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Impact of compost and bio-fertilizers on performance of spring wheat at Kailali district of Nepal

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A B S T R A C T

The imbalanced application of chemicals has degraded the environment, reduced soil fertility and declined crop productivity. To promote sustainable agriculture through integrated nutrient management, a study was conducted to evaluate the combined effects of inorganic fertilizers, compost and bio-fertilizers on performance of wheat. The research was carried out from December 8, 2023 to April 21, 2024 in factorial randomized complete block design having 3 replications and 8 treatments at Agronomy farm, Faculty of Agriculture, Tikapur, Kailali, Nepal. The treatments consisted control group and combinations of compost manure treated with effective micro-organisms (EM-1) and *Trichoderma* viride, applied to wheat varieties; Aaditya and Gautam. Results indicated combination of all fertilizers in both the varieties (i.e, in T3: Gautam+Compost manure+EM-1+Trichoderma and T7: Aaditya+Compost manure+EM-1+*Trichoderma*) outperformed all other treatments, showing significant plant height, effective tillers, spike length, grains per spike and yield. Aaditya recorded with significant increase in peduncle length (23.55 cm) and 1000-grain weight (49.25 g) whereas Gautam showed the highest plant height (106.67 cm), spike length (13.23 cm) and straw yield (6.44 t ha^{-1}). However, Aaditya and Gautam exhibited non-significant increase in grain yield i.e. 4.35 t ha^{-1} and 4.22 t ha^{-1}. The combined application of fertilizers showed 19.69% increase in grain yield (4.68 t ha^{-1}) ensuring good performance over control in all parameters.

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1. Introduction

Wheat (*Triticum aestivum* L.) is among the most widely cultivated cereal crops across the world, which ranks third in Nepal, after rice and maize. It is an important food crop having high protein (10-13%), carbohydrates, vitamins (riboflavin, thiamine and niacin), fibers and minerals like Zn, Fe, Se, Mg etc. (Iqbal et al., 2022). In the year 2080/81 Nepal produced 20,35,559 tons of wheat from 6,81,851 ha of land (AITC, 2025) at the same time it alone contributed 5.87% to the total agricultural GDP of the country in 2023/24 (MoALD, 2025). Wheat can be grown in various of climates and soil types requiring higher amounts of chemical fertilizers, particularly nitrogen for improving growth and yield of grains (Vista et al., 2022).

The organic fertilizers, such as manure, crop residues and compost, has long been used to enhance the number of micro-organisms present in the soil, soil fertility and agricultural productivity (Aredehey and Berhe, 2016). A study performed by Higa and Wididana in 1991 discovered various co-existing beneficial soil micro-organisms species, known as EM, including photosynthetic bacteria (*Rhodobacter sphaeroides* and *Rhodopseudomonas palustris*), lactic acid bacteria (*Lactobacillus casei*, *Lactobacillus plantarum*, and *Streptococcus lactis*), actinomycetes (*Streptomyces* spp.); and yeasts (*Saccharomyces* spp.). These microorganisms enhance plant growth and productivity by promoting photosynthesis. When applied with compost, EM can improve soil health and enhances soil fertility by reducing soil acidity and salinity due to its acidic nature and anti-oxidizing effects, leading to enhanced crop yield and quality (Iriti et al., 2019; Joshi et al., 2019). Studies show that EM application through seed treatment, foliar spray, or soil incorporation enhance plant height, shoot biomass, photosynthetic performance, and drought resilience in cereals (Naik et al., 2020). In wheat, combined use of EM with compost or vermicompost has been found to significantly improve the stem and root biomass, grain yield, and 1000-grain weight, particularly under drought conditions (Talaat and Abdel-Salam, 2024a; 2024b). Cvijanović et al. (2022) reported that foliar application of EM significantly improved wheat grain yield and 1000-grain weight, offering a sustainable, low-cost alternative to chemical fertilizers, especially when combined with appropriate fertilization strategies.

EM and bio-fertilizers is gaining attention as sustainable alternatives to chemical fertilizers in Nepal. Bio-fertilizers such as *Azotobacter*, *Rhizobium*, Phosphate Solubilizing Bacteria (PSB), *Trichoderma*, and *Mycorrhizae* are eco-friendly microbial inputs, enhancing soil fertility and crop productivity by naturally fixing nitrogen, mobilizing nutrients, and stimulating plant growth (Subedi, 2025). For example, *Trichoderma* species like *T. haziarum*, *T. viride*, *T. atroviride*, *T. asperellum* are well known for their biocontrol properties. Employing Trichoderma as a biological agent is beneficial as it reduces fertilizer use, pesticide residues in crop fields, and enhances yield (Thapa et al., 2020). Through mechanisms of mycoparasitism, antibiosis, toxin degradation, and inactivation of pathogenic enzymes, solubilization and sequestration of inorganic nutrients, it enhances nutrient uptake, promotes root hair development and improves overall plant performance (Mahato et al., 2018). In Iraq, combination of bio-fertilizers with recommended chemical fertilizer dose significantly improved wheat grain yield by 17–18%, mainly due to increased spike number per m^2 and 1000-grain weight, while enhancing soil nutrient balance (Hadwan et al., 2019).

Similarly, under water stress condition, *Azotobacter chroococcum*, *Mycorrhiza*, and *Trichoderma* positively influenced the plant height, grain yield, and 1000-grain weight, with *Mycorrhiza* showing the strongest impact (Khiniab, 2023). Moreover, applying *Azotobacter* and PSB along with 100% recommend dose of fertilizer significantly increased the height of the wheat plant, number of total and productive tillers per meter of row, harvested grain weight, straw and total biomass yield (Kumawat et al., 2021).

Various organic wastes like farm waste, vegetable scraps, animal refuse, sewage, and domestic waste remain unutilized, especially in poor countries like Nepal. Composting such wastes can provide an effective, eco-friendly method of disposal, conserving natural resources, improving nutrient cycling and supporting sustainability (Ibrahim, 2008). The increasing demand for wheat due to population growth has compelled the adoption of high-yielding varieties along with rise in chemical fertilizer use. For improved production, inorganic fertilizers are used in combination with organic fertilizers (Chen, 2006). This has increased the crop productivity but there are times when chemical fertilizers are not available in right time or in enough quantity even though they are expensive. The imbalanced application of chemicals for long period; especially DAP and Urea, have negative impacts on environment as well as human health, leading to reduced soil fertility, lower yield, and ecological imbalance (Rai and Khadka, 2009). Therefore, there is a shift towards Integrated Nutrient Management (INM) which involves the integration of inorganic fertilizers with organic amendments and bio-fertilizers leading towards sustainable agriculture. So, this field experiment was carried out to investigate the response on biometric, phenological, yield and yield attributing components of two popular wheat varieties to different fertilizers combinations at Tikapur municipality of Kailali district, Nepal.

2. Material and methods

2.1. Site of the experiment

The field experiment was carried out at Agronomy farm, School of Agriculture, FWU, Tikapur-1, Kailali, Nepal between December 2023 to April 2024. Geographically situated at 28054’06” North and 81012’34” East at an elevation of 156.04 masl, the site has a subtropical climate characterized by hot and humid summers and cold winters. Both minimum and maximum temperatures gradually decrease from October, reaching their lowest in December. The 15 days’ average minimum and maximum temperature ranged from 9.03 °C to 16.83 °C and 23.36 °C to 38.09 °C during December to April respectively, with higher precipitation (26.7 mm) from 21st Feb to 6th March.

The soil in the research area was classified as an Inceptisol with sandy loam and neutral pH of 7. Soil samples collected from the depth of 0–15 cm, showed low fertility status of soil with 1.03% soil organic matter based on the standard interpretation scale (<2.5% = low, 2.5–5% = medium, >5% = high). The available nitrogen was found 0.05%, also categorized as low (<0.10% = low, 0.11–0.20% = medium, >0.20% = high) determined by alkaline $KMnO_4$ method. The available phosphorus was 14.89 kg per hectare, which is considered low (<31 = low, 32–55 = medium, >55 = high), estimated using Modified Olsen’s method, and available potash, extracted with neutral ammonium acetate and measured via flame photometer, was 121.15 kg per hectare falling within moderate range (<110 = low, 111–280 = medium, >280 = high), as per the soil sample report obtained from Soil and Fertilizer Testing Laboratory, Sundarpur, Kanchanpur, Nepal.

2.2. Experimental details

2.2.1. Experimental design

The study was carried out in factorial randomized complete block design (RCBD) including 3 replications and 8 treatments, combining two factors. The first factor being the popular wheat varieties viz. Aaditya and Gautam; and second factor being the fertilizers (Control, Compost manure, EM-1 and Trichoderma). The chemical fertilizers were applied to all plots under experiment as per recommended by Government of Nepal (125:50:20 NPK kg/ha) through Urea (46% N), Di-ammonium phosphate (DAP; 46% P2O5 and 18% N) and Muriate of potash (MOP; 60% K_2O) (AITC, 2023). The control group means only chemical fertilizers applied which is common and adopted by most of farmer in the country. There were 24 plots with each plot sized (3.0 m x 2.0 m) 6 m^2 maintaining 0.50 m and 1.0 m spacing between each plot and replication. Fertilizers were applied as per treatment combinations. The details of the treatment and treatments combinations are given in the Table 1 and 2.

2.2.2. Fertilizer and bio-fertilizer treatments details and application

Compost manure: About 100 kg compost manure was collected from the farmer’s field made by decomposing various organic wastes like FYM, residues, household refuse, ash, weeds and grasses over 6 months. It was well decomposed and applied in the field @6 t ha^{-1} on a dry weight basis, as per the treatment. Despite containing 37.92% moisture, all nutrient values and application rates were calculated on the basis of dry weight to ensure consistency and accuracy in estimating nutrient input. The compost manure was analyzed on a dry weight basis, had a pH of 7.25, 25.77% carbon, 1.16% total nitrogen, 0.85% total phosphorus, 2.93% total potash, 37.92% moisture, and a carbon-to-nitrogen (C:N) ratio of 22.2:1. Based on the minimum quality standards for compost (pH: 6.0-8.0, carbon ≥20%, nitrogen ≥1.0%, phosphorus ≥0.5%, potassium ≥1.0%, and moisture ≤25%), the compost exceeded all the nutrient requirements except for slightly high moisture. Despite that, it was considered good enough for field application because it had all the necessary nutrients. Each of the total N, P, and K contents of compost were analyzed at the Soil and Fertilizer Testing Laboratory in Sundarpur, Kanchanpur using the following methods: Kjeldahl digestion and distillation for nitrogen, wet digestion followed by the Vanadomolybdate method for phosphorus, and wet digestion with flame photometry for potassium.

Bio-fertilizer: EM-1 and Trichoderma viride were used as bio-fertilizer. Two liters of EM-1 was bought from an agrovet of Tikapur, Kailali, manufactured by EMCO-Nepal and certified by the Nepal government. It mainly included yeast, photosynthetic bacteria, lactic acid bacteria and actinomycetes (108 cfu/ml). EM was applied in two ways: first, by treating compost manure with EM-1 (2% per kg) and second, by applying 1% foliar spray of EM-1 (1% solution) during booting stage of wheat (Olle and Williams, 2013). The liquid *Trichoderma* (200 ml bottle) mainly contained *Trichoderma* viride species at a concentration of 109 cfu/ml. It was manufactured in Nepal by Agricare Nepal Pvt. Ltd. The compost manure was treated with EM-1 (2% per kg) and Trichoderma (5 ml per kg) prior to 5 days before applying in the field. The treated compost manure with Trichoderma and EM was left inside the cool and dark room and was covered with plastic. The white growth of mycelium indicated the presence and good growth of micro-organisms enhancing the performance of compost manure in the field.

Table 1. Treatment details

Treatments	Symbol
Factor A	
Gautam	V_1
Aaditya	V_2
Factor B	
Control	N_1
Compost manure + EM-1	N_2
Compost manure + EM-1 + Trichoderma	N_3
Compost manure	N_4

2.2.3. Planting materials

Aaditya and Gautam are the improved wheat varieties released in Nepal in 2010 and 2004 respectively, are popular in Kailali district and selected for the experiment (Bhatt et al., 2020a). Aaditya and Gautam variety both matures in 118 to 119 days, whereas the yield of Aaditya is 4.7 t ha^{-1} far greater than 3.4 t ha^{-1} in Gautam (AITC, 2023).

Table 2. Treatment combinations

Treatment No.	Symbol	Treatment combination
T_1	N_1V_1	Gautam+Control
T_2	N_2V_1	Gautam+Compost manure+EM-1
T_3	N_3V_1	Gautam+Compost manure+EM-1+Trichoderma
T_4	N_4V_1	Gautam+Compost manure
T_5	N_1V_2	Aaditya+Control
T_6	N_2V_2	Aaditya+Compost manure+EM-1
T_7	N_3V_2	Aaditya+Compost manure+EM-1+Trichoderma
T_8	N_4V_2	Aaditya+Compost manure

2.2.4. Agronomic practices

The field was prepared using conventional tillage with a tractor, including one deep ploughing followed by two harrowing and leveling. The site had a cropping history of lentil cultivation followed by a fallow period before current wheat cultivation. Urea was applied in 3 splits viz. ½ N at the time of sowing, ¼ N each at 55 and 75 days after sowing (DAS) whereas DAP and MOP were applied basally into the soil when seeds were sown. The control plots received only the recommended dose of chemical fertilizers (MoALD, 2023), whereas the other treatments were supplemented with compost manure and bio-fertilizers (EM-1 and *Trichoderma viride*) depending on the treatment combination. The seeds were continuously sown in rows 25 cm apart on 22nd Mangsir (December 8, 2023) at a rate of 120 kg per ha. Flood irrigation using an electric pump was carried out at 21, 50, 70 and 85 DAS, corresponding to critical growth stages of the crop i.e., Crown root initiation, tillering, jointing and flowering stages. Each plot was irrigated by creating separate channels. Manual harvesting was done with a sickle when the grains were hard, and the straw had dried out and become brittle.

2.2.5. Observation and data recording

For each treatment, plants were randomly selected for measurement, leaving out those along the borders. Observations were made on the different traits. Plant height was measured in centimeters, using a meter scale, at 40, 60, and 80 days after sowing and again at harvest. It was measured from the base of the plant to the tip of the uppermost leaf during vegetative phase, and to the tip of the spike during reproductive phase, excluding the awn. Peduncle length was recorded from the base of the flag leaf to the base of the spike before harvesting. Spike length was measured from its base to the tip, excluding the awn, just before harvest. The number of tillers were manually counted within a marked 1.0 m^2 area during harvest. Days to heading were noted when half of the plants population in a plot showed ear emergence from the flag leaf sheath. Days to anthesis were recorded when 50% of the spikes displayed yellowish anthers. Maturity was determined when 80% of the spikes produced a cracking or metallic sound when grains were pressed between the teeth. Effective tillers, those bearing filled spikes, were counted from a 1 m^2 area at harvest. Grain number per spike was taken from ten randomly selected spikes per plot. Thousand grain weight was measured by weighing 1000 grains from each plot using a digital balance. Grain yield was determined from 1 m² harvested area, converted to tons per hectare, and adjusted to 13% moisture content using the method described by Mulvaney and Devkota (2020).

$$\text{Yield} = (\text{Harvest yield}) \times (1 - \text{Harvest moisture\%}) / (1 - \text{Standard moisture \%})$$

Where, standard moisture was taken at 13%.

Biological yield was calculated by collecting all above-ground biomass from the marked 1 m^2 area, drying it in the sun, weighing it, and converting it into tons per hectare. Harvest index was expressed as the percentage ratio of grain yield to biological yield.

$$\text{Harvest index} = \text{Grain Yield} / \text{Biological Yield}$$

2.3. Statistical assessment

The collected data were compiled and arranged systematically for data analysis in Microsoft Excel 2016. All the treatments were then evaluated using analysis of variance (ANOVA) in R studio (version 4.4.1) with "doe bioresearch" package. The differences between the average treatment were estimated using the Duncan Multiple Range Test (DMRT) at 5% significance level (Gomez and Gomez, 1984).

3. Results and discussion

3.1. Biometric parameters

3.1.1. Plant height

The result showed the significant difference between the wheat varieties and fertilizers application at 40, 60 and 80 DAS and harvest. Gautam variety was found to be statistically superior than Aaditya, exhibiting the taller plant height from the very beginning till the harvest, with 106.67 cm plant height at harvest. The plant height was significantly influenced from 40 DAS to harvest except for the 60 DAS which showed non-significant difference among fertilizers. The greatest plant height of 34.14 cm was observed in CM+EM followed by CM at 40 DAS. Though non-significant, the plant height stayed greatest in CM+EM at 60 DAS. But at 80 DAS and at harvest, maximum plant height was found in case of CM+EM+T which revealed 4.01% increase in plant height than sole application of chemical fertilizers (control) for both varieties. The sudden increase in plant height after 80 DAS in CM+EM+T was due to the foliar application of EM at booting stage. Mahato et. al (2018) reported 4.6% height increase in wheat over control with FYM and Trichoderma, highlighting Trichoderma viride as growth promoter. The organic manures increase the crop growth by enhancing nutrients availability and apical meristem functions. The findings align with Doni et al. (2014), Asfaw (2022) and Syamsiyah et al. (2023). Likewise, no interaction effect can be seen among varieties and fertilizers.

Table 3. Plant height of wheat at different growth stages as influenced by varieties and different fertilizers at Tikapur Municipality, Kailali

Treatments	Plant height (cm)				Spike length	Peduncle
	40 DAS	60 DAS	80 DAS	At harvest	(cm)	length (cm)
Factor A (Variety)						
Gautam	33.86^{a}	61.60^{a}	100.16^{a}	106.67^{a}	13.23^{a}	21.85^{b}
Aaditya	32.34^{b}	58.65^{b}	94.48^{b}	103.90^{b}	12.59^{b}	23.55^{a}
$CD_{0.05}$	1.07	1.95	2.14	1.67	0.46	1.17
SEm (±)	0.35	0.64	0.70	0.55	0.15	0.38
F test	**	**	***	**	**	**
Factor B (Fertilizers)						
Control	32.21^{b}	58.91	94.64^{b}	103.21^{b}	12.42^{c}	23.88
CM+EM	34.14^{a}	61.03	98.33^{a}	105.66^{ab}	12.69^{bc}	22.14
CM+EM+T	32.33^{b}	60.43	99.38^{a}	107.35^{a}	13.42^{a}	22.61
CM	33.73^{ab}	60.11	96.95^{ab}	104.92^{ab}	13.11^{ab}	22.19
$CD_{0.05}$	1.51	2.76	3.03	2.37	0.65	1.65
SEm(±)	0.50	0.91	1.00	0.78	0.21	0.54
F test	*	Ns	*	*	*	Ns
A:B						
$CD_{0.05}$	2.14	3.91	4.29	3.35	0.92	2.34
P value	0.36	0.85	0.45	0.83	0.82	0.46
CV%	3.70	3.72	2.52	1.82	4.09	5.89
Grand mean	33.10	60.12	97.32	105.29	12.91	22.70

CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, Ns: Non-Significant; *: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, ***: significant at $p \leq 0.001$ l; CM: Compost manure; EM: Effective Micro-organism; T: *Trichoderma*

3.1.2. Peduncle length

Significant variation in peduncle length was noticed in varieties, with Aaditya having the longest peduncle length i.e. 23.55 cm. However, non-significant difference was observed among the various fertilizer application. CM+EM had shorter peduncle length after CM+EM+*Trichoderma* and CM with mean value of 22.70. No interaction effect was perceived within varieties and different fertilizers. Rajbanshi et al. (2024) reported different peduncle length among different genotypes of wheat. This might be due to unique genetic traits in each wheat variety that influence its growth characteristics, including peduncle length. There was no interaction effect was observed among different fertilizers and varieties.

3.1.3. Spike length

Statistically significant difference in terms of spike length among the treatments was recorded at the time of harvest, at a 5% significance level. The spike length of Gautam variety peaked at 13.23 cm, 5% longer than Aaditya (12.59 cm). Among fertilizers, CM+EM+T showed the longest spike length of 13.42 cm, 8% longer than Control. The increase in spike length could be due to increased plant height having the positive correlation of r=0.53. Taller wheat plants often allocate more resources to reproductive structures such as spike development, resulting in longer spikes with improved photosynthetic efficiency (Acevedo et al., 2002). Arithmetically, no interaction effect was recorded with varieties and different fertilizers with mean value of 12.91 cm. The results were in line with El-Kouny (2007).

3.2. Phenological parameters

Neither varieties nor fertilizers exhibited significant effect on phenological parameters like days to heading, anthesis, senescence, maturity and the duration of grain filling as shown in Table 4. There was no interaction effect among the fertilizers and varieties. The fertilizers primarily affect the nutrient availability, root development, growth and yield component by enhancing the microbial activity rather than triggering the timing of developmental stages of wheat plants. Also, Aaditya (118 days) and Gautam (119 days) varieties reached stage of maturity at same duration due to similar genetic potential.

3.2.1. Days to 50% heading

Although the variation among the varieties and fertilizers was non-significant, Aaditya showed early heading than the Gautam taking 82.91 days to reach at heading stage. At the same time, CM+EM took shortest days to reach at heading stage followed by CM, Control and CM+EM+T, which may be attributed to the stimulation of early development due to improved nutrient availability and root-zone microbial activity. EM formulations have been found to produce growth-promoting hormones like auxins, abscisic acid and gibberellins which bring faster vegetative growth and accelerate the reproductive phase (Ncube, 2024).

Table 4. Phenological parameters of wheat as influenced by varieties and different fertilizers at Tikapur municipality, Kailali

Treatments	Days to				
	Heading	Anthesis	Flag leaf senescence	Grain filling period	Maturity
Factor A					
Gautam	83.08	85.33	113.83	28.50	126.50
Aaditya	82.91	85.25	113.83	28.58	126.75
$CD_{0.05}$	1.06	0.83	1.38	1.18	0.97
SEm (±)	0.35	0.27	0.45	0.39	0.32
F test	Ns	Ns	Ns	Ns	Ns
Factor B					
Control	83.16	85.50	114.33	28.83	126.00
CM+ EM	82.50	85.00	113.66	28.66	126.66
CM+EM+T	83.50	85.66	113.83	28.16	126.83
CM	82.83	85.00	113.50	28.50	127.00
$CD_{0.05}$	1.50	1.17	1.96	1.67	1.37
SEm (±)	0.49	0.38	0.64	0.55	0.45
F test	Ns	Ns	Ns	Ns	Ns
A:B					
$CD_{0.05}$	2.13	1.66	2.77	2.36	1.94
P value	0.95	0.98	0.63	0.39	0.69
CV%	1.46	1.11	1.39	4.73	0.87
Grand mean	83	85.29	113.83	28.541	126.625

CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, Ns: Non-Significant; *: p≤0.05, **: significant at p≤0.01, ***: p≤0.001; CM: Compost manure; EM: Effective Micro-organism; T: *Trichoderma*

3.2.2. Day to 50% anthesis

Anthesis was observed insignificant among varieties recording 85 days being statistically alike. Correspondingly, the different fertilizers also showed non-significant differences in terms of days to anthesis with an average of 85.29 days. CM+EM+T was found with the maximum days to start anthesis (85.66 days) followed by Control (85.50 days), CM+EM (85 days) and CM (85 days). This could be due to minor changes in physiological processes, especially slower nutrient release and hormonal activity since EM release growth regulators such as auxins, cytokinins and gibberellins, which enhances the microbial and photosynthetic activity, leading to longer vegetative phase than flowering (Cvijanović et al., 2022).

3.2.3. Days to 50% flag leaf senescence

Both the varieties; Aaditya and Gautam, recorded 113.83 days to senescence. However, the data also revealed that the minimum number of days to reach senescence was recorded from CM followed by CM+EM, CM+EM+T and Control. The non-significant observations in days to 50% flag leaf senescence could be associated with the interaction of cytokinins with auxins and ethylene produced by bio-fertilizers, slowing down the chlorophyll degradation and leaf senescence (Hönig et al., 2018).

3.2.4. Grain filling period

The Aditya and Gautam were statistically similar, taking 28.58 and 28.50 days to complete grain filling. The shortest duration for grain filling was recorded in the treatment CM+EM+T (28.16 days) and the longest duration was observed for Control recording 28.83 days. All the treatments were statistically identical with each other where CM+EM exhibited 28.16 days and CM was recorded with 28.50 days. Hence, the observed differences were not significant. Naik et al. (2020) reviewed that EM influences nutrient uptake, grain yield, photosynthetic efficiency, and overall biomass in cereals. *Trichoderma* improve grain quality and filling under stressed environment by producing various phytohormones (Illescas et al., 2021).

3.2.5. Days to maturity

No statistically significant differences were observed among the treatments regarding the days to maturity. Both Aaditya and Gautam exhibited same time to reach maturity i.e., 126.75 and 126.50 days, respectively. Similarly, the treatment CM took the longest time to reach maturity (127 days) followed closely by CM+EM+T (126.83 days), CM+EM (126.66 days) and Control (126 days). This might be due to prolonged grain filling period from early nutrient availability and extended vegetative growth. Treatments with bio-fertilizers (EM and *Trichoderma*) matured slightly earlier since they produce growth regulators like cytokinins and auxins, which delay senescence, maintain chloroplast stability, and improve nutrient translocation during grain development (Yang et al., 2016).

3.3. Yield attributing traits

3.3.1. Number of effective tillers per plant

Mean productive tillers per plant were 225.41, with significant variation among fertilizers but not between the varieties. No interaction effect between varieties and fertilizers were recorded. Effective tillers at harvest significantly increased by 13.01% with combined application of CM+EM+T than the Control. The treatment CM+EM+T was ensured with greatest number of effective tillers i.e., 240.16 followed by CM+EM (228.22), CM (220.66) and Control (212.50).

The significant increase in effective tillers is attributed to the combined application of fertilizers where the Trichoderma and EM might have enhanced the nutrient uptake and physiological processes, thereby increasing more tillers and grains. These bio-fertilizers produce hormones like auxins, IAA, cytokinin and gibberellic acid, enzymes, sugars that promote cell division and elongation of shoot (Martinez et al., 2011; Chaube and Pandey, 2022), resulting in greater plant growth and eventually formation of tillers. The results were consistent with Mathivanan et al. (2005) and Devi and Manimaran (2012).

3.3.2. Tiller sterility percentage

Tiller sterility was not significantly affected by varieties or fertilizer, but Gautam showed greater tiller sterility

(19.15%) than Aaditya (17.75%) affecting the grain yield. Likewise, CM+EM+T indicated minimum tiller sterility followed by CM+EM, CM and Control. The combined application of bio-fertilizers and compost manure performed better in increasing the number of effective tillers with less tiller sterility as compared to Control. The increased tiller sterility among varieties might be due to poor soil structure and extreme temperature in later growth stages as shown in Figure 1. No interaction between fertilizers and varieties was observed, with a mean tiller sterility of 18.45%.

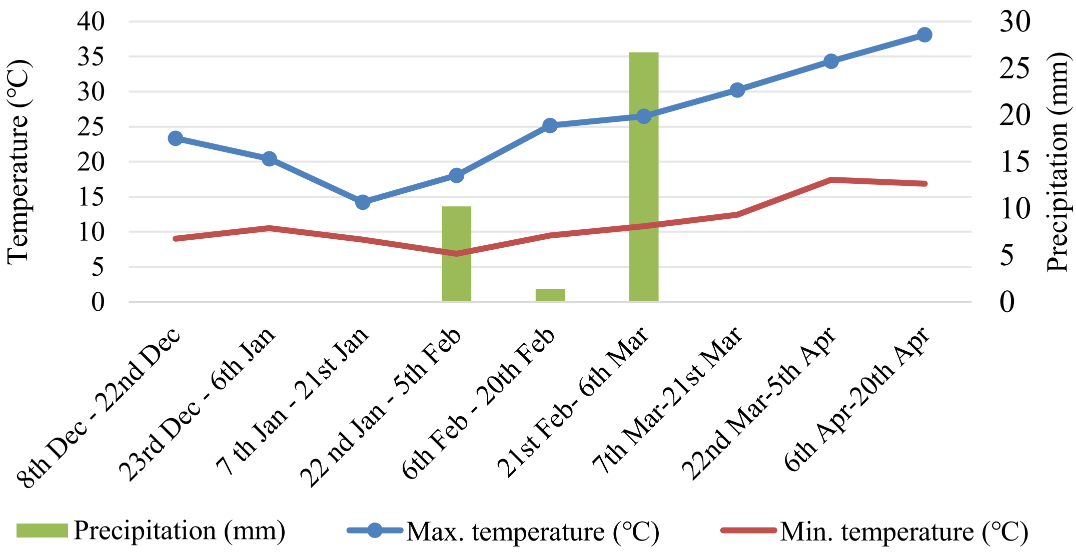

Figure 1. Average minimum and maximum temperature and total rainfall recorded at Tikapur weather station (index 0207) Nepal from Feb to Jun, 2024. Source: Department of hydrology and meteorology, Babarmahal, Kathmandu, Nepal

3.3.3. Grains per spike

The non-significant variation between the wheat varieties were observed for this trait i.e., grains count per spike under the present trial. Numerically Gautam variety yielded an average of 52.69 grains per spike, greater than Aaditya. Regarding the fertilizer treatments, CM+EM+T recorded significantly maximum number of grains per spike which was 15.17% more than Control. The integration of compost manure and bio-fertilizers have the synergistic effects where compost provides organic matter and EM and *Trichoderma* improve nutrient availability and uptake, strengthen the soil quality, boost disease resistance and promote overall plant growth (Asghar et al., 2021; Lyu et al., 2022; Ahmed et al., 2023), thereby supporting the robust spike development and a higher number of grains. The CM+EM and CM also showed better performance after CM+ EM+T with 53.36 and 51.88 grains count per spike. The result indicated superiority of the treatment CM+EM+T over other treatments with the 55.25 grains count per spike. The control was recorded with minimum number of grains per spike (47.97). The varieties and different fertilizers had non-significant interaction effect for grains per spike with grand mean value of 52.11 at the time of harvest. Similar results were reported by Sharma et al. (2012) and Hu and Qi (2013a).

3.3.4. Weight of 1000 grains

The thousand grain weight recorded statistically significant variation among varieties at the time of harvest. Statistically, Aaditya recorded maximum thousand grain weight i.e., 49.25 g over Gautam. At the same time, non-significant effect was observed among the application of various fertilizers. Though at 12% moisture, the maximum weight of 1000 grains were noted in CM (48.16 g). The lowest weight of 1000 grains were recorded in CM+EM-1 (47.66 g) with mean value of 47.87 g. There was non-significant interaction effect between wheat varieties and fertilizers. This suggests that bio-fertilizers may have influenced other yield components more significantly, such as number of tiller, grains per spike or total grain count, rather than having a direct impact

Table 5. Yield attributing traits of wheat as influenced by varieties and different fertilizers at Tikapur municipality, Kailali

Treatments	Effective tillers	Tiller sterility %	Grains per spike	Thousand grain weight (g)
Factor A				
Gautam	220.75	19.15	52.69	46.50^b^
Aaditya	230.08	17.75	51.54	49.25^a^
$CD_{0.05}$	13.66	4.78	2.17	1.17
SEm (±)	4.50	1.57	0.71	0.38
F test	Ns	Ns	Ns	***
Factor B		0.54		
Control	212.50^b^	22.85	47.97^c^	47.67
CM+EM	228.22^ab^	16.84	53.36^ab^	47.66
CM+EM+T	240.16^a^	14.82	55.25^a^	48.00
CM	220.66^ab^	19.29	51.88^b^	48.16
$CD_{0.05}$	19.33	6.77	3.07	1.66
SEm (±)	6.37	2.23	1.01	0.55
F test	*	Ns	**	Ns
A: B				
$CD_{0.05}$	27.33	9.57	4.34	2.35
P value	0.31	0.71	0.36	0.84
CV%	6.92	29.63	4.75	2.81
Grand mean	225.41	18.45	52.11	47.8

CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, Ns: Non-Significant; *: $p \leq 0.05$, **: significant at $p \leq 0.01$, ***: $p \leq 0.001$; CM: Compost manure; EM: Effective Micro-organism; T: *Trichoderma*

on individual grain filling. The results align with the findings of Hu and Qi (2013b) and Al-naqeeb et al (2018), who reported non-significant effect of bio-fertilizers on thousand grain weight.

3.4. Yield

3.4.1. Grain yield

Both the varieties i.e., Aaditya and Gautam yielded 4.35 t ha^{-1} and 4.22 t ha^{-1}, respectively indicating non-significant difference. This finding is in line with their yield potential as indicated in Bhatta et al. (2020b). However, the slightly higher grain yield of Aaditya might be due to increased thousand grain weight, effective tillers, less tiller sterility and increased grain yield than that of Gautam.

Correspondingly, significant variation was observed among fertilizers for grain yield, which ranged from 3.92 t ha^{-1} to 4.68 t ha^{-1} with an average value of 4.28 t ha^{-1}. CM+EM+*Trichoderma* achieved the highest (4.68 t ha^{-1}) among all being statistically at par with CM+EM (4.46 t ha^{-1}) and CM (4.08 t ha^{-1}), whereas the grain yield from the Control (3.91 t ha^{-1}) showed poor performance among all the treatments. The result revealed 19.69% increase in combined application of fertilizers over control due to increased spike length, effective tillers and grains per spike as observed from Table 3 and 5. Each effective tiller contributes a spike that bears grain. The more effective tillers a plant has, the more grain producing units it can generate, hence, directly increasing the potential yield. In the same way, greater spike length bears the greater number of grains per spike contributing directly to the total grain weight harvested per unit area. Our observations align with the studies of Rehman et al. (2013), Thapa et al. (2020) and Iriti et al. (2019).

The increase in rice yield resulted from more nutrient availability, or because EM had direct positive impacts on plant development and health and provided protection against environmental and biological stresses (Shao et al., 2008). However, Mayer et al. (2010) revealed the influence of bio-fertilizers on yield of potatoes, winter barley, alfa-alfa and winter wheat was not evident.

3.4.2. Straw yield

Statistically significant difference was observed among the varieties amounting 6.44 t ha^{-1} for Gautam and 5.85 t ha^{-1} of straw for Aaditya. The Gautam variety was found to be superior than the Aaditya, showing 9.16% increase in straw yield. Inverse relationship between the grain and straw yield were recorded, as illustrated in Table 6. The increased straw yield might be due to increased vegetative growth in Gautam variety.

Likewise, the various fertilizer application showed significant effect among all treatments. The CM+EM+T yielded highest amount of straw i.e., 6.66 t ha^{-1}, which was statistically at par with CM+EM (6.45 t ha^{-1}). This might be due to increased vegetative growth and greater number of tillers compared to the control. The finding is in accordance with Xiaohou et al. (2008), but Daiss et al. (2008) reported no significant effect of EM on crop growth and yield.

Table 6. Grain yield, biological yield, straw yield and harvest index of wheat as influenced by varieties and different fertilizers at Tikapur municipality, Kailali

Treatments	Grain Yield	Straw Yield	Harvest Index
Factor A			
Gautam	4.22	6.44^{a}	0.395^{b}
Aaditya	4.35	5.85^{b}	0.427^{a}
$CD_{0.05}$	0.30	0.40	0.017
SEm (±)	0.10	0.13	0.00
F test	Ns	**	**
Factor B			
Control	3.91^{c}	5.58^{c}	0.41
CM+EM	4.46^{ab}	6.45^{ab}	0.41
CM+EM+T	4.68^{a}	6.66^{a}	0.41
CM	4.08^{bc}	5.88^{bc}	0.40
$CD_{0.05}$	0.43	0.57	0.02
SEm (±)	0.14	0.19	0.00
F test	**	**	Ns
A: B			
$CD_{0.05}$	0.61	0.81	0.03
P value	0.80	0.83	0.62
CV%	8.18	6.14	4.74
Grand mean	4.28	7.55	0.41

CV: Coefficient of Variation; CD: Critical Difference; SEm: Standard Error of the Mean, Ns: Non-Significant; *: $p\leq0.05$, **: significant at $p\leq0.01$, ***: $p\leq0.001$; CM: Compost manure; EM: Effective Micro-organism; T: *Trichoderma*

3.4.3. Harvest index

The Aaditya variety recorded the highest HI (0.42), showing significant differences at the 5% level, while Gautam recorded 0.39. Statistically, non-significant effect of fertilizers on HI was observed at harvest. The Table 6 showed the treatments, including Control, CM+EM and CM EM+T were statistically equal with HI around 0.41 whereas CM recorded the HI of 0.40. The interaction effect of wheat varieties and different fertilizers showed non-significant differences on HI with a mean of 0.41. Bam et al. (2022) reported non-significant effect on HI with application of various bio-fertilizers. The consistent HI (0.41) could be due to proportional enhancement in biomass and grain yield despite significant fertilizer influence, as depicted in Table 6.

3.5. Correlation coefficient analysis

A significant positive relationship was observed between grain yield as well as plant height (correlation coefficient, r=0.34), spike length (r=0.26), thousand grain weight (r=0.13), effective tillers (r=0.37), yield of straw (r= 0.58**), time to maturity and duration of grain filing (r=0.22), indicating that grain yield increases as these traits improve (Table 7). However, grain per spike and straw yield exhibited a statistically significant positive correlation with grain yield at 5% significance level. In contrast, peduncle length (r= -0.13) and tiller sterility percentage (r= -0.54) showed negative correlations with grain yield, suggesting that a reduction in peduncle length and tiller sterility contributes to an increase in grain yield.

Table 7. Correlation Coefficient among different traits under selection in wheat at Tikapur, Kailali.

	PH	SL	PL	GPS	TGW	GY	ET	TS %	SY	DM	GFP
PH	1										
SL	0.53**	1									
PL	-0.3	-0.4	1								
GPS	0.33	0.3	-0.3	1							
TGW	-0.18	-0.27	0.54**	-0.09	1						
GY	0.34	0.26	-0.13	0.41*	0.13	1					
ET	0.38	0.11	0.01	0.42*	0.1	0.37	1				
TS %	-0.13	-0.01	0.2	-0.35	-0.08	-0.54	-0.28	1			
SY	0.69***	0.59**	-0.27	0.41*	-0.29	0.58**	0.26	-0.33	1		
DM	0.36	0.15	0.07	0.12	0.14	0.01	0.39	0.27	0.12	1	
GFP	-0.14	0.13	-0.02	-0.23	-0.16	0.22	0.01	-0.03	0.14	-0.11	1

*: significant at p≤0.05, **: significant at p≤0.01, ***: significant at p≤0.001, PH: Plant height (cm), SL: Spike length (cm), PL: Peduncle length (cm), GPS: Grain per spike, TGW: Thousand grain weight (g), GY: Grain Yield (t ha^{-1}), ET: Effective tiller, TS%: Tiller sterility percentage, SY: Straw yield, DM: Days to maturity and GFP: Grain filing periods

4. Conclusions

The study revealed that integrating compost manure with bio-fertilizers such as EM (Effective microorganisms) and Trichoderma significantly improved biometric and yield performance compared to that of Control, which used only chemical fertilizers. The combined application of chemical fertilizers, EM, compost manure and *Trichoderma* (i.e. T3 and T7) led to a 19.69% increase in grain yield under Tikapur conditions. It also improved plant height, the number of effective tillers, and total grain count per spike. These results suggest that bio-fertilizers like EM and *Trichoderma*, when combined with compost and minimal chemical inputs, enhanced the production by accelerating the decomposition of organic matter. Although the interaction between fertilizer treatments and wheat varieties (Aaditya and Gautam) was not statistically significant, Aaditya performed slightly better in terms of peduncle length and thousand grain weight, while the combined effects of the integrated treatments clearly outperformed the control in overall crop productivity. The enhancement in crop performance was attributed more to the integrated nutrient management (INM) approach rather than varietal differences. Therefore, the study suggests CM+EM+T as a sustainable nutrient management strategy for improving wheat yield, while maintaining soil fertility and reducing the reliance on chemical fertilizers. This approach also encourages reuse of organic wastes through compost manuring and supports environmental-friendly farming. Although various studies have reported both significant and non-significant impacts of organic manures and bio-fertilizers on crop development and productivity, but the positive outcomes here support further research focused to identify efficient combinations of bio-fertilizers and organic manures.

Compliance with Ethical Standards

Conflict of Interest

The authors claim that they have got no conflict of interest.

Authors' Contributions

Archana CHAUDHARY: Methodology, Investigation, Conceptualization, Validation, Data collection, Formal analysis, Writing- Original draft, Review and editing. **Raksha SHARMA**: Investigation, Supervision, Conceptualization, Validation, Review and editing, Finalizing draft. **Devraj RAJBANSHI**: Investigation, Formal analysis, Data curation, Validation, Review and editing. **Binod BOHARA**: Investigation, Validation, Writing- original draft, Visualization, Review and editing. **Priyanka RASALI**: Methodology, Data collection, Validation, Review and editing.

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