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RESEARCH ARTICLE
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Evaluating the impact of various biofertilizer sources on growth and yield attributes of spring rice (*Oryza sativa* L.) in Eastern Terai of Nepal

Evaluación del impacto de varias fuentes de biofertilizantes en los atributos de crecimiento y rendimiento del arroz de primavera (*Oryza sativa* L.) en Terai oriental de Nepal

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Abstract

A field study was conducted at a farmer's field in Ratuwamai, Morang, from February 2023 to June 2023 to assess the impact of various bio-fertilizer sources on the growth and yield characteristics of rice. The experiment followed a randomized complete block design (RCBD) with three replications and seven treatments. The treatments included: T1: Recommended NPK dose (100:30:30 kg/ha), T2: Farmyard manure (FYM) (12 t/ha), T3: Goat manure (8 t/ha), T4: Mycorrhiza (11.25 kg/ha), T5: Organic manure (11.25 kg/ha), T6: Mustard seed cake (3.75 t/ha), and T7: Control (no fertilizer). Our investigation explored the significant effects of these treatments on the growth and yield-contributing attributes of the Chaite-4 rice variety. Results indicated that T1 (7021.47 kg/ha) and T2 (6681.70 kg/ha) exhibited the highest grain yield, followed by T3 (5128.35 kg/ha), T2 (4482.78 kg/ha), T5 (4335.79 kg/ha), T4 (4253.80 kg/ha), with T7 showing the lowest yield (3971.64 kg/ha). The maximum straw yield was observed in T1 (11037.50 kg/ha) and T6 (10644.16 kg/ha), while the control (T7) had the lowest (7681.66 kg/ha). Additionally, parameters such as plant height, number of tillers per hill, effective tillers per hill, panicle length, panicle weight, 1000-grain weight, grains per panicle, and SPAD value were highest in T1 and T6, and lowest in T7. Furthermore, the biofertilizers with the greatest benefit-to-cost ratios were organic manure and mycorrhiza (2.0 and 1.9, respectively), while goat manure showed an average ratio (1.6), indicating their cost-effectiveness. These findings demonstrate that the application of these biofertilizers enhances rice crop development and output, leading to substantial returns on investment.
Keywords: *Fertilizer rate, Paddy, Yield performance, B: C ratio, Mycorrhiza*

Resumen

Con el objetivo de investigar los efectos de varias fuentes de biofertilizantes en el crecimiento y las características del rendimiento del arroz, se llevó a cabo un estudio de campo en un campo de agricultores en Ratuwamai, Morang, desde febrero de 2023 hasta junio de 2023. Con tres repeticiones y siete tratamientos diferentes, el experimento se estableció utilizando un diseño de bloques completos al azar (RCBD). Los tratamientos se designaron de la siguiente manera: T1: Dosis recomendada de NPK (100:30:30 kg/ha), T2: Estiércol de corral (12 t/ha), T3: Estiércol de cabra (8 t/ha), T4: Micorriza (11.25 kg/ha), T5: Estiércol orgánico (11.25 kg/ha), T6: Torta de semillas de mostaza (3.75 t/ha) y T7: Control (sin fertilizante). Los diferentes tratamientos

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utilizados en esta investigación exploraron el efecto significativo en el crecimiento y los atributos que contribuyen al rendimiento de la variedad Chaite-4. Los resultados revelaron que los tratamientos T1 (7021.47 kg/ha) y T2 (6681.70 kg/ha) registraron el máximo rendimiento de granos, seguidos de T3 (5128.35 kg/ha), T2 (4482.78 kg/ha), T5 (4335.79 kg/ha), T4 (4253.80 kg/ha) y el rendimiento más bajo lo dio T7 (3971.64 kg/ha). Del mismo modo, el máximo rendimiento de paja fue dado por la dosis recomendada de NPK (11 037.50 kg/ha) y la torta de semillas de mostaza (10 644.16 kg/ha), y el rendimiento más bajo de paja lo dio el Control (7681.66 kg/ha). Asimismo, otros parámetros como la altura de la planta, número de macollos por planta, macollos efectivos por planta, longitud de panícula, peso de panícula, peso de 1000 granos, granos por panícula y valor SPAD fueron máximos en T1 y T6, mientras que fueron mínimos en T7. Las mayores relaciones beneficio-costo de estos biofertilizantes se obtuvieron para los abonos orgánicos y la micorriza (2.0 y 1.9, respectivamente), mientras que los estiércoles de cabra tuvieron una relación promedio (1.6), lo que indica que su uso es más ventajoso que los costos asociados. Esto demuestra que la aplicación de estos biofertilizantes mejora el desarrollo y el rendimiento de los cultivos de arroz y genera retornos significativos de la inversión.
Palabras clave: *Tasa de fertilizante, Arroz, Rendimiento, Relación B: C, Micorriza.*

1 Introduction

Cereal crops, including rice, maize, and wheat, play a dominant role in Nepal's agricultural sector (Paudel et al., 2021). Rice (*Oryza sativa* L.), a fundamental cereal crop, goes beyond basic sustenance to symbolize global nourishment. With more than half of the world's population depending on its grains, rice is an essential staple for survival and sustenance (Yadav et al., 2023a; Yadav et al., 2023b). Rice is a semi-aquatic, annual, and self-pollinated plant belonging to the Poaceae family (Pant et al., 2020). Among cereals, rice holds the top position (Ranabhat & Amgain, 2016), making it a crucial agricultural commodity in Nepal. The country covers an area of 1 491 744 hectares for rice cultivation, resulting in a production of 5.6 t (Ministry of Agriculture and Land Management, 2022). Rice cultivation contributes approximately 21 % to the Agricultural (GDP) of Nepal (Pant et al., 2020). Cereals, including rice, play a significant role in the dietary energy supplies of the Nepalese population, accounting for 65 % of the total intake. Notably, rice alone contributes 30 % of dietary energy supplies (Osti et al., 2017). Most rice cultivation, approximately 92 %, occurs during the main monsoon season known as "Barkhe" in Nepal, while only a small portion, around 7 %, is cultivated during the spring season known as "Chaite" (Regmi et al., 2023). Popular spring rice varieties include Hardinath-1, Chaite-6, Chaite-4, Chaite-2, and CH-45 (Parajuli et al., 2022). Roughly 50 % of the total caloric intake for the global population is derived from rice consumption (Jeson et al., 2022). Due to the growing population in the country, the existing rice production is inadequate to meet the food requirements. To fulfil the growing food demand in the nation, it should be prioritized to increase productivity per unit area given the constraints on extending cultivable land (Adhikari et al., 2021). Nepal must increase its rice output by more than 6.0 million tons by 2020 to meet the demands of its growing population (Devkota et al., 2019). Several factors play a role in achieving high rice yields, which are essential for ensuring global food security (Sarwar et al., 2009).

Fertilizers containing nitrogen and irrigation are two important elements that have a substantial impact on rice output (Qiu et al., 2022). The provision of necessary nutrients for crop development and production is made possible by fertilizers. A form of all-purpose fertilizer among them is NPK fertilizer, which contains nitrogen, phosphate, potassium, calcium, and magnesium (Pramayudi et al., 2023). Employing chemical fertilizers may dramatically enhance crop yields (Bailey-Serres et al., 2019). Although the use of chemical fertilizers has been associated with higher crop yields (Wang et al., 2023), prolonged and heavy usage of these fertilizers may cause soil deterioration and ultimately result in a reduction in rice production, less profitable and more cost of production (Thu et al., 2022). The lengthy and extensive investment in these fertilizers, however, not only increases production costs and depletes vital resources but also creates a serious negative impact on crop yield, soil health, and the environment (Xing et al., 2023, Wang et al., 2023). Meeting the high demand for chemical fertilizers in our country poses a significant challenge. While the overuse of these fertilizers might enhance crop output, it also has unfavourable effects on the soil's health, including increased salinity, decreased porosity, and general degradation (Naz et al., 2015a). To improve soil quality, encourage reproductive development potential, raise crop output, and improve plant nutrition, it is essential to increase soil fertility (Ma et al., 2023). This can be accomplished by using bio-fertilizers (Eginarta et al., 2021) in conjunction with suitable cultivation methods (Lestari et al., 2021, Choong et al., 2021). Bio-fertilizer contains living material without any chemicals which is detrimental to the soil living (Ghimire et al., 2021). Lately, there has been an increasing trend in utilizing natural fertilizers such as Farmyard Manure (FYM), Vermicompost, Poultry manure, Neem cake, and Goat manure to improve crop yield and maintain soil fertility, according to Yadav et al. (2023c). Further, biofertilizers are involved in symbiotic and associative microbial activities with higher plants (Islam et al., 2012). The use of bio-fertilizers in the cultivation of rice not only increases crop output but is also essential for maintaining soil fertility and improving soil health (Siavoshi et al., 2011; Noraida & Hisyamuddin, 2021). The positive effects of applying biofertilizers on crop development and production have been continuously shown by several studies undertaken by academics (Patriyawaty et al., 2022). Yadav et al. (2023d) emphasized the significant contribution of soil biota in improving soil quality, supporting plant health, and enhancing soil resilience, highlighting its indispensable role. Rhizobacteria that promote plant development do so by mobilizing nutrients, making phytohormones, and fixing nitrogen in a non-symbiotic way (Jalal et al., 2022). Additionally, the presence of beneficial microorganisms plays a critical role in maintaining soil fertility, enhancing plant resilience, and promoting overall crop health, as highlighted by Yadav et al. (2023e). It is hypothesized that a major reason underlying the biofertilizer's capacity to boost crop output is the enhanced absorption of vital elements including nitrogen (N), phosphorus (P), and potassium (K) (Islam et al., 2012). The use of biofertilizer, which contains helpful microorganisms, helps to slow down the breakdown of organic matter and improve the availability of vital plant nutrients, including nitrogen, phosphorous, sulfur and phosphorous (Jena et al., 2020). As a result, the presence of beneficial microbes in biofertilizers increases soil water retention, stimulates soil aggregate growth (Li et al., 2023), and has a buffering impact on soil acidity, alkalinity, salinity, harmful heavy metals, and, pesticides (Yengkokpam et al., 2022). Furthermore, bio-fertilizer could reduce the cost of production, and eco-friendly, and renewable sources of plant nutrients (Sarker et al., 2018). This fertilizer could also reduce pollution (Sarwar et al., 2009) and reduce the need for synthetic fertilizer hence causing an increase in crop production (Palanivell et al., 2013) and speeding up the composting process (Patriyawaty et al., 2022). Additionally, biofertilizers provide affordable, environmentally friendly, and regenerative plant nutrition sources (Sarker et al., 2018). They may reduce pollution, lessen the need for synthetic fertilizers, increase agricultural output (Sarwar et al., 2009; Sarker et al., 2018), and hasten the composting process (Patriyawaty et al., 2022). Therefore, biofertilizers are essential for easing the transition from the current rice production system to an agroecologically based, sustainable rice production system (Choong et al., 2021). This research aimed to investigate the effects of different biofertilizer sources on the development and productivity of spring rice. The study also sought to pinpoint the most effective biofertilizer that might raise rice yield and related qualities.

2 Material and methodology

2.1 Description of experimental site

From February 2023 to June 2023, the study was carried out on a farmer's field in Ratuwamai Municipality, in the southern Terai of the Morang district and Koshi Province of Nepal. To precisely identify the site, its specific geographical coordinates are provided as 26° 29' 52.3" N latitude and 87° 37' 12.4" E longitude, with an elevation of 60 meters above sea level. Moreover, Figure 1 and Table 1 illustrates the meteorological data and soil properties studied throughout the research.

2.2 Variety and treatment selection

The Chaite-4 rice variety was used in the research. The cultivar is resistant to rice pests including bacterial leaf blight (BLB), blast, and others. It matures in 115–120 days and has a 4-6 ton per hectare output capability. In contrast to other Chaite rice varieties, the grain is finer, softer, and more aromatic. Throughout the trial, seven different treatments were employed; the specifics of each are listed in Table 2.

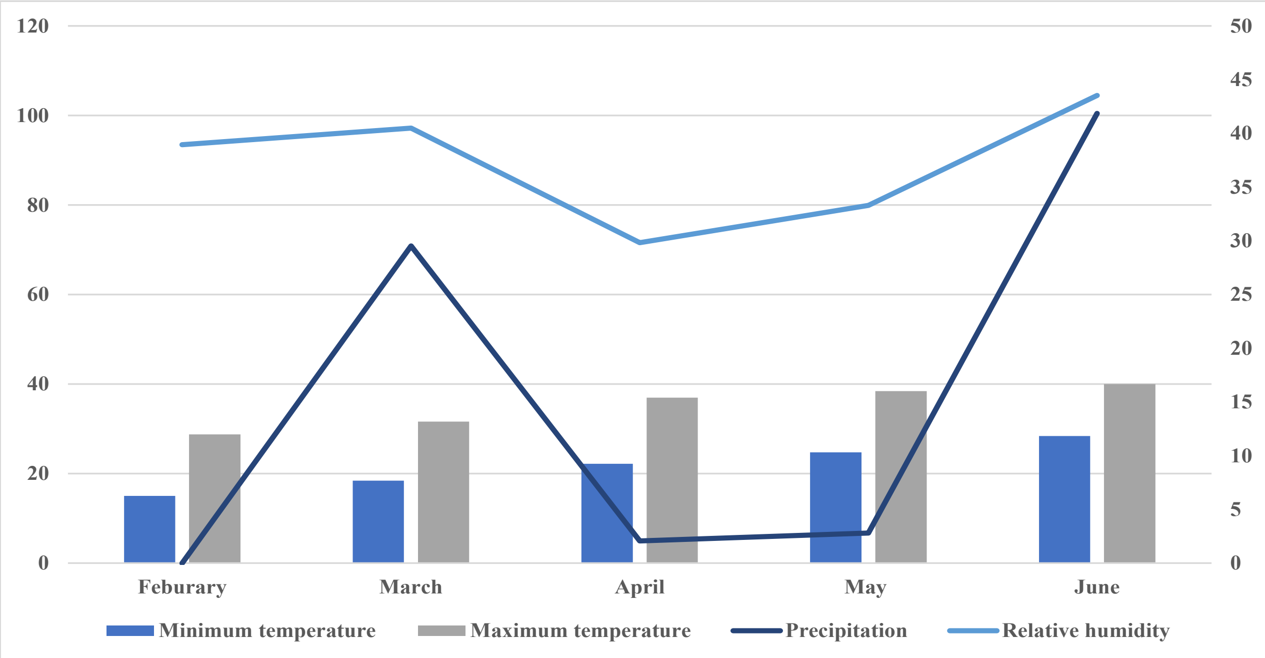

Figure 1. Meteorological data throughout the study period.

Table 1. Physical and chemical properties of the soil before planting at the depth of 0-20 cm.

S. N.	Properties	Value
1	Total organic content	3.68 %
2	Nitrogen	0.14 %
3	Phosphorous	52.84 mg/kg
4	potassium	218.33 mg/kg
5	pH	7.26

Table 2. Various treatment utilized in the research.

Treatment Symbol	Treatment Name	Dose per hectare
T1	Recommended dose of NPK	100:30:30 kg/ha
T2	FYM	12 t/ha
T3	Goat Manures	8 t/ha
T4	Mycorrhiza	11.25 kg/ha
T5	Organic manures	11.25 kg/ha
T6	Mustard seed cake	3.75 t/ha
T7	Control	-

2.3 Experimental setup and cultural practices

The study used a Randomized Complete Block Design (RCBD) with three replications and seven treatments, including five distinct biofertilizer sources, one advised dose of NPK and one without any fertilizer. There were almost 21 small plots, and each plot was 2 m^2 x 2 m^2 and contained ten rows of rice with ten hills in each row. The plants and row spacing were both kept at 20 cm x 20 cm. In each small plot raised bunds were made. By carrying out these procedures, the bunds serve as actual barriers that stop fertilizer from moving across plots and support the maintenance of the nutritional balance within each area. The rice seeds were soaked in water for 18 hours before sowing, and they were then sowed in a nursery bed. The seedlings were immediately planted into the main field after 25 days, with two to three seedlings per hill. Different treatments used in the research were applied in their specific plots just after seedlings were transplanted in the main field. Two hand weeding sessions were used to physically manage weeds at 30 and 45 days after transplanting throughout the rice-growing season. The crop received irrigation at all stages, including pre-planting, tillering, panicle initiation, booting, flowering, and grain-filling. Yellow stem borer infestation was seen during the tillering stage and grain-filling stage. Neem oil was applied twice with a 10-day gap to suppress this pest infestation.

2.4 Data observation and collection

The study assessed the impact of several biofertilizer sources and the suggested NPK dosage on spring rice development and yield-attributing attributes. Ten hills from the Center of each plot were randomly chosen for data collection, with the boundary hills being disregarded. Ribbons were used to tag these hills, and data was collected for 12 distinct features at various vegetative and reproductive development phases. These characteristics were plant height, effective and total tillers per hill, grain and straw yields, test weight, grains per panicle, panicle length, days to blooming, days to maturity, Chlorophyll content, and panicle weight. The vegetative data including plant heights, and the total number of tillers per hill were taken at 30, 45, 60, and 75 DAT and harvest respectively. Using a SPAD (Soil Plant Analysis Development) meter, the amount of chlorophyll was measured during the crucial time of rice. Similarly, measurements of the reproductive parameters were made before and after rice harvesting. After harvest, 1000 seeds were counted and weighed using an electric weighing machine to determine the test weight. The height of the plant was measured from the lower root to the tip of the plant. Days until blooming and days till maturity were determined directly from observation, and panicle length—the separation between the base and the tip of the panicle was computed. Grain yield was calculated using the method suggested by Shrestha et al. (2021) and Shrestha et al. (2022) by assessing the grain's moisture content using a grain moisture tester and plot yield, as given in Eq. 1.

$$\text{Grain yield (Kg/ha)}_{12\,\%} = \frac{(100 - M) \times \text{Plot yield (Kg)} \times 10{,}000\ (m^2)}{(100 - 12) \times \text{Net plot area}\ (m^2)} \quad \text{Eq. 1.}$$

M stands for the proportion of grain moisture content

2.5 Economics analysis:

The gross return was expressed in NRs per hectare for all replications and treatments and was derived by dividing the per-unit price of grain and straw based on the local market by the grain yield and straw yield of each plot. Utilising local prices for different agro-inputs, such as tractors, manpower, fertilizer, irrigation, and other necessary supplies, crop cultivation expenses were calculated. The total cost for these expenses was given in NRs per hectare. The formula proposed by Ghimire et al. (2021) was used to determine the benefit-cost ratio of various therapies under economic analysis.

$$\text{B: C ratio} = \frac{\text{Gross returns}}{\text{Cost of cultivation}} \quad \text{Eq.2}$$

2.6 Statistical analysis

The data were entered chronologically for replication and treatment blocks in the Microsoft Excel (2021) program, and then Analysis of variance (ANOVA) was performed using R-Studio statistical software (version 4.2.3), to assess the major agronomic characteristics of spring rice. The analysis of variance was performed using the 'datasets' and 'agricolae' packages. To compare mean values across several treatments at the 5% level of significance, Duncan's Multiple Range Test (DMRT) was used. The growth and yield parameters were further examined for regression analysis.

3 Results

3.1 Growth observation parameters:

3.1.1 Plant height

The results of the study showed that the treatment of a prescribed amount of NPK and various biofertilizers considerably influenced the plant height at 30, 45, 60, and 75 DAT, and at harvest, as shown in Table 3. At 30 DAT, the average plant height across all treatments was 41.64 cm; this average grows over time and reaches its maximum mean height of 92.45 cm at harvest. The findings of the various treatments revealed that the prescribed amount of NPK achieved the highest plant height (50.06 cm) at 60 DAT, increased steadily, and reached the maximum height at harvest (98.86 cm), which was followed by mustard seed cake (45.46 cm) at 30 DAT & (96.14 cm) at harvest, respectively. Similar average plant heights were seen at 30 DAT for goat manure (42.10 cm), FYM (39.76 cm), organic manure (38.80 cm), and mycorrhiza (38.00 cm), which continued to grow until it reached its maximum height at harvest. Similarly, plant height across treatments showed extremely significant (<0.01) at 30 DAT and harvest and very highly significant (<0.001) at 45, 60, and 75 DAT. Similar to before, NPK exhibited the greatest pooled plant height of 82.18 cm, followed by mustard seed cake at 78.90 cm, goat manure at 75.71 cm, FYM at 75.03 cm, organic manure at 72.80 cm, mycorrhiza at 71.57 cm, and control at 70.05 cm, respectively.

3.1.2 Number of tillers per hill

From 30 DAT to harvest, fertilizer treatments had a substantial impact on the number of tillers, which is a measure of plant growth. Table 3 shows how the number of tillers was impacted by the availability of nutrients. The average number of tillers per hill was 20.91 at 30 DAT, climbed quickly to 45 DAT, and then increased at a progressively slower pace to reach a mean total of 24.94 at the end of that period. According to the results, the total number of tillers per hill increased significantly (<0.01) at 30, 45, 60, and 75 DAT, and harvest following the administration of various fertilizer treatments. The NPK treatments show an increase in the number of tillers from 24.76 at 30 DAT to 27.23 at 45 DAT After that, the tiller count continues to rise but at a slower rate, reaching its peak at 28.73 at harvest. Similarly, the application of Mustard seed cake results in 22.46 tillers per hill at 30 DAT, which then increases gradually and reaches its maximum of 27.16 tillers at harvest, like the NPK treatment. The average number of tillers per hill is also produced by goat manures, organic manure, FYM, and mycorrhiza. At 30DAT, Control generates the fewest tillers (16.70) and grows the most tillers (20.10) by harvest. Similarly, NPK (27.53) exhibited the highest number of pooled tillers, followed by Mustard seed cake (25.88), Goat manures (24.98), Organic Manure (23.80), FYM (23.65), Mycorrhiza (22.12), and Control (19.22) accordingly.

3.1.3 Effective Tillers per hill

The outcome demonstrated that diverse sources of biofertilizers and the suggested dose of NPK, which is shown in Table 4, had a substantial impact on effective tillers. According to our research, the Recommended amount of NPK produces the most productive tillers per hill (26.30). Treatments such as mustard seed cake (24.76) and goat manure (23.66) generated an equivalent number of productive tillers per hill, whereas organic manure (22.40) and FYM (20.56) create a comparable number of productive tillers, with mycorrhiza (19.43) coming in second and third, respectively. The control (16.70) had the

Table 3. Effect of different biofertilizers on plant height and number of tillers per hill.

Treatments	Plant height						No. of tiller per hill					
	60 DAS	75 DAS	90 DAS	105 DAS	At harvest	Pooled	60 DAS	75 DAS	90 DAS	105 DAS	At harvest	Pooled
RD of NPK	50.06^{a}	72.50^{a}	92.30^{a}	97.20^{a}	98.86^{a}	82.18^{a}	24.76^{a}	27.23^{a}	28.20^{a}	28.73^{a}	28.73^{a}	27.53^{a}
FYM	39.76^{c}	64.97^{b}	85.15^{bcd}	90.22^{bc}	95.07^{abc}	75.03^{cd}	20.56^{b}	23.60^{ab}	24.50^{bc}	24.76^{bc}	24.83^{bc}	23.65^{bc}
Goat manures	42.10^{bc}	65.11^{b}	86.58^{bc}	91.65^{bc}	93.13^{bc}	75.71^{c}	21.80^{ab}	24.90^{ab}	25.83^{abc}	26.16^{abc}	26.20^{ab}	24.98^{abc}
Mycorrhiza	38.00^{c}	63.94^{bc}	82.03^{de}	86.17^{d}	87.70^{d}	71.57^{e}	19.43^{bc}	22.36^{bc}	23.10^{cd}	22.90^{cd}	22.80^{cd}	22.12^{cd}
Organic manure	38.80^{c}	63.43^{bc}	83.24^{cde}	88.30^{cd}	90.23^{cd}	72.80^{de}	20.70^{b}	23.80^{ab}	24.76^{abc}	25.00^{bc}	24.76^{bc}	23.80^{bc}
Mustard seed cake	45.46^{ab}	70.80^{a}	88.41^{b}	93.70^{ab}	96.14^{ab}	78.90^{b}	22.46^{ab}	25.76^{ab}	26.76^{ab}	27.23^{ab}	27.16^{ab}	25.88^{ab}
Control	37.30^{c}	60.92^{c}	80.87^{e}	85.14^{d}	86.01^{d}	70.05^{e}	16.70^{c}	19.13^{c}	19.96^{d}	20.23^{d}	20.10^{d}	19.22^{d}
Grand mean	41.642	65.956	85.515	90.341	92.451	75.181	20.919	23.828	24.733	25.004	24.942	23.885
CV (%)	6.909	2.476	2.429	2.297	3.069	1.988	9.377	7.996	7.521	7.264	6.921	7.731
SEM (±)	2.90	2.69	2.50	2.69	2.94	2.53	1.64	1.66	1.68	1.74	1.75	1.69
F value	**	***	***	***	**	***	**	**	**	**	**	**

CV: Coefficient of variation, SEM: Significant error of mean, DAS: Days after sowing, **Significant at 1% level of significance, ***Significant at 0.1 % level of significance

Table 4. Different growth & yield attributing parameters influenced by the application of different biofertilizers.

Treatments	ET/H	SPAD	PL	PW	G/P	TW	DF	DM	GY	BY
RD of NPK	26.30[a]	48.02[a]	28.90[ab]	4.13[a]	113.66[a]	29.83[a]	54.66[b]	79.33[b]	7021.47[a]	11037.50[a]
FYM	22.53[bc]	36.43[d]	27.33[ab]	3.16[bc]	101.00[bcd]	25.50[bc]	57.00[b]	79.00[b]	4482.78[c]	8316.66[c]
Goat manures	23.66[ab]	40.81[c]	27.60[ab]	3.43[b]	108.66[abc]	26.30[abc]	58.66[ab]	80.00[b]	5128.35[b]	8915.83[b]
Mycorrhiza	20.33[cd]	31.33[f]	26.00[bc]	2.86[cd]	104.66[abc]	23.03[cd]	58.66[ab]	80.33[b]	4253.80[c]	8263.33[c]
Organic manures	22.40[bc]	33.66[e]	23.50[cd]	3.10[bc]	98.33[cd]	23.93[bcd]	58.00[ab]	78.66[b]	4335.79[c]	8357.50[c]
Mustard seed cake	24.76[ab]	45.82[b]	30.36[a]	4.06[a]	111.66[ab]	27.96[ab]	61.33[a]	86.66[a]	6681.70[a]	10644.16[a]
Control	17.63[d]	30.60[f]	21.56[d]	2.60[d]	91.33[d]	20.46[d]	57.66[ab]	82.00[b]	3971.64[c]	7681.66[d]
Grand mean	22.519	38.100	26.466	3.338	104.190	25.290	58.00	80.85	5125.081	9030.952
CV (%)	7.335	2.555	7.668	6.460	5.436	8.564	3.721	2.25	5.707	3.249
SEM (±)	1.74	3.84	1.90	0.33	5.15	1.98	1.55	1.77	689.13	725.26
F value	***	***	**	***	**	**	NS	**	***	***

ET/H: Effective tillers per hill, SPAD: Soil plant analysis development, PL: Panicle length, PW: panicle weight, G/P: Grains per panicle, TW: Test weight, DF: Days to 50 % flowering, DM: Days to 75 % maturity, GY: Grain yield, BY: Biomass yield, CV: Coefficient of variation, SEM: Significant error of mean, DAS: Days after sowing, CV: Coefficient of variation, SEM: Significant error of mean, DAS: Days after sowing, **Significant at 1 % level of significance, ***Significant at 0.1 % level of significance, [NS]Non-significant

fewest effective tillers per hill. Between different treatments, there was a mean effective tiller count of 22.51. Among several fertilizer treatments, the findings showing effective tillers are highly significant (<0.001).

3.1.4 SPAD readings

The effects of several biofertilizers and the suggested NPK dosage on the chlorophyll content of spring rice were investigated; the results are shown in Table 4. The findings showed that there was a highly significant connection between fertilizer treatments and chlorophyll content (<0.001). The average amount of chlorophyll found in spring rice was 38.10. Among the several biofertilizers, mustard seed cake had the greatest chlorophyll concentration (45.82), followed by goat dung (40.81). The other biofertilizers exhibited a standard amount of chlorophyll. The minimal chlorophyll level was 30.60 in the control group.

3.2 Yield attributing traits

3.2.1 Panicle length

The results of the panicle length test are shown in Table 4, which unmistakably shows that the spring rice panicle length is greatly impacted by the various treatments. 26.46 cm was the mean length of the panicles. The findings demonstrated that, among the many treatments utilized in our study, panicle length is very significant (<0.01). The mustard seed cake had the longest panicles (30.36 cm), followed by RD of NPK (28.90 cm), Goat manure (27.60 cm), FYM (27.33 cm), Mycorrhiza (26.00 cm), and Organic manure (23.50 cm), resulting in an average panicle length. The control had the shortest panicles, at 21.56 cm.

3.2.2 Panicle weight

The results of our investigation, which are shown in, show that various biofertilizer sources have a significant impact on the panicle weight of spring rice Table 4. The outcomes showed that 3.33 g was the overall mean of the various treatments on panicle weight. The recommended dosage of NPK and the various sources of biofertilizer showed statistically very highly significant (<0.001) variance. The largest panicle weight of any biofertilizer is produced by mustard seed cake, which weighs 4.06 g, or about the same as the dosage of NPK (4.13 g). Likewise, Control had panicles with the smallest weight (2.60 g).

3.2.3 Grains per panicle

There was a very significant ($p < 0.01$) difference between the required amount of NPK on the grains per panicle of spring rice and the various sources of biofertilizer. Table 4 displays the grains per panicle of spring rice for various fertilizer treatments. The average number of grains per panicle across all treatments was 104.19. The most grain per panicle among the several biofertilizers was achieved by mustard seed cake (111.66), while the average grains per panicle were generated by goat manure, mycorrhiza, FYM, and organic manures, and the lowest grain per panicle was recorded by control (91.33).

Test weight

The study revealed that the application of different fertilizers had a positive impact on the test weight of spring rice. The weight of 1000 grains in response to various fertilizer treatments is presented in Table 4. On average, the weight of 1000 grains of spring rice were measured at 25.29 g. The test weight exhibited a highly significant correlation (<0.01) with the different fertilizer treatments. Among them, NPK displayed the highest test weight at 29.83 g compared to biofertilizers. Among the biofertilizers, Mustard seed cake had the highest weight at 27.96 g, followed by Goat manure at 26.30 g. FYM, Organic manure, and Mycorrhiza exhibited an average weight. The control group displayed the lowest weight of 1000 grains.

3.2.4 Days to 50 % flowering

When treatments were applied to spring rice, several biofertilizers had no statistically significant effects on the days to 50 % bloom. 58 days on average were needed for all these treatments to attain 50 % blooming. The RD of NPK (54.66 days), FYM (57.00 days), and control (57.66 days) among these treatments attained 50 % flowerings first, followed by organic manures (58.00 days), goat manures (58.66 days), and mycorrhiza (58.66 days) in that order. Like other treatments, Mustard seed cake (61.33 days) recently attained 50 % blooming.

3.2.5 Days to 75 % maturity

The use of several biofertilizers caused a highly significant (<0.01) variance in the maturity of spring rice at 75 %. 80.85 days was discovered to be the overall mean number of days needed to reach 75 % maturity. Among these treatments, Organic manures (78.66 days) and FYM (79.00 days) reach 75 % maturity earlier than RD of NPK (79.33 days), Goat manures (80.00 days), Mycorrhiza (80.33 days), and control (82.00 days), in that order. Among these treatments, mustard seed cake (86.66 days) was the last to mature to 75 %.

3.2.6 Grain yield

The use of biofertilizers in conjunction with chemical fertilizers had a substantial impact on grain output across all treatments. Table 4 shows the influence of different biofertilizer sources and recommended NPK doses on grain production. The approved quantity of NPK produced the best yield (7021.47 kg/ha) among the seven treatments, followed by biofertilizer Mustard seed cake (6681.70 kg/ha). Similarly, goat manure yielded (5128.35 kg/ha), whereas treatments like FYM (4482.78 kg/ha), organic manure (4335.79 kg/ha), and mycorrhiza (4253.80 kg/ha) had an average grain yield. The control had the lowest grain yield (3971.64 kg/ha). Overall, the average weight of grain output was (5125.081 kg/ha). The results show that the application of various biofertilizers along with a prescribed amount of NPK had a highly significant (<0.001) effect on grain production.

3.2.7 Biomass yield

The use of various biofertilizers alongside chemical fertilizer NPK substantially impacts spring rice straw production. Table 4 shows the influence of different treatments on straw productivity. The average straw production across all treatments was 9030.952 kg/ha. These treatments have extremely substantial (0.001) effects on straw yield. Mustard seed cake yielded the highest output of any biofertilizer at 10 644.16 kg/ha, followed by goat manure at 8915.83 kg/ha. Additionally, organic manure, FYM, and Mycorrhiza produced an average straw yield, whereas control produced the least amount of straw (7681.66 kg/ha).

3.3 Economics analysis

Although technically successful, treatment may not be economical if the costs of production outweigh the advantages. The most important factor in choosing a manufacturing technology is hence economic analysis. The cost of cultivation, gross return, net return, and benefit: cost ratio for the various study treatments are shown in the data analysis (Table 5). The average cost of cultivation for all treatments in the study was 80 558.05 NRs/ha; however, the costs for chemical and biofertilizers varied since the fields had varying nutrient concentrations and costs. The mustard seed cake treatment had the greatest cost of production (20 0558.05 NRs/ha), total gross profit (26 0469.9 NRs/ha), and net returns (59 911.85 NRs/ha) Simultaneously. Like this, the lowest cost of cultivation was noted in mycorrhiza (85 013.05 NRs/ha), organic manures (85 013.05 NRs/ha), and control (80 558.05 NRs/ha), with total gross profit (169 541.32 NRs/ha), total net return (84 528.27 NRs/ha), and total net return (87 633.35 NRs/ha) being observed for each of these, respectively. The average cost of cultivation varied among the different treatments, with FYM costing 122 558.05 NRs/ha, Goat Manure costing 120 558.05 NRs/ha, and the recommended dose of NPK costing 114 345.09 NRs/ha. The corresponding gross profits were 177 688.95 NRs/ha, 201 781.82 NRs/ha, and 273 345.2 NRs/ha, while the net returns were 55 130.9 NRs/ha, 81 223.77 NRs/ha, and 159 000.11 NRs/ha, respectively. Among the treatments, the recommended dose of NPK exhibited the highest benefit-cost ratio (2.3), followed by Organic Manures (2.0) and Mycorrhiza (1.96). On the other hand, the lowest benefit-cost ratio was observed in Mustard Seed Cake (1.2).

4 Discussions

4.1 Growth observation parameters:

4.1.1 Plant height

The growth of the spring rice plant is significantly influenced by using various biofertilizers in addition to chemical fertilizers. The results showed that the mean plant height of spring rice at harvest time was 92.451 cm; the prescribed amount of NPK produced the maximum plant height, which was followed by mustard seed cake, a biofertilizer source. This outcome is quite like the conclusions made by Ghimire et al. (2021). In contrast to our plant height of 12 t/ha FYM, which is 95.07 cm, the earlier work by Adhikari et al. (2021), indicated that the application of 6 t/ha FYM generated a plant height of 75.76 cm. This is because, the dose of FYM is almost double in our study and climatic factors such as favourable temperature, the intensity of light, water, etc play a significant role in gaining good height. Among different sources of biofertilizer, Mustard seed cake, FYM, Goat manures gained maximum plant height as compared to Organic manure, Mycorrhiza because Mustard seed cake, Farm yard manures, Goat manure are rich in essential plant nutrients along with micronutrients as well as significant amounts of organic matter which aids in improving soil structure, enhances water holding capacity, and promotes nutrients availability to plants also these factors are responsible for better root development and nutrient uptake, leading to increased plant height. Likewise, without any fertilizer treatments gave the lowest plant height because, without an adequate supply of nutrients, plants are unable to carry out essential physiological processes such as photosynthesis, cell division, and protein synthesis. This deficiency limits plant growth, resulting in reduced height which is like the findings given by Bhuiyan et al. (2006).

4.1.2 Number of tillers per hill

The use of various biofertilizer sources with chemical fertilizers has a substantial impact on the number of tillers per hill. The findings showed that 3.75 t/ha of mustard seed cake

Table 5. Economic analysis of incurred application of different biofertilizers.

Treatments	Common cost (NRs/ha)	Fertilizer cost (NRs/ha)	Total cost (NRs/ha)	Gross Profits (NRs/ha)	Net returns (NRs/ha)	B: C ratio
RD of NPK	80558.05	33787.04	114345.09	273345.2	159000.11	2.3
FYM	80558.05	42000	122558.05	177688.95	55130.9	1.4
Goat Manures	80558.05	40000	120558.05	201781.82	81223.77	1.6
Mycorrhiza	80558.05	4455	85013.05	169541.32	84528.27	1.9
Organic manures	80558.05	4455	85013.05	172646.4	87633.35	2.0
Mustard seed cake	80558.05	120000	200558.05	260469.9	59911.85	1.2
Control	80558.05	-	80558.05	158211.55	77653.5	1.9

produced results comparable to those obtained with the prescribed amount of NPK (100:30:30 kg/ha), which delivered the maximum tiller number per hill. According to Naher et al. (2018), N, P (50 %), and K with biofertilizer (10 t/ha) gave the highest tiller number per plant which is nearly similar to our findings. Different studies have shown the positive impact of different biofertilizers on growth parameters such as plant heights, and tiller number per hill which is well documented in experiments performed by Biswas et al. (2023), Ghimire et al. (2021) and Naher et al. (2018). Among various biofertilizers, Goat manure, FYM, Organic manure, and Mycorrhiza gave the average number of tillers per hill which is parallel to the results documented in research by Biswas et al. (2023), Wangiyana et al. (2021a), and Wangiyana et al. (2023) respectively. The overall mean of total tiller per hill at harvest time in our research was parallel to the results given by Noraida & Hisyamuddin (2021). Similarly, control gave the lowest tiller numbers per hill which is similar to the results provided by Amenyogbe & Dzomeku (2023).

4.1.3 Effective tillers per hill

The quantity of net effective tillers is significantly impacted by the application of various biofertilizers in combination with chemical fertilizer dosage. Due to various treatments, the effective number of tillers per hill ranged from 26.30 to 17.63. The highest number of effective tillers was given by the recommended dose of NPK. This is because the plant receives optimal nutrition, ensuring its physiological needs are met during the critical stages of tiller formation in spring rice leading to a higher number of tillers. A similar result was documented in the experiment conducted by Ghimire et al. (2021), and Noraida & Hisyamuddin (2021). Among various biofertilizers, Mustard seed cake and Goat manure give a higher number of effective tillers per hill as compared to FYM, Organic manures, and Mycorrhiza. This will be due to several factors like nutrient composition, nutrient release rates, microbial activity, and soil condition. Also, Mustard seed cake and Goat manures contribute to increased microbial activity in the soil, thus helping in facilitating nutrient release and uptake, leading to a higher number of effective tillers inspiring rice. Similarly, our result showed that without any fertilizer gave the lowest number of effective tillers per hill which depends on a variety of factors such as nutrient deficiency (N, P, K), poor soil fertility, competition of weeds, environmental factors including temperature, moisture availability, and light. This result coincides with the finding documented by Palkar et al. (2022) from their research.

4.1.4 SPAD readings

The Spad value is a metric for how much chlorophyll is present in plants and is frequently employed as a sign of the health and nutritional condition of plants (Dang et al., 2023). A SPAD value of 35 in rice, according to Peter & Umemiya (2021), denotes a critical quantity of leaf nitrogen required for ensuring optimum plant development and subsequently optimizing production. The SPAD values which represent chlorophyll concentrations were taken during a critical period in rice growth. Depending on the precise treatments used, there were differences in how mixing biofertilizer, and chemical fertilizer affected these SPAD values. Among these treatments, NPK gave the maximum number of SPAD values, which was followed by Mustard seed cake. This result was similar to the SPAD value given by Naher et al. (2018). The overall mean SPAD value was 38.10 which is above the value of 35 that the rice plant effectively photosynthesizes and generates sufficient levels of chlorophyll, which is essential for the plant's capacity to transform light energy into chemical energy and create sugars leading to improved growth, yield, and general plant health. Similarly, Biofertilizers like Mustard seed cake, goat manures, and FYM gave SPAD values above 35 which is a positive sign for rice plants. These results were parallel to the outcomes recorded by Naher et al. (2018) and Peter & Umemiya (2021). Organic manure and mycorrhiza gave an average SPAD value which is close to 35. The lowest SPAD value was measured in treatments without any treatments because of nutrient deficiency, environmental conditions, and overall plant vigour. These results were similar to the results given by Naher et al. (2018).

4.2 Yield attributing traits:

4.2.1 Panicle length:

The combination of biofertilizers and chemical fertilizers has a substantial influence on the panicle length of spring rice. The highest panicle length was given by mustard seed cake which is followed by the recommended dose of NPK. Organic amendments like mustard seed cake often release nutrients slowly over time as they decompose ensuring a continuous supply of nutrients to the plants over an extended period. In contrast, synthetic fertilizers like NPK are more readily available to plants but can be quickly leached from the soil. The gradual nutrient release from the mustard seed cake may have provided a sustained supply of nutrients, promoting better plant growth and longer panicles. The overall mean of panicle length documented by Ghimire et al. (2021) coincides with our findings. Similarly, other biofertilizers Goat manures, FYM, and Mycorrhiza gave a similar panicle length. The identical panicle lengths seen with goat manure, FYM, and mycorrhiza may be due to their nutritional content, organic matter contribution, and soil-improving abilities. Our research showed that applying 12 t/ha of farmyard manure (FYM) produced longer panicles as compared to the results documented by Adhikari et al. (2021) applying 6 t/ha of FYM. The possible reasons may be a higher dose of FYM, crop variety, soil type, and climatic conditions. The lowest panicle length was given by the control which is almost similar to the results revealed by Naz et al. (2015b).

4.2.2 Panicle weight

The application of biofertilizers along with chemical fertilizers demonstrates favourable outcomes in enhancing the panicle weight of spring rice. The highest panicle weight was obtained by NPK and Mustard seed cake as compared to other biofertilizers because NPK fertilizer supplies vital nutrients like nitrogen (N), phosphorus (P), and potassium (K), which are important for plant growth and development and boost panicle weight. Similarly, the use of mustard seed cake as a biofertilizer improves plant development and, eventually, panicle weight by supplying the soil with beneficial elements such as organic matter, micronutrients, and growth-promoting chemicals. The lowest panicle weight was achieved by treatment without fertilizer which is due to the lack of essential nutrients required for proper growth and development.

4.2.3 Grains per panicle

The various biofertilizers as well as chemical fertilizers had a big impact on the amount of filled grain per panicle. The overall mean of grains per panicle in our study was parallel to the results documented by Ghimire et al. (2021). The maximum number of grains per panicle was observed in the recommended dose of NPK which is followed by Mustard seed cake. This result is found almost similar to the results documented by Gupta et al. (2016). Similarly, various biofertilizers like Goat manure, Mycorrhiza, FYM, and Organic manure gave the average number of grains per panicle. This result shows that all these biofertilizers were equally effective in promoting grain development in rice plants. The lowest number of grains per panicle was recorded by treatment without any fertilizer. The same results were demonstrated by Wangiyana et al. (2021b). The lower number of grains is due to a deficiency of all nutrients required for the proper growth and development of plants.

4.2.4 Test weight

In spring rice application of different biofertilizers and chemical fertilizers significantly helps in increasing 1000 grains weight. The application of a recommended dose of NPK gave the highest test weight (29.83 g) of rice which is also reported by Peter & Umemiya (2021). The application of different treatments gave an overall mean weight of 1000 grains 25.290 g. The test weight of 1000 grains reported by Noraida & Hisyamuddin (2021) in their research with biofertilizers and chemical fertilizers is almost similar to our findings. Among biofertilizers, Mustard seed cake gave the highest test weight (27.96 g) which is followed by Goat manures (26.30 g) and FYM (25.50 g) respectively. This is because the vital elements nitrogen, phosphorus, and potassium, which are necessary for plant growth and development, are abundant in mustard seed cake. While goat manures and FYM both include nutrients, their concentrations or nutrient ratios may be different, resulting in somewhat lower test weights. Similarly, Organic manures (23.93 g) and Mycorrhiza (23.03 g) gave a nearly equal and average weight of 1000 grains. Both organic manures and Mycorrhiza increase the fertility and availability of the soil's nutrients, although they may do so in different ways depending on the nutrients they contain or how they work, which is why the grains' test weights were similar and average in both cases. In a similar vein, the control provided the lowest test weight (20.46 g). According to research done by Palkar et al. (2022) to evaluate the potential impact of biofertilizers on rice plant growth and yield, treatments without any biofertilizers produced the lowest test weight (19.88 g), which is nearly identical to our findings. This may be due to the lack of extra nutrients and helpful microorganisms that biofertilizers provide, which causes subpar nutrient uptake and growth of the plants.

4.2.5 Days to 50 % flowering

The treatment using RD of NPK achieves 50 % blooming the earliest among these fertilizers, followed by FYM, the control, organic manures, mycorrhiza, and goat manures, in that order. In our investigation, the results with RD dosage of NPK were observed to attain 50 % flowerings sooner than the findings reported by Reddy et al. (2020) with the recommended dose of NPK but in both results, the treatments showed non-significant results. The difference in days to 50 % blooming between the treatments may be caused by the crop's accessibility to nutrients, which combined improve the crop's photosynthetic rate and dry matter buildup. Among these biofertilizers, Mustard seed cake reached lately to 50 % flowering due to the nutrients' gradual release. In comparison to synthetic or organic fertilizers, mustard seed cake takes longer to break down and release nutrients, delaying plant development and blooming.

4.2.6 Days to 75 % maturity:

Organic fertilizers, subsequently followed by FYM and RD of NPK, were among the treatments that attained maturity at a rate of 75 % sooner. Similar results were documented by Reddy et al. (2020) with a 100 % Recommended dose of fertilizers + Biofertilizers consortium. Within these biofertilizers, Mustard seed cake reached lately to 75 % maturity because of differences in the nutrients they contain and how quickly they decompose. Goat manures and Mycorrhiza reached 75 % maturity at the same time which might be due to their advantageous symbiotic interaction and comparable nutritional composition, environmental and climatic factors may be other reasons behind this.

4.2.7 Grain yield:

Utilizing biofertilizer in addition to chemical fertilizer has significantly enhanced rice growth and yield performance. The overall mean of grain yield (5125.081 kg) was obtained with the application of different fertilizer treatments. Among these treatments, the recommended dose of NPK produces the highest grain yield (7021.47 Kg). This is because the ideal nutrition of nitrogen, phosphorus, and potassium which are crucial for plant growth and development is provided by the required amount of NPK fertilizer, resulting in the maximum grain production. According to Naher et al. (2018), the application of 50 % N, P, K with 10 t/ha biofertilizer gave almost similar grain yield as compared to our results. Within different biofertilizers, Mustard seed cake produced maximum grain production (6681.70 kg) which is followed by Goat manures (5128.35 kg), and FYM (4482.78 kg). Mustard seed cake, being a biofertilizer, contributes to higher grain production due to its rich nutrient content, including nitrogen, phosphorus, and potassium, enhancing soil fertility, and promoting plant growth. Goat manure and FYM also provide nutrients but at comparatively lower levels, resulting in slightly lower grain yields. According to research conducted by Kamraye & Kumar (2020), the results of grain yield with 60 t/ha FYM was 4.10 t/ha. This result is slightly lower as compared to our findings. Variations in soil composition, climate, pest/disease pressure, cultivation methods, experimental mistakes during data collecting, and variety used in research may be the cause. Similarly, Organic manures (4335.79 kg) and Mycorrhiza (4253.80

kg) gave nearly equal and average grain yields per hectare. Due to their balanced nutrient enrichment and symbiotic association with plant roots, organic manures, and mycorrhiza have equal grain yields, increasing total crop output. The treatment without any fertilizer resulted in the lowest grain yield (3971.64 kg). This finding is consistent with Adhikari et al. (2021) observation that the control group yielded the lowest grain output, corroborating our results.

4.2.8 Biomass yield

The application of biofertilizers in conjunction with chemical fertilizers had a substantial impact on straw production across various treatments. The application of different treatments in our study produced an overall mean straw yield was 9030.952 kg/ha. According to Ghimire et al. (2021), straw yield with treatments (Azolla + N:P: K @50:15:15 kg/ha), (Azotobacter+ N:P: K @50:15:15 kg/ha), (Azotobacter +Mycorrhiza + N:P: K @50:15:15 kg/ha), (Azotobacter + Phosphorus Solubilizing Bacteria+ Potassium Mobilizing Bacteria+ N:P: K @50:15:15 kg/ha) and (Recommended chemical fertilizer i.e. N:P: K @100:30:30 kg/ha) gave overall mean of 10 630 kg straw yield which is slightly higher as compared to our findings because the above-mentioned treatments may include a variety of helpful microbes, certain nutrient combinations, as well as suggested chemical fertilizers as remedies. In contrast to the treatment utilized in our study, which could have been deficient in certain beneficial components or had insufficient nutritional ratios, these treatments probably improved nutrient availability, soil health, and plant development, resulting in increased straw output. The highest straw yield was given by recommended dose of NPK (11 037.50 kg) which is followed by mustard seed cake (10 644.16 kg) and goat manures (8915.83 kg) respectively. The prescribed amount of NPK fertilizer produced the largest straw production (11 037.50 kg) because of its well-balanced mix of nitrogen, phosphorous, and potassium, which provides crucial nutrients for optimum plant growth. Even though they are helpful, goat and mustard seed cake may have unbalanced or reduced nutritional concentrations, which may cause somewhat lower yields. The research conducted by Ali et al. (2012) to examine the plant growth and yield attributes of rice records 11 320 kg/ha straw yield with a recommended dose of NPK which is almost parallel to our findings. Among various biofertilizers, organic manures (8357.50 kg), FYM (8316.66 kg), and mycorrhiza (8263.33kg) gave similar straw yield Due to their capacity to improve soil fertility, increase nutrient availability, and foster healthy root development, organic manures, FYM, and mycorrhiza all produced straw yields that were comparable to one another. The lowest straw yield (7681.66 kg) was given treatments without any fertilizer because there aren't enough of the vital nutrients needed for plant development and growth.

4.3 Economics analysis

The cost of cultivation among different treatments showed the highest in mustard seed cake (200 558.05 NRs/ha) with the lowest net returns (59 911.85 NRs/ha) and benefit-cost ratio (1.2) whereas the average cost of cultivation was observed in the recommended dose of NPK (114 345.09 NRs/ha) with highest net returns (159 000.11 NRs/ha) and benefit-cost ratio (2.3). Within biofertilizers, the lowest and equal cost of cultivation was found on Mycorrhiza (85 013.05 NRs/ha) & Organic manures (85 013.05 NRs/ha) with the highest net returns (84 528.27 NRs/ha & 87 633.35 NRs/ha) & benefit-cost ratio of (1.9 and 2.0) respectively. The average cost of cultivation was seen on FYM (122 558.05 NRs/ha) and Goat manures (120 558.05 NRs/ha) with net returns (55 130.9 NRs/ha & 81 223.77 NRs/ha) and benefit-cost ratio (1.4 and 1.6). Among these biofertilizers, the highest net returns and the benefit-cost ratio were observed in Organic manures, Mycorrhiza, and Goat manures where FYM and Mustard seed cake showed similar and lowest net returns and benefit-cost ratios. Highest the benefit-cost ratio among these treatments suggests that the fertilizer option provides the greatest economic returns relative to its cost. The higher benefit-cost ratio implies that the benefits obtained from using that fertilizer outweigh the expenses associated with its application. Among these treatments, the recommended dose of NPK, Organic manures, and Mycorrhiza gave

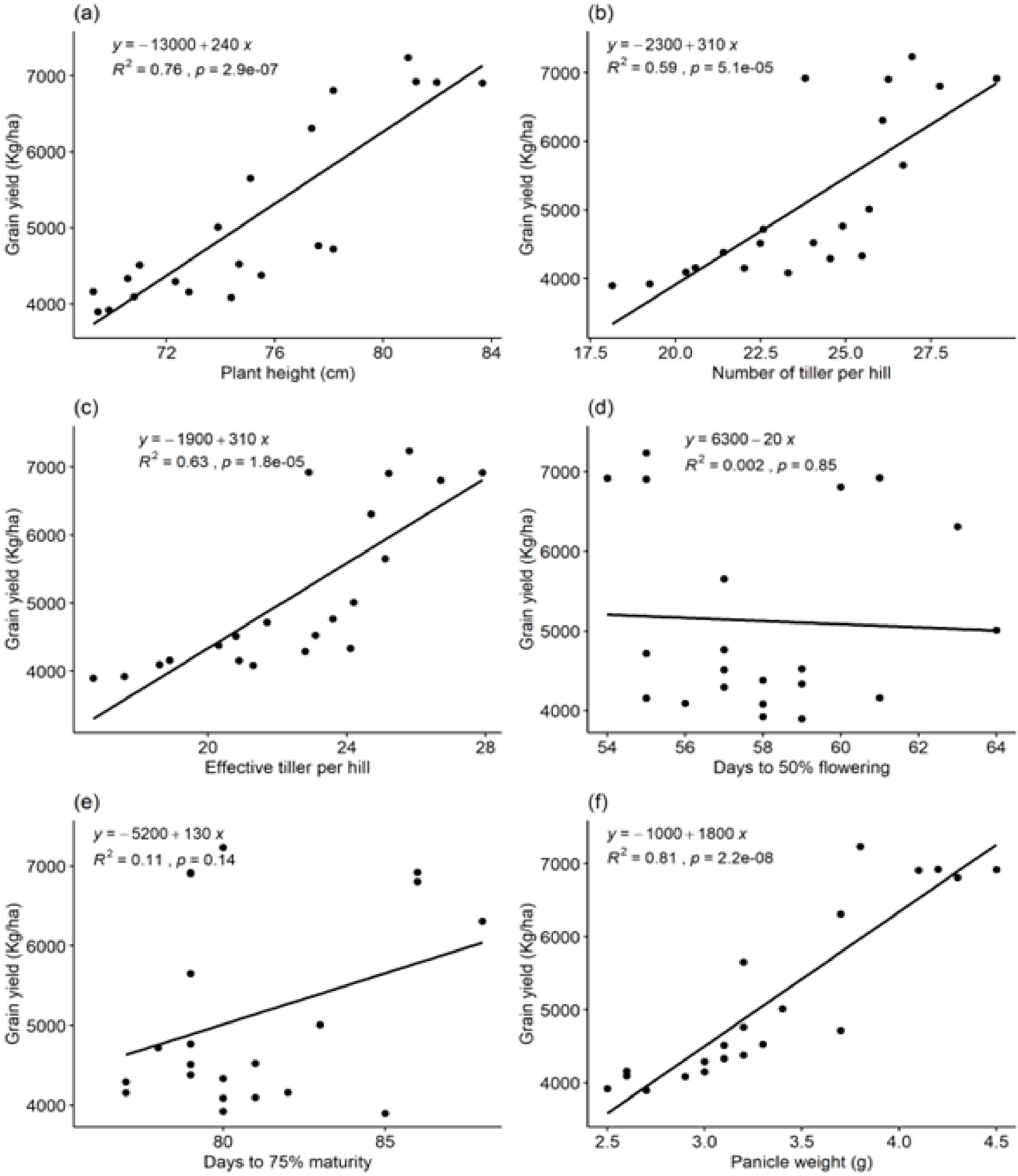

Figure 2. Coefficient of determination (R^2), Linear regression equation, and scatter diagram showing the fitted simple regression line of Y (Yield) on X ((a) Plant heights, (b)Number of tillers per hill, (c) Effective tiller per hill, (d)Days to 50 % flowering, (e)Days to 75 % maturity, (f)Panicle weights).

the highest benefit-cost ratio and Goat manures gave the average benefit-cost ratio thus, As evidenced by the high benefit-cost ratios of these treatments, choosing them during cultivation has several benefits, including improved nutrient availability, higher soil fertility, greater crop production, and long-term sustainability.

Figure 2 presented above displays the coefficient of determination (R^2), linear regression equation, and scatter diagram illustrating the fitted simple regression lines of various factors (plant heights, number of tillers per hill, effective tiller per hill, days to 50 % flowering, days to 75 % maturity, and panicle weights) on grain yields in spring rice. The results indicate that all factors except days to 50 % flowering exhibit significant linear relationships with grain yields. The R^2 values, which represent the proportion of variance in yield that can be explained by each factor, indicate the strength of the relationship. Among the factors analyzed, plant height (76 %), number of tillers per hill (59 %), effective tiller per hill (63 %), and panicle weights (81 %) showed substantial contributions to the total grain yield of rice. The remaining contribution can be attributed to other factors. A higher R^2 value signifies a better fit

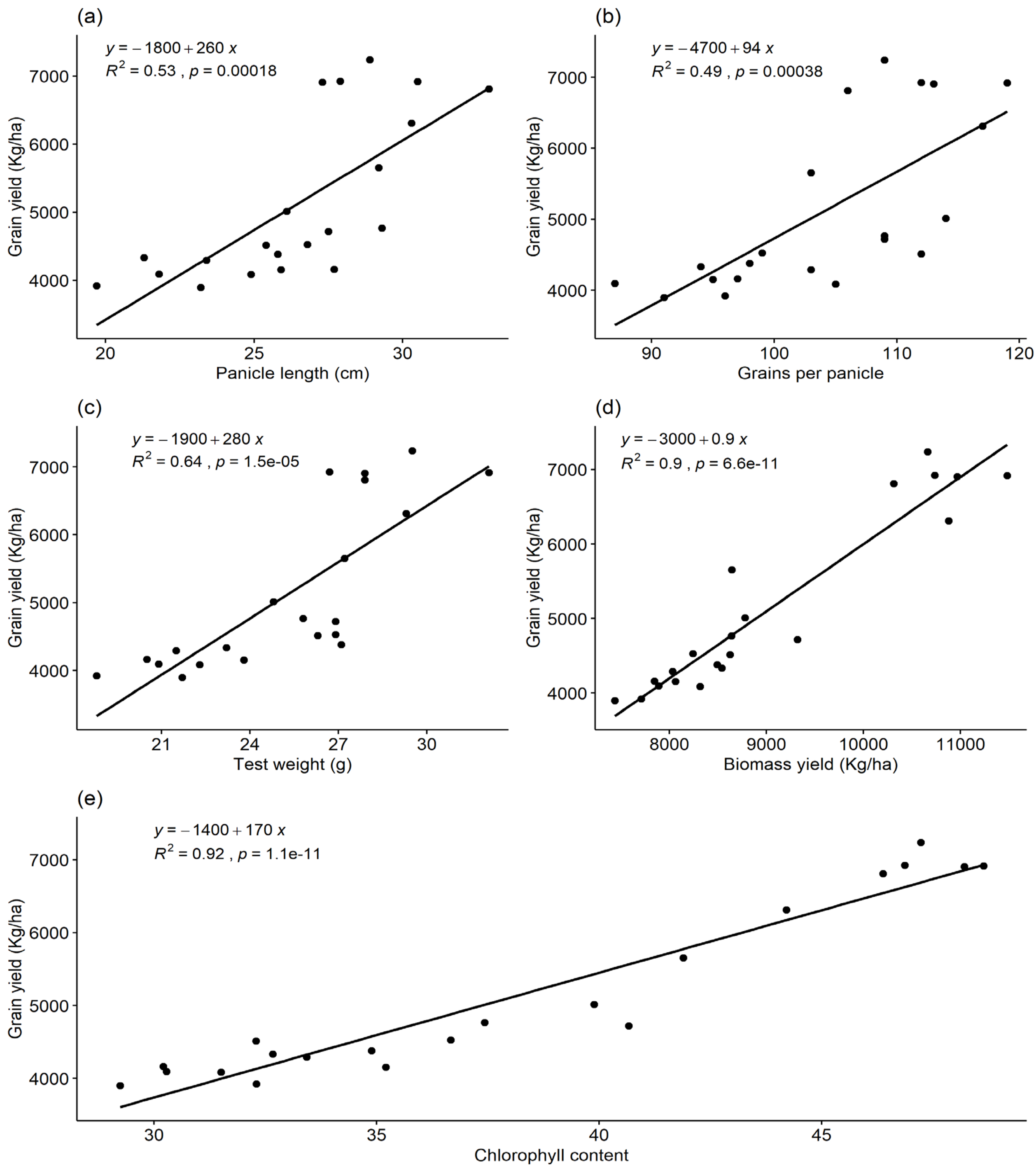

Figure 3. Coefficient of determination (R^2), Linear regression equation, and scatter diagram showing the fitted simple regression line of Y (Yield) on X ([(a)]panicle length, [(b)]grains per panicle, [(c)]test weight, [(d)]biomass yield, [(e)]chlorophyll content).

of the regression line to the data, indicating a more accurate representation of the relationship between the independent variables and grain yields.

In Figure 3, the scatter diagram exhibits the fitted simple regression lines of panicle length, grains per panicle, test weight, biomass yield, and chlorophyll content on grain yields (Y). Additionally, the linear regression equation and the coefficient of determination (R2) are presented. The results indicate that all the mentioned parameters exhibit significant linear relationships with grain yields. Figure 3 illustrates that the R2 values for all the parameters are higher, indicating a better fit of the regression lines to the data. This suggests a more accurate representation of the relationship between the independent variables (panicle length, grains per panicle, test weight, biomass yield, chlorophyll content) and grain yields. Among the parameters analyzed, panicle length accounted for 53 % of the total variation in grain yield, grains per panicle contributed 49 %, test weight contributed 64 %, biomass yield contributed 90 %, and chlorophyll content contributed 92 %. These results highlight the significant roles played by panicle length, grains per panicle, test weight, biomass yield, and chlorophyll content in the contribution to grain yield.

5 Conclusions

In conclusion, our investigation, various biofertilizers significantly influenced rice development and yield characteristics. Treatments T1 and T2, involving recommended NPK dosage and farmyard manure, respectively, showcased the highest grain and straw yields, underscoring their productivity enhancement. T1 and T6 consistently excelled across parameters, indicating their superior ability to foster plant growth. Moreover, organic manures and mycorrhiza exhibited favourable benefit-to-cost ratios, highlighting their economic viability. Mycorrhiza, goat, and organic manures emerged as potent biofertilizers with positive effects on rice crops. Overall, their use promotes sustainable and environmentally friendly rice cultivation, improving soil health and enhancing crop output. Further studies are recommended to optimize application techniques and rates, maximizing the benefits of these biofertilizers in rice production.

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The authors declare no irreconcilable circumstances.

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Authors contribution
DKM, BO, and SPSY: Conceived and designed the experiments. DKM, NPG, and RKM: Performed the experiments, interpreted the data, and wrote the paper. SPSY: Conducted the data analysis and visualization of the data. RA: Supervising the research.

Data availability:
The data will be available on request.

Consent for publication:
We humbly give consent for this article to be published.

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