphosphate (0-18-0), muriate of potash (0-0-60), and POLY4 (polyhalite, 0-0-14). Single-nutrient fertilizers were used in the study to facilitate split applications during the critical growth stages of lowland rice.

The timing of fertilizer application involved three split applications during the critical stages of lowland rice growth. Table 3 shows the timing of fertilizer application in relation to the rice growth stages, as well as the proportion of nutrients applied for each period. Basal fertilizer was applied 5–7 days after transplanting while side dressing was done during the active tillering stage of the plant, about 21 days after transplanting. Two to five days before panicle initiation, the final potassium application was done, approximately 40 days after transplanting.

Table 3. Timing and method of application of nutrients applied in each stage

Timing of application	Method of application	Percent (%) fertilizer applied		
		N	P	K
Early Vegetative Stage	Basal Application	75%	100%	25%
Active Tillering Stage	Top Dressing	25%	-	-
Panicle Initiation Stage	Top Dressing	-	-	75%

Growth and yield parameters

The study used various growth and yield parameters to determine the effect of POLY4 fertilizer and its combination with other inorganic fertilizers. Plant height, tiller count (number of tillers per plant), and SPAD measurements were taken at 30-35 DAT and 56-60 DAT. Ten representative plants were selected from each plot, excluding the borders from the sampling areas. A detailed description of the measured growth and yield parameters is provided in Table 4.

Table 4. Measured growth and yield parameters

Growth and Yield Parameters	*Description*
Plant Height (cm)	This was determined by measuring the length of distance from the soil surface to the tip of the longest rice leaf.
Tiller Count	This was measured by counting the tillers or shoots from each representative plant from the sampling area.
Chlorophyll content (SPAD units)	This was measured using the SPAD Minolta 502-Plus chlorophyll meter. The leaf should be from the third fully expanded leaf from the tip of the representative plant. This was done during late in the morning and early in the afternoon when maximum photosynthetic activity occurs.
Straw weight (g 10 plants^{-1})	This was done by measuring the aboveground biomass of the representative plants from the sample plot.
Weight of Filled Grains (g 10 plants^{-1})	This was measured by weighing the filled grains from the representative plants from the sample plot.
Grain Yield (t ha^{-1})	This was measured by weighing the actual total grain yield from the plots and adjusted to 14% moisture content.

Statistical analysis

The data collected were analyzed statistically using Minitab® 21.4. Analysis of Variance (ANOVA) was performed on growth parameters such as plant height, tiller count, and leaf chlorophyll content (SPAD-based) and on yield parameters such as straw weight, filled grain weight, and grain yield. Treatment means were compared at 5% level of significance using Tukey's Honest Significant Difference.

Results

Plant height

In Oriental Mindoro, during both the dry and wet seasons, plant height at the active tillering stage (30–35 DAT) showed minimal variation among treatments. Plant heights ranged from 67.54 cm (T7, 100% NP + 100% POLY4) to 70.29 cm (T8, 100% NP + 40% MOP + 60% POLY4) in the dry season and 72.61 cm (T2) to 77.91 cm (T1) in the wet season, with no significant differences observed. At the panicle initiation stage (56–60 DAT), T7 achieved the tallest plants during the dry season (119.43 cm) and wet season (119.43 cm), significantly outperforming T1 (Control, 104.02 cm). Other POLY4-inclusive treatments, such as T8 and T9 (60% MOP + 40% POLY4), also performed well (Figures 2a-b).

In Nueva Ecija, at the active tillering stage during the dry season, T10 (61.84 cm) and T9 (61.75 cm) resulted in the tallest plants, significantly outperforming T4 (50% NP + 50% MOP, 54.04 cm) and T1 (55.79 cm). Similar trends were observed during the wet season, where T10 (61.84 cm) and T9 (61.75 cm) again achieved the tallest plants, significantly exceeding the Control. At the panicle initiation stage, POLY4-inclusive treatments continued to outperform the Control. During the dry season, T8 and T9 (both exceeding 115 cm) and T10 (117.16 cm) were among the tallest, significantly better than T1 (81.98 cm). In the wet season, T8 (91.13 cm) and T10 (89.09 cm) were significantly taller than the Control (Figures 2c-d).

In Laguna, significant differences in plant height were observed during both seasons. At the active tillering stage, POLY4-inclusive treatments such as T9 (85.43 cm) and T8 (82.28 cm) consistently produced taller plants during the dry season compared to the T1 (63.15 cm). Similarly, during the wet season, T9 (85.43 cm) resulted in the tallest plants, followed closely by T8 (82.28 cm). At the panicle initiation stage, T9 and T8 continued to outperform other treatments. In the dry season, T9 produced the tallest plants (100.97 cm), significantly exceeding the T1 (80.50 cm). Similar trends were observed during the wet season, where T9 and T8 again recorded the tallest plants (Figures 2e-f).

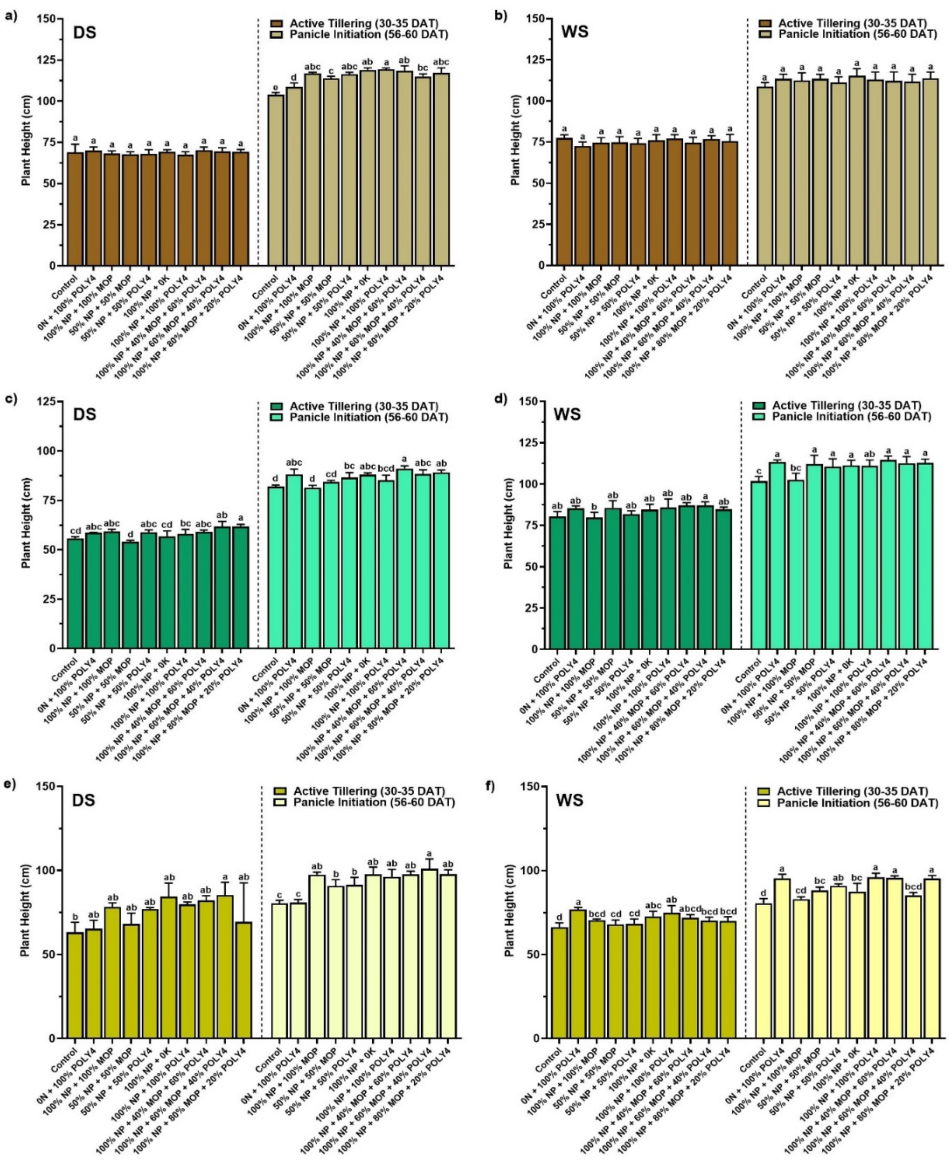

Figure 2. Plant height (in cm) of rice at active tillering and panicle initiation stages during the dry and wet seasons in three locations: (a, b) Oriental Mindoro, (c, d) Nueva Ecija, and (e, f) Laguna

Tiller count

In Oriental Mindoro, tiller counts at the active tillering stage (30–35 DAT) during the dry season showed no significant differences among treatments, with values ranging from 15.68 (T1, Control) to 18.70 (T8, 100% NP + 40% MOP + 60% POLY4). However, during the wet season, POLY4-inclusive treatments such as T8 (18.80) and T9 (60% MOP + 40% POLY4, 18.78) significantly outperformed the T1 (13.98). At the panicle initiation stage (56–60 DAT), T3 (100% NP + 100% MOP, 20.18) and T7 (100% NP + 100% POLY4, 20.15) produced the highest tiller counts during the dry season, significantly outperforming the T1 (14.35). Similarly, in the wet season, T3 and T10 (both 19.93) maintained the highest tiller counts (Figures 3a-b).

In Nueva Ecija, during the dry season, T5 (50% NP + 50% POLY4, 22.55) and T6 (100% NP, 21.50) recorded the highest tiller counts at the active tillering stage, significantly outperforming the T1 (12.64). At the panicle initiation stage, T4 (50% NP + 50% MOP, 28.93) and T6 (27.95) produced the highest counts, significantly exceeding the Control (20.68). During the wet season, T6 and T10 (100% NP + 80% MOP + 20% POLY4) recorded the highest tiller counts of 19.00 at the active tillering stage, significantly better than the Control (14.65). At the panicle initiation stage, T9 (14.34) and T7 (13.67) performed best (Figures 3c-d).

In Laguna, significant differences were observed in tiller count across treatments. During the dry season, at the active tillering stage, T9 (12.25) and T10 (11.88) achieved the highest tiller counts, significantly outperforming T1 (7.35). At the panicle initiation stage, T10 (17.23) and T6 (16.07) recorded the highest counts, while the T1 (8.78) had the lowest. During the wet season, T2 (22.32) and T3 (21.13) achieved the highest tiller counts at the active tillering stage, significantly exceeding the T1 (13.57). At the panicle initiation stage, T5 (19.23) and T6 (19.36) recorded the highest tiller counts (Figures 3e-f).

Chlorophyll content

In Oriental Mindoro, during the dry season, chlorophyll content at the active tillering stage (30–35 DAT) was similar across treatments, ranging from 34.07 SPAD units (T5, 50% NP + 50% POLY4) to 35.34 SPAD units (T8, 100% NP + 40% MOP + 60% POLY4), with no significant differences observed. However, at the panicle initiation stage (56–60 DAT), T10 (100% NP + 80% MOP + 20% POLY4) produced the highest chlorophyll content (58.85 SPAD units), significantly outperforming the T1 (Control, 36.30 SPAD units) and other treatments. During the wet season, treatments such as T8 (40.65 SPAD units) and T7 (100% NP + 100% POLY4, 40.38 SPAD units) achieved the highest chlorophyll content at the active tillering stage, significantly exceeding the T1 (31.32 SPAD units). At the panicle initiation stage, T7 (49.25 SPAD units) and

T9 (48.62 SPAD units) recorded the highest chlorophyll content, while T1 (39.52 SPAD units) remained the lowest (Figures 4a-b).

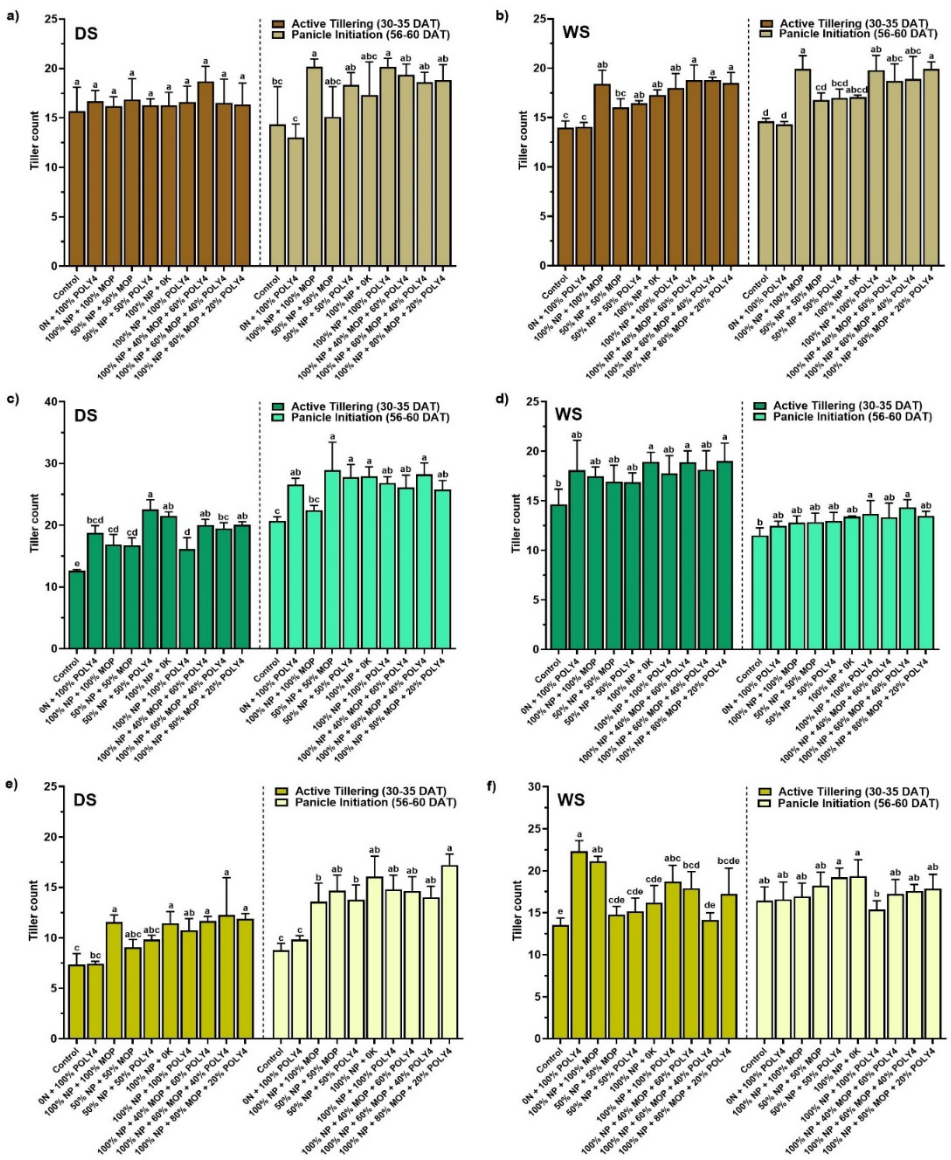

Figure 3. Tiller count of rice at active tillering and panicle initiation stages during the dry and wet seasons in three locations: (a, b) Oriental Mindoro, (c, d) Nueva Ecija, and (e, f) Laguna

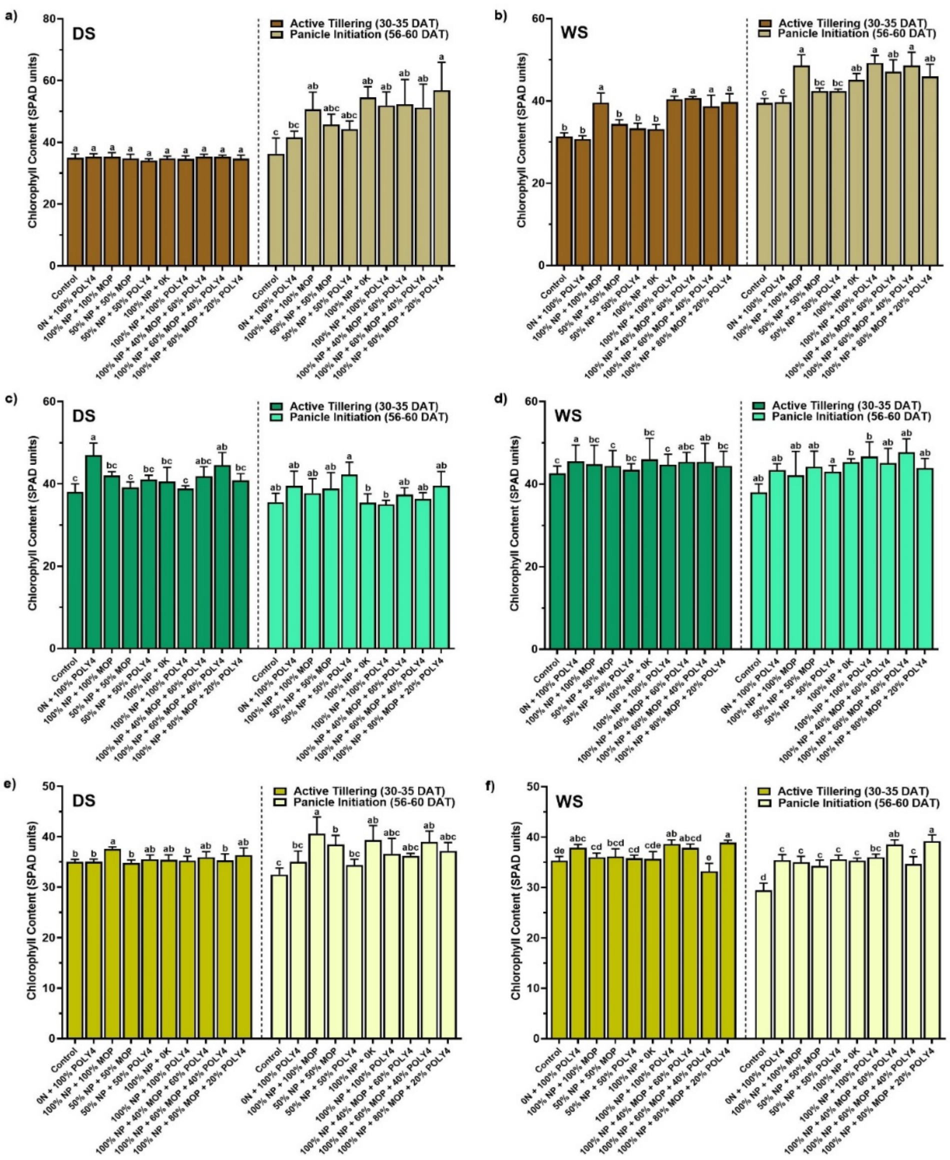

Figure 4. Chlorophyll content of rice at active tillering and panicle initiation stages during the dry and wet seasons in three locations: (a, b) Oriental Mindoro, (c, d) Nueva Ecija, and (e, f) Laguna

In Nueva Ecija, chlorophyll content during the dry season at the active tillering stage ranged from 37.99 SPAD units (T1) to 46.95 SPAD units (T2, 0% NP + 100% POLY4). At the panicle initiation stage, T10 (58.85 SPAD units) and T6 (54.53 SPAD units) achieved the highest chlorophyll content, significantly exceeding T1 (20.68 SPAD units). During the wet season, chlorophyll content at the active tillering stage was highest in T6 (45.96 SPAD units) and T8 (45.36 SPAD units), significantly better than T1 (42.56 SPAD units). At the panicle initiation stage, T9 (47.70 SPAD units) and T7 (46.65 SPAD units) produced the highest chlorophyll content (Figures 4c-d).

In Laguna, during the dry season, chlorophyll content at the active tillering stage was highest in T3 (100% NP + 100% MOP, 37.61 SPAD units) and T10 (36.32 SPAD units), significantly outperforming the control (T1, 35.04 SPAD units). At the panicle initiation stage, T3 (40.63 SPAD units) and T9 (38.98 SPAD units) performed best, with the T1 (Control, 32.53 SPAD units) being the lowest. During the wet season, T10 (38.92 SPAD units) and T7 (38.61 SPAD units) achieved the highest chlorophyll content at the active tillering stage, significantly exceeding T1 (35.32 SPAD units). At the panicle initiation stage, T10 (39.22 SPAD units) and T8 (38.57 SPAD units) performed best, while the control (29.41 SPAD units) remained the lowest (Figures 4e-f).

Straw weight

During the dry season, straw weights varied significantly among treatments and locations. In Oriental Mindoro, the highest straw weights were recorded in T3 (100% NP + 100% MOP) at 318.12 g and T5 (50% NP + 50% POLY4) at 317.40 g, while T1 (Control) produced a comparable 316.50 g. In Laguna, straw weight was highest in T6 (100% NP) at 279.80 g, closely followed by T8 (100% NP + 40% MOP + 60% POLY4) at 275.10 g, both significantly outperforming the T1 (131.84 g). In Nueva Ecija, T7 (100% NP + 100% POLY4) and T8 recorded the highest straw weights at 277.43 g and 280.10 g, respectively, while the T1 was significantly lower at 144.92 g (Figures 5a-c).

In the wet season, the effect of POLY4 on straw weight was even more pronounced. In Oriental Mindoro, the highest straw weight was observed in T9 (100% NP + 60% MOP + 40% POLY4) at 313.42 g, with T8 and T10 (100% NP + 80% MOP + 20% POLY4) close behind at 312.22 g and 311.18 g, respectively, all outperforming T1 (282.49 g). In Laguna, T10 achieved a remarkable straw weight of 725.90 g, significantly exceeding T7 (532.50 g) and T9 (533.10 g). The T1 recorded the lowest straw weight at 230.10 g, highlighting the effectiveness of POLY4-based treatments. In Nueva Ecija, T7 and T10 produced the highest straw weights at 345.30 g and 301.40 g, respectively, while the T1 lagged significantly at 185.21 g (Figures 5a-c).

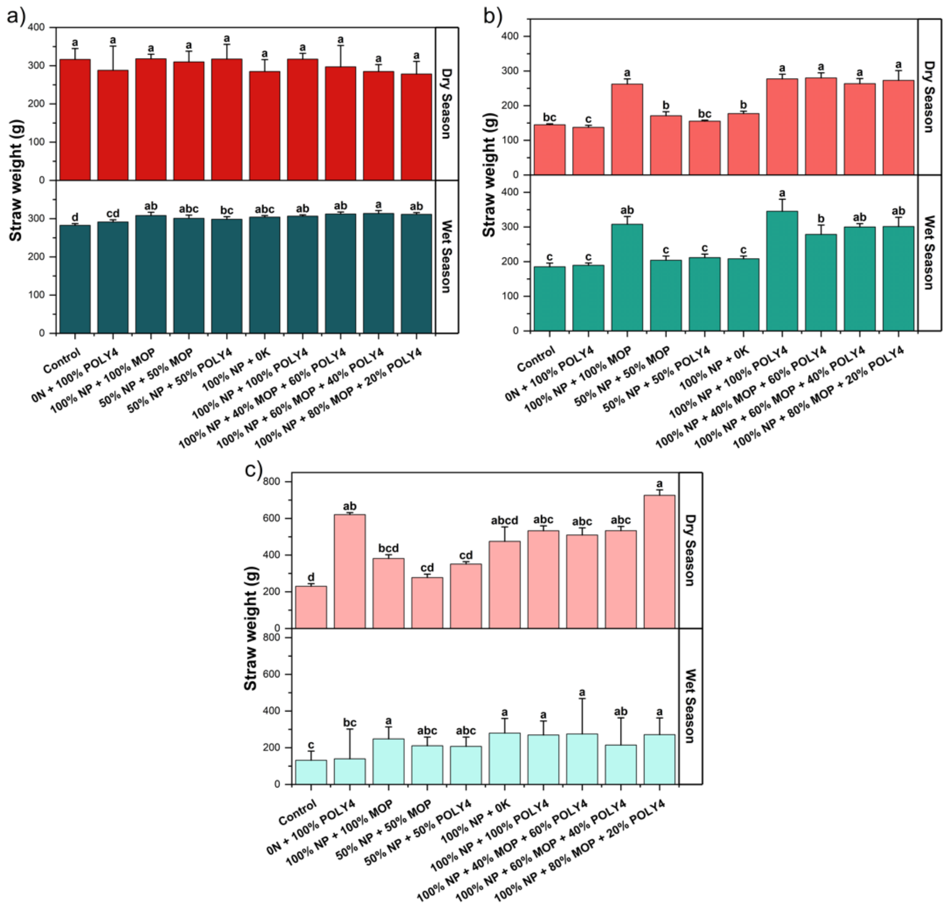

Figure 5. Straw weight (in g) in (a) Oriental Mindoro, (b) Nueva Ecija, and (c) Laguna during the dry and wet seasons

Filled grain weight

During the dry season, notable variations in filled grain weight were observed across locations and treatments. In Oriental Mindoro, T4 (50% NP + 50% MOP) recorded the highest filled grain weight at 386.90 g, followed by T7 (100% NP + 100% POLY4) at 363.51 g and T6 (100% NP) at 354.30 g. The T1 (Control) exhibited a comparable grain weight of 359.60 g, indicating a limited response to fertilizers in this location. In Laguna, T8 (100% NP + 40% MOP + 60% POLY4) and T9 (100% NP + 60% MOP + 40% POLY4) achieved the highest filled grain weights at 289.88 g and 280.10 g, respectively, significantly surpassing T1 (173.80 g). In Nueva Ecija, T7 and T9 recorded the highest filled grain weights at 296.57 g and 299.91 g, respectively, with T1 producing only 172.53 g (Figures 6a-c).

During the wet season, similar trends were observed, with POLY4 treatments consistently outperforming T1 across locations. In Oriental Mindoro, T7 produced the highest filled grain weight at 285.00 g, significantly exceeding the T1 (218.78 g). T8 (257.87 g) and T9 (271.60 g) also showed strong performance. In Laguna, T8 achieved the highest filled grain weight at 335.90 g, followed by T7 (268.80 g) and T10 (236.11 g), while the T1 produced the lowest value at 179.74 g. In Nueva Ecija, the highest filled grain weights were recorded in T8 (321.60 g) and T7 (313.10 g), with T1 producing 304.00 g (Figures 6a-c).

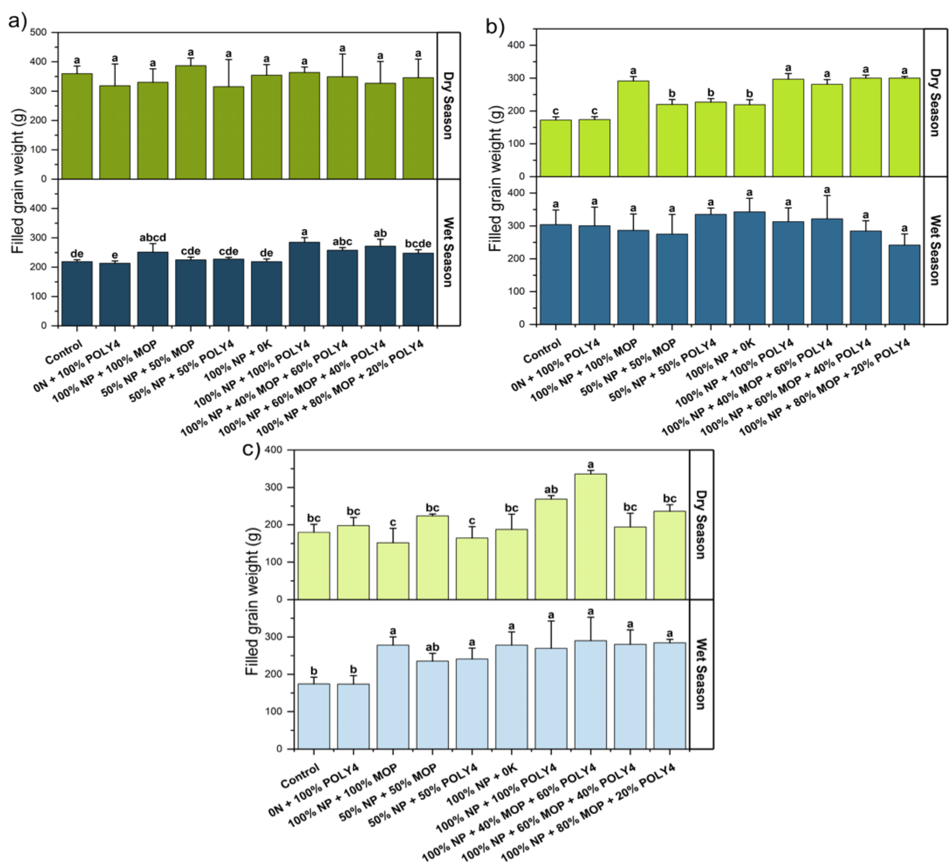

Figure 6. Filled grain weight (in g) in (a) Oriental Mindoro, (b) Nueva Ecija, and (c) Laguna during the dry and wet seasons

Grain yield

During the dry season, grain yields varied among treatments and locations. In Oriental Mindoro, the highest grain yield was observed in T4 (50% NP + 50% MOP) at 10.12 tons ha^{-1}, while the Control produced a comparable 9.63 tons ha^{-}

^{1}. In Laguna, T10 (100% NP + 80% MOP + 20% POLY4) and T9 (100% NP + 60% MOP + 40% POLY4) achieved the highest yields at 7.76 tons ha^{-1} and 7.60 tons ha^{-1}, respectively, significantly exceeding T1, which yielded only 4.46 tons ha^{-1}. In Nueva Ecija, T7 (100% NP + 100% POLY4) and T3 (100% NP + 100% MOP) delivered the highest yields at 7.39 and 7.37 tons ha^{-1}, respectively, while T1 (Control) produced a significantly lower 4.81 tons ha^{-1} (Figures 7a-c).

During the wet season, the benefits of POLY4 on grain yield are more pronounced. In Oriental Mindoro, T7 achieved the highest yield at 10.06 tons ha^{-1}, followed closely by T8, T9, and T10 with 9.54, 9.49, and 9.48 tons ha^{-1}, respectively, all significantly outperforming T1 (7.77 tons ha^{-1}). In Laguna, T8 again led with the highest yield of 8.85 tons ha^{-1}, followed by T7 (8.26 tons ha^{-1}), while T1 yielded only 4.89 tons ha^{-1}. In Nueva Ecija, T8 recorded the highest grain yield at 9.26 tons ha^{-1}, closely followed by T7 (9.17 tons ha^{-1}), both significantly exceeding T1 (8.30 tons ha^{-1}) (Figures 7a-c).

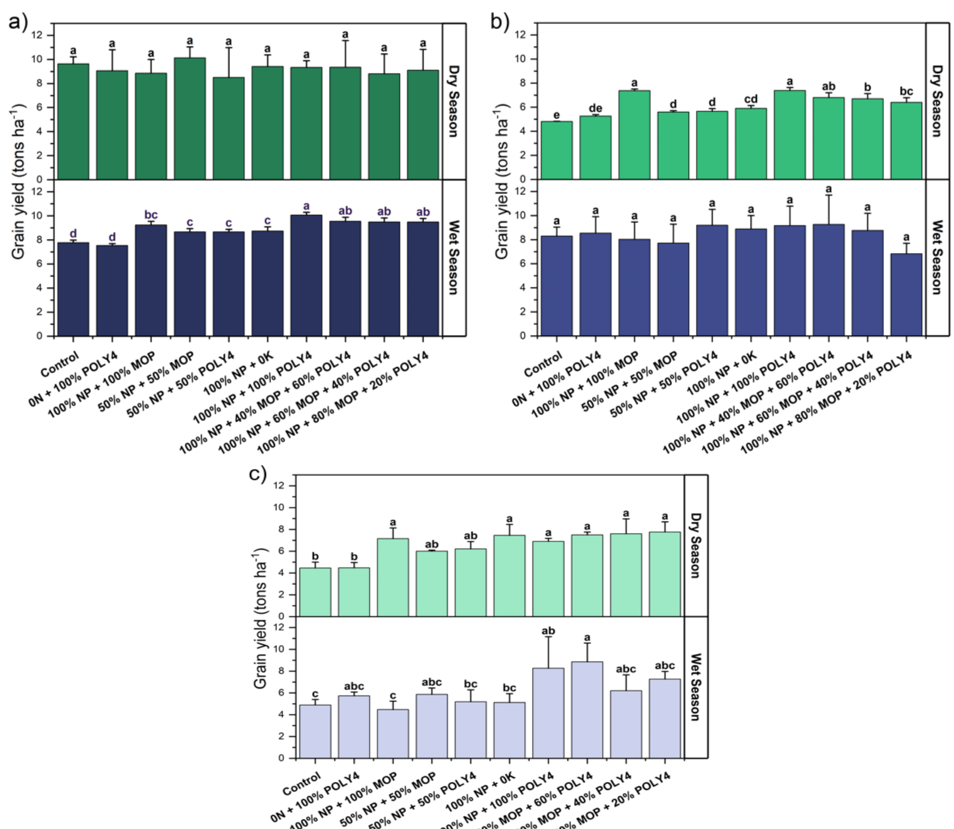

Figure 7. Grain yield (in tons ha^{-1}) in (a) Oriental Mindoro, (b) Nueva Ecija, and (c) Laguna during the dry and wet seasons

Discussion

The findings indicate that POLY4 and MOP demonstrated comparable effects on growth and yield. Specifically, the use of polyhalite fertilizer (POLY4), particularly as a partial substitute for muriate of potash (MOP), enhanced the growth and productivity of lowland rice. Treatments involving POLY4—such as T8 (100% NP + 40% MOP + 60% POLY4), T9 (100% NP + 60% MOP + 40% POLY4), and T10 (100% NP + 80% MOP + 20% POLY4)—consistently improved plant height, tiller count, chlorophyll content, and overall yield during both dry and wet seasons across the regions of Oriental Mindoro, Nueva Ecija, and Laguna. However, the data revealed notable variations depending on location and season. POLY4's unique nutrient composition and lower chloride levels offer distinct agronomic advantages over traditional potassium fertilizers. Furthermore, a study by Yeo and Imas (2019) on two rice varieties, Sertani and Kabir, in Karawang, Indonesia, also reported positive impacts on plant height and grain yield.

Although research on polyhalite application in rice is limited, its beneficial effects on growth and yield have been observed in other crops. Polyhalite has demonstrated the ability to enhance crop performance, including yield and quality, under various agricultural systems and soil conditions. For instance, in sugarcane cultivation, polyhalite significantly improved growth in potassium- and calcium-deficient soils (Bhatt *et al.,* 2021; Bhatt *et al.,* 2024). In Southern India, peanuts treated with polyhalite-based POLY4 achieved a 5.3–12.8% increase in pod yield compared to conventional NPK and gypsum treatments (Gopinath *et al.,* 2024). Similarly, applying polyhalite at 37.5 kg K_2O ha^{-1} in black gram boosted growth metrics, yield attributes, and grain production (Karthikeyan *et al.,* 2023). In wheat cultivation, polyhalite enhanced plant height and grain yield, and a full potassium application via polyhalite improved nutrient uptake and soil health, showcasing its sustainability potential (Kumar, 2023; Kumar *et al.,* 2023). Additionally, granulated polyhalite (GPOLY4) increased coffee cherry yield and improved quality attributes like acidity and body in Colombia by supplying essential nutrients such as potassium, magnesium, calcium, and sulfur (González-Osorio *et al.,* 2023). In Brazil, under potassium-deficient soil conditions, polyhalite application significantly boosted tomato yields, enhanced nutrient levels in foliage and fruit, and improved soil nutrient status postharvest (Da Costa Mello *et al.,* 2018; Da Costa Mello *et al.,* 2020). Polyhalite's role as a partial replacement for MOP also improved cabbage yield and quality in northern Vietnam, further highlighting its adaptability (Tien *et al.,* 2021).

The positive performance of POLY4-enriched treatments across different locations and growth stages shows its value in enhancing the sustainability and efficiency of rice production. Its multi-nutrient profile, which includes potassium, magnesium, calcium, and sulfur, makes POLY4 a promising alternative to conventional potassium fertilizers such as MOP. Incorporating POLY4 into fertilizer management strategies can help farmers achieve higher yields while promoting better soil health. However, the research results also showed the importance of considering location-specific factors such as soil properties, environmental conditions, and cropping seasons. Future studies should investigate its interactions with diverse crops, long-term effects on soil health, and integration with comprehensive soil management strategies. Research focusing on its impact on soil structure, nutrient retention, and microbial activity would provide deeper insights into its potential benefits.

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Conflicts of interest

The authors declare no conflict of interest.

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