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RESEARCH ARTICLE

Effect of Trichoderma and filter mud cake on growth and productivity of peas under Sohag conditions

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Abstract

The excessive use of chemical fertilizers poses hazardous environmental effects and compromises food safety. In contrast, organic fertilizer usage has an advantage of being cheap, improving soil properties, and stimulating root development. The effect of filter mud cake (FMC) as an organic fertilizer and *Trichoderma viride* (TRI) as a biofertilizer, either individually or combined with NPK as a chemical fertilizer (CF) on pea growth, yield, and chemical constituents were evaluated. Field treatments were assigned in a randomized complete block design (RCBD) for two consecutive seasons with three replicates. Our results showed that all treatments resulted in an increase in pea plant growth, yield, and chemical constituents compared to the control. However, the highest improvements were observed with the FMC + TRI + $CF_{75\%}$ (reduced chemical fertilizer doses) treatment, in most of the studied parameters, including fresh pod weight, nutrient content (N, P, K), and protein percentage. Additionally, the FMC + $CF_{75\%}$ treatment also demonstrated notable increases, particularly in fresh pod weight and phosphorus content. While $CF_{100\%}$ (full chemical fertilizer doses) showed good performance in certain parameters, it was less effective overall compared to the combined treatments. Therefore, the combination of FMC, TRI, and $CF_{75\%}$ is recommended as the most effective treatment for enhancing pea plant productivity and nutritional value, with the highest economic feasibility.

***Keywords*:** Biofertilizer, Chemical fertilizer, *Pisum sativum* and yield

1. *Introduction*

Pea (*Pisum sativum* L.) is an important leguminous crop that enhances soil fertility through nitrogen fixation. Its seeds are highly nutritious, containing significant amounts of carbohydrates, protein, and essential minerals (Azam *et al.*, 2020). In Egypt, green peas are known for their quality and taste, making them attractive for international markets. However, despite these strengths, Egypt's pea exports are relatively, at low 2.7 thousand tons, accounting for only a small percentage (0.83%) of the global market (Hussein and Abd El Halim, 2024). One of the main goals of modern sustainable agriculture is to support the rising demands for food and energy of a growing world population but at the same time to maintain soil health and fertility (Ampt *et al.*, 2019). Soil fertility has declined due to the wide gap between nutrient loss through plant uptake or leaching and the insufficient addition of organic and chemical fertilizers. Moreover, the continuous rise in chemical fertilizer prices has made them increasingly unaffordable, posing significant challenges, especially for small-scale farmers. However, the excessive use of chemical fertilizers also leads to serious environmental hazards (EL-Etr *et al.*, 2004). Nitrogen is a vital nutrient for plant growth and development due to its role in cell division and expansion (Bhuiyan *et al.*, 2023). However, excessive use of nitrogen fertilizers has led to severe environmental consequences, including groundwater and surface water contamination, acid rain, soil degradation, and nutrient runoff (Liu *et al.*, 2014; Umar *et al.*, 2007; Zhao *et al.*, 2016; Gu *et al.*, 2009). These practices contribute to soil salinization, organic matter

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depletion, and reduced biological activity, ultimately threatening soil fertility (Zhang *et al.*, 2023; Zhong and Cai, 2007). Therefore, adopting a balanced fertilization approach is essential to mitigate these environmental risks. Soil microbial communities are essential for maintaining soil health, productivity, and sustainability (Zhao *et al.*, 2014). Understanding their response to agricultural practices helps develop strategies for long-term soil fertility (Li *et al.*, 2012). Among these practices, biofertilizers enhance microbial activity, improve root conditions, and facilitate nutrient absorption, reducing dependence on chemical fertilizers (Meena *et al.*, 2014). They also contribute to sustainable, agrochemical-free crop production while improving plant biological functions (El-Azab and El-Dewiny, 2018). Additionally, biofertilizers are economically viable, being more efficient and accessible for small farmers (Kumar, 2017). Trichoderma, belonging to Ascomycota, is widely found in soils and plays a key role in solubilizing soil phosphates into plant-available forms (Bononi *et al.*, 2020). Its secondary metabolites enhance plant growth, nutrient uptake, water efficiency, photosynthesis, and polyphenol accumulation (Carillo *et al.*, 2020; Şesan *et al.*, 2020). Specifically, *T. harzianum* increases hormone levels, alters sugar partitioning, and promotes tomato plant growth (Fiorini *et al.*, 2016). Over twenty studies have shown that endophytic Trichoderma strains improve photosynthesis by increasing pigment production or regulating genes linked to chlorophyll biosynthesis and the Calvin cycle (Harman *et al.*, 2021). The sugar industry is one of the largest agro-based industries in Egypt, generating significant byproducts during the extraction of sugar from cane or beet. One of these by products is filter cake (pressing mud), a secondary product of juice clarification and filtration using a rotary filter (Vasconcelos *et al.*, 2020; González *et al.*, 2014). Filter cake accounts for approximately 3-4% of the raw materials used in sugar production, with an estimated annual production of 170 thousand tons in Egypt, posing a considerable environmental challenge (Alotaibi *et al.*, 2021). Filter cake consists of a mixture of ground sediment and compressed sludge, forming an organic compound rich in organic matter and essential nutrients, particularly phosphorus, along with macronutrients such as nitrogen, potassium, and magnesium, and micronutrients like iron, manganese, and zinc (Montiel-Rosales *et al.*, 2022; Prado *et al.*, 2013). This chemical composition makes it an effective natural soil conditioner. It is applied in agriculture either directly or after composting, improving the physicochemical and biological properties of soil, especially in calcareous and saline soils. Filter cake enhances microbial activity, increases soil water and nutrient retention, and reduces reliance on chemical fertilizers, contributing to sustainable farming practices (Formann *et al.*, 2020; Bridhikitti *et al.*, 2023; Kumar *et al.*, 2017). Additionally, it enhances soil structure and boosts nutrient availability, ultimately supporting better crop growth (Byrareddy *et al.*, 2019; El-Tayeh *et al.*, 2019; Shaaban *et al.*, 2022). The high amount of NPK content in filter mud makes it a valuable organic resource (Rakkiyappan *et al.*, 2001).

Combining organic waste with chemical fertilizers offers a promising approach to enhancing soil potassium availability during plant growth stages (Chew *et al.*, 2019). The use of organic materials such as filter mud cake (FMC) and Trichoderma as biofertilizers provides a rich source of soil nutrients, improving crop yield and quality while ensuring the safe disposal of organic waste (Mansour, 2012). This practice not only supports sustainable agriculture but also promotes environmental health, highlighting the need to raise farmers' awareness of its benefits (Valbuena *et al.*, 2015). Based on this, we hypothesize that applying filter mud cake alone or in combination with chemical fertilizers and biofertilizers may significantly enhance soil properties, plant growth, nutrient uptake, and pea yield compared to full reliance on chemical fertilization. This integrated approach could offer an effective alternative, reducing chemical fertilizer dependency while maintaining high agricultural productivity. The current study aims to (1) evaluate the effect of *Trichoderma viride* (TRI) and filter mud cake (FMC) on the growth and productivity of peas under Sohag conditions and (2) evaluate the possibility of partially or completely replacing chemical fertilizers (CF) by organic ones along with biofertilization.

2. Materials and Methods

2.1. Experimental location

Field experiments were conducted during the winter seasons of 2023/2024 and 2024/2025 at the Shandaweel Agricultural Research Station, Agricultural Research Centre, Sohag Governorate, Egypt (latitude 24.54° N and longitude 32.94° E). The study aimed to investigate the effects of Trichoderma and filter mud cake on the growth and productivity of peas (cv. Super 2 from horticulture research institute) under Sohag conditions.

2.2. Experimental design, agronomic practices and soil sampling

The study employed a randomized complete block design (RCBD) with three replicates in each season. The experimental field was prepared and shaped to ridges 60 cm apart, each experimental plot was 10.5 m^2 (3 m width × 3.5 m length), with hills spaced 10 cm apart, and two seeds were sown per hill. The sowing date was 15^{th} November in both seasons. Seeds of peas were planted at 2 cm soil depth/hole with a cultivation distance of 15 cm on one side of the ridges. The other agronomic practices of peas (irrigation, pest control and weeding) were applied as recommended provided by the Agricultural Research Center during both studied seasons. The plants were harvested 90 days after sowing. A soil sample was collected from the surface layer (0-30 cm) before planting and during plant bed preparation. The soil samples were air-dried, ground, well mixed and passed through a 2mm sieve and analyzed to determine the soil's chemical and physical properties (Hesse, 1971; Jackson, 1973). The results are presented in Table 1.

Table 1. Some chemical and physical properties of field soil for the 2023/2024 and 2024/2025 seasons

Item	Particles size distribution%				Organic matter (%)	EC (1:5, dS m^{-1})	pH (1:2.5)
	Sand%	Silt%	Clay%	Texture class			
2023/2024	23.90	38.60	37.50	Clay loam	0.61	0.21	7.80
2024/2025	26.20	35.30	38.50	Clay loam	0.72	0.22	7.80

Item	Available Macro-Nutrients (mg kg^{-1})			Soluble Cations (cmol kg^{-1})				Soluble Anions (cmol kg^{-1})		
	N	P	K	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}
2023/2024	51.00	14.30	363.33	0.80	0.40	0.75	0.34	1.20	0.65	0.40
2024/2025	58.00	17.00	385.00	0.52	0.49	0.79	0.33	0.93	0.80	0.30

2.3. Treatments

2.3.1. Chemical fertilizer (CF)

The recommended doses for nitrogen, phosphorus and potassium according to the bulletin of the Egyptian ministry of agriculture is superphosphate (15.5% P_2O_5) at a rate of 150 kg P_2O_5 fed^{-1} during service operations, nitrogen fertilizer (Ammonium sulfate, 20.5% N) at a rate of 200 kg $(NH_4)_2SO_4$ fed^{-1}, and potassium sulfate (48% K_2O) at a rate of 100 kg K_2SO_4 fed^{-1}, Nitrogen and potassium fertilizers were divided into two equal doses, applied before the first and second irrigations.

2.3.2. Filter mud cake (FMC)

Filter mud cake (FMC) was brought from a factory of sugarcane, Girga sugar factory, Sohag Governorate, Egypt. Filter mud cake was chemically analyzed, its composition is illustrated in Table 2.

Table 2: Chemical composition of filter mud cake used in first and second seasons of the experiment.

Chemical composition	Total - N (%)	Total - P (%)	Total - K (%)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
2023/2024	2.87%	1.40%	0.70%	33	285	108	123
2024/2025	3.00%	1.49%	0.75%	34	305	113	135

	Organic matter (%)	Organic - C (%)	pH (1:5) Susp.	EC (dSm^{-1}) (1:5)	C/N Ratio	Moisture (%)
2023/2024	30.50	18.60	7.44	1.025	9.3	52%
2024/2025	31.60	23.33	7.61	1.050	13.7	50.8%

The dry filter mud cake was added at the rate of 5 kg/plot (2 ton/fed) and uniformly spread on the surface of the soil and was incorporated into the soil at a depth of 0-30 cm one week before pea planting.

2.3.3. *Trichoderma biofertilizer (TRI):*

To prepare the Trichoderma spore suspension, 50 ml of distilled water was added to a five-day Trichoderma colony culture (cultivated on PDA at 28 °C). The spores were then scraped off with a sterile spatula, transferred into a 1L sterile flask, the concentration of the spore suspension was adjusted to 5×10^6 CFU/ml using a hemocytometer, following the dilution formula:

$$C1V1 = C2V2$$

where C1and V1represent the concentration and volume of the stock suspension, and C2 and V2 represent the desired concentration and final volume. Pea seeds were surface-sterilized and inoculated by soaking in the freshly prepared *Trichoderma viride* spore suspension for 1 to 2 hours prior to sowing. This soaking period was selected based on previous studies indicating that 1-2 hours is sufficient for effective spore adhesion and colonization without compromising seed viability (Naseby *et al.,* 2000). The examined treatments of filter mud cake (FMC), chemical fertilizers (CF), Trichoderma (TRI) and their combinations were applied as follows:

T_1: $CF_{100\%}$
T_2: TRI
T_3: FMC
T_4: TRI + $CF_{75\%}$
T_5: TRI + $CF_{50\%}$
T_6: FMC + $CF_{75\%}$
T_7: FMC + $CF_{50\%}$
T_8: FMC + TRI + $CF_{75\%}$
T_9: FMC + TRI + $CF_{50\%}$.

2.4. *Studied measurements*

2.4.1. *Vegetative and yield traits*

- ***Stem length (cm):*** At the end of each season, a sample consisting of 10 plants was randomly taken from each plot to determine stem length by using a measuring tape.
- ***Pod width and pod length (cm):*** At fresh harvesting time, samples consisting of 30 pods were randomly taken from each plot by using ruler and vernier caliper.
- ***Number of seeds per pod*:** Samples consisting of 30 pods were randomly taken from each plot.
- ***Shellout percentage*:** was calculated to evaluate the efficiency of seed development within pods, reflecting the proportion of usable seeds relative to the total pod weight. This was determined by averaging several randomly selected pods from each treatment. The percentage was then calculated using the following equation:

$$\textbf{shellout}\ \% = \frac{\textbf{Weight of seeds in pods}}{\textbf{Weight of whole pods}}\ \textbf{x 100}$$

- ***100-Green seed weight (g):*** was estimated at fresh harvesting time.
- ***Fresh pods yield (ton/fed):*** It was calculated from all pods weight which harvested per plot and then calculated as ton per feddan.

2.4.2. Chemical constituents

At fresh harvesting time, samples were collected and oven-dried at 70°C for 48 hours. The contents of nitrogen, phosphorous, and potassium in dry seeds were analyzed by employing a combination of concentrated sulphuric acid and perchloric acid, as described in the study conducted by Wicks and Firminger (1942). The concentration of nitrogen was assessed utilizing the micro Kjeldahl method as described by the Association of Official Analytical Chemists (A.O.A.C., 1995). The concentration of phosphorus was determined using calorimetric analysis following Jackson's (1958) method, which involved the utilization of the chlorostannous - reduced molybdophosphoric blue color approach. The estimation of potassium concentration (%) was conducted using photometric means with a flame photometer, as stated by Jackson (1958). The crude protein content was estimated by multiplying the nitrogen percentage by a conversion factor of 6.25 (Mariotti *et al.,* 2008).

2.4.3. Economic evaluation

Economic evaluation for the results was conducted to investigate the variations between the different studied factors to get the highest profitability using some economic criteria according to the method described by Buckett (1981). Economic criteria were estimated from the following formulas:

1. **Total costs** are calculated each season according to the cost of labor and the seed price for each season separately.
2. **Gross income** = Total revenue of yield was calculated using the formula: Gross income = yield (ton/fed.) x price of ton.
3. **Net income** (NI) = Gross income (GI) – Total costs.
4. **Benefit cost ratio** (BCR) was calculated according to Greene and Stellman (2007), by dividing the gross income by the total expenditures of each treatment.

2.5. Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA) according to Snedecor and Cochran (1980) using MSTAT-C software version 2.1. The means of the various treatments were compared by using L.S.D. at 0.05.

3. Results and discussion

3.1. Vegetative traits

The results in table 3 indicated that the longest stem was recorded for the $CF_{100\%}$ treatment (107.17 and 105.04 cm) followed by FMC + TRI + $CF_{75\%}$ which recorded (103.57 and 102.25 cm) in 2023/24 and 2024/2025 seasons, respectively without significant difference in the second season. The widest pod in the 2023/2024 season was recorded in the TRI and FMC treatments, with a value of 1.27 cm, followed by $CF_{100\%}$, which recorded 1.26 cm without a significant difference between them. However, in the 2024/2025 season, there were no significant differences between treatments for pod width, indicating that the treatments had no clear effect on this trait. The longest pod was recorded in the FMC + TRI + $CF_{75\%}$ treatment in the two studied seasons measuring (10.88 and 10.71 cm), followed by FMC + $CF_{75\%}$ (10.78 cm in the first season), in addition to the two treatments FMC + TRI + $CF_{50\%}$ (10.76 and 10.63 cm), $CF_{100\%}$ (10.74 and 10.55 cm) in 2023/24 and 2024/25 winter seasons respectively, then FMC + $CF_{75\%}$ with (10.54 cm in the second season) without significant differences between these treatments. The results indicate that the FMC + TRI + $CF_{75\%}$ treatment consistently achieved the highest values for growth parameters. Our results align with those of Byrareddy *et al.,* (2019); El-Tayeh *et al.,* (2019) and Shaaban *et al.,* (2022) who demonstrated that filter cake enhances microbial activity, increases soil water and nutrient retention, and improves plant growth. Meena *et al.,* (2014) emphasized that biofertilizers enhance microbial activity, improve root growth conditions, and facilitate plant nutrient absorption and enzyme activation, ultimately improving vegetative traits. The addition of filter cake (FMC) enhances soil fertility and microbial activity, providing an optimal environment for Trichoderma colonization and growth. Therefore, Trichoderma further enhances the effects of FMC by promoting nutrient uptake, reducing plant stress, and supporting vegetative growth and crop yield (Budiono *et al.,* 2016; Shahinul Islam *et al.,* 2023).

Table 3. Effect of chemical fertilization, *Trichoderma viride* and filter mud cake treatments on vegetative traits in pea plants at 2023/2024 and 2024/2025 winter seasons

Traits / Seasons / Treatments	Stem length (cm)		Pod width (cm)		Pod length (cm)	
	2023/ 24	2024/ 25	2023/ 24	2024/ 25	2023/ 24	2024/ 25
$CF_{100\%}$	107.17	105.04	1.26	1.25	10.74	10.55
TRI	87.74	86.72	1.27	1.26	10.03	9.84
FMC	93.00	91.84	1.27	1.27	10.54	10.34
TRI + $CF_{75\%}$	95.70	92.53	1.21	1.22	10.37	10.15
TRI + $CF_{50\%}$	91.55	92.31	1.22	1.20	10.20	10.00
FMC + $CF_{75\%}$	100.38	98.54	1.24	1.25	10.78	10.54
FMC + $CF_{50\%}$	97.52	95.64	1.21	1.20	10.67	10.46
FMC + TRI + $CF_{75\%}$	103.57	102.25	1.20	1.23	10.88	10.71
FMC + TRI + $CF_{50\%}$	100.02	98.58	1.19	1.21	10.76	10.63
$LSD_{0.05}$	2.24	3.15	0.02	NS	0.22	0.18

NS refers to non-significant at $p < 0.05$, **CF**: chemical fertilizer, **FMC**: filter mud cake and **TRI**: Trichoderma

3.2 The yield and its components

The data tabulated in table 4 showed that the highest number of seeds was recorded by using the $CF_{100\%}$ (8.84 seeds), in the first season followed by FMC + TRI + $CF_{75\%}$ (8.80 seeds), then FMC + $CF_{75\%}$ (8.72 seeds), then FMC + TRI + $CF_{50\%}$ (8.71 seeds), then FMC+$CF_{50\%}$ (8.65 seeds) with no significant differences between them, while, in the second season, the highest values were observed in the FMC + TRI + $CF_{75\%}$ (8.73 seeds), followed by FMC + $CF_{75\%}$ (8.54 seeds), then both of FMC + TRI + $CF_{50\%}$ and $CF_{100\%}$ (8.53 seeds) without significant differences between these treatments. The FMC + TRI + $CF_{75\%}$ (57.73 and 60.29%) and FMC + TRI + $CF_{50\%}$ (58.68 and 60.19 %) treatments recorded the highest shellout percentage in 2023/2024 and 2024/2025 seasons, respectively, with significant differences between them and the other studied treatments. However, the FMC + $CF_{75\%}$ (56.34 and 58.91%) and FMC + $CF_{50\%}$ (56.29 and 57.51%) treatments did not significantly differ from the 100% chemical fertilizer (56.61 and 57.53 %) in the two winter seasons, respectively.

The FMC + TRI + $CF_{75\%}$ treatment recorded the heaviest weight of 100 green seeds (58.42 and 59.08 g) and it did not differ significantly from the FMC + $CF_{75\%}$ treatment at 56.87 and 57.51 g in both seasons respectively, in addition to the treatments FMC + TRI + $CF_{50\%}$ (58.28 g) and $CF_{100\%}$ (57.28 g) in the second season only. The FMC + TRI + $CF_{75\%}$ treatment recorded the highest fresh pod yield (4.235 and 4.278 ton/fed), which was significantly higher than the $CF_{100\%}$ treatment (4.044 and 4.025 ton/fed) in both seasons, respectively, while the FMC + TRI + $CF_{50\%}$ treatment (4.029 ton/fed) did not differ significantly from $CF_{100\%}$ in the second season. These findings are consistent with those of Montiel-Rosales *et al.*, (2022) and Prado *et al.*, (2013) who reported that filter cake is rich in organic matter and essential nutrients such as nitrogen, phosphorus, and potassium, improving soil physicochemical properties and supporting vegetative growth and crop yield. Furthermore, the improved performance of the FMC + TRI treatment may be attributed to a synergistic interaction between the two components. The addition of filter cake (FMC) enhances soil fertility and microbial activity, providing an optimal environment for Trichoderma colonization and growth. Studies such as those by Budiono *et al.*, (2016) and Shahinul Islam *et al.*, (2023) indicate that *Trichoderma spp.* can improve soil fertility, promote root development, and increase nutrient solubilization, thereby enhancing plant growth and productivity. In turn, Trichoderma further enhances the effects of FMC by promoting nutrient uptake, reducing plant stress, and supporting vegetative growth and crop yield. This synergistic relationship likely results in the superior performance observed in the FMC + TRI treatment compared to individual applications.

Table 4. Effect of chemical fertilization, *Trichoderma viride* and filter mud cake treatments on fresh yield and its component traits in pea plants at 2023/2024 and 2024/2025 winter seasons

Traits	No. of seeds /pod		Shellout percentage (%)		100 green seeds wt. (g)		Fresh pod yield (Ton/fed)	
Treatments \ Seasons	2023/24	2024/25	2023/24	2024/25	2023/24	2024/25	2023/24	2024/25
$CF_{100\%}$	8.84	8.53	56.61	57.53	56.65	57.28	4.044	4.025
TRI	7.98	7.83	51.74	52.94	47.96	48.98	2.860	2.854
FMC	8.41	8.27	54.51	55.32	53.34	53.23	3.704	3.725
TRI + $CF_{75\%}$	8.55	8.36	53.70	55.59	53.19	54.21	3.519	3.501
TRI + $CF_{50\%}$	8.14	8.13	52.84	54.96	51.48	52.58	3.383	3.403
FMC + $CF_{75\%}$	8.72	8.54	56.34	58.91	56.87	57.51	3.960	3.943
FMC + $CF_{50\%}$	8.65	8.43	56.29	57.51	53.95	55.18	3.712	3.652
FMC + TRI + $CF_{75\%}$	8.80	8.73	57.73	60.29	58.42	59.08	4.235	4.278
FMC + TRI + $CF_{50\%}$	8.71	8.53	58.68	60.19	56.62	58.28	4.002	4.029
$LSD_{0.05}$	0.22	0.22	1.83	1.96	1.67	2.43	0.01	0.02

CF: chemical fertilizer, **FMC**: filter mud cake and **TRI**: Trichoderma.

3.3. Chemical constituents and protein content in green seeds:

The results showed that the FMC + TRI + $CF_{75\%}$ treatment recorded the highest nitrogen content in both seasons, reaching 220.46 and 210.16 ppm, in the 2023/24 and 2024/25 seasons, respectively. This indicates that combining chemical fertilization (CF) with biofertilizers (FMC and TRI) at 75% was the most effective in enhancing nitrogen content in pea plants. For phosphorus content in the plant, the results showed that the FMC+ TRI + $CF_{75\%}$ treatment recorded the highest phosphorus content in both seasons, reaching 35.02 and 34.49 ppm in the 2023/24 and 2024/25 seasons, respectively. With no significant differences from the treatments of FMC + $CF_{75\%}$ (33.44 and 34.04 ppm in the 2023/24 and 2024/25 seasons, respectively), FMC + TRI + $CF_{50\%}$ (33.36 ppm and 32.77 ppm in the 2023/24 and 2024/25 seasons, respectively) and $CF_{100\%}$ (32.23 and 33.47 ppm in the 2023/24 and 2024/25 seasons, respectively). Regarding potassium content in the plant, the FMC + TRI + $CF_{75\%}$ treatment exhibited the highest potassium content in both seasons, recording 285.27 ppm and 290.35 ppm in the 2023/24 and 2024/25 seasons, respectively. This indicates that the combination of chemical fertilization (at 75%), TRI, and filter mud cake (FMC) significantly enhanced potassium content in pea plants. Followed by $CF_{100\%}$ treatment, recording a potassium content of 283.26 ppm and 283.46 ppm in the 2023/24 and 2024/25 seasons, respectively. This suggests that while full chemical fertilization provided high potassium levels, it was slightly less effective than the integration of biofertilization and chemical fertilization. The combined application of FMC + $CF_{75\%}$ treatment, recording 277.48 ppm and 278.13 ppm in the 2023/24 and 2024/25 seasons, respectively, supports the positive impact of filter mud cake in enhancing potassium absorption when combined with chemical fertilizers.

With respect to protein content, the results showed that the FMC + TRI + $CF_{75\%}$ treatment recorded the highest protein content in both seasons, reaching 13.78% and 13.13% in the two seasons, respectively. This suggests that combining filter mud cake, Trichoderma, and 75% chemical fertilization ($CF_{100\%}$) significantly enhanced protein synthesis in pea plants. The $CF_{100\%}$ treatment ranked second, with protein content values of 11.68% and 11.89% in the 2023/24 and 2024/25 seasons, respectively. The observed variations in nitrogen, phosphorus, potassium, and protein content among different treatments can be attributed to the synergistic effects of filter mud cake, biofertilizers and chemical fertilizers in enhancing nutrient availability. The highest values recorded in the FMC + TRI + $CF_{75\%}$ treatment suggest that the combination of FMC, TRI, and 75% chemical fertilization provided optimal conditions for nutrient absorption and metabolism. This synergy likely improved soil microbial activity, increased nutrient solubilization, and enhanced root development, resulting in higher nitrogen, phosphorus, potassium, and protein levels (Chew *et al.,* 2019; Mansour, 2012).

Table 5: Effect of chemical fertilization, *Trichoderma viride* and filter mud cake treatments on nutrient and protein content in green seeds pea at 2023/2024 and 2024/2025 winter seasons

Traits	N-content (ppm)		P-content (ppm)		K-content (ppm)		Protein (%)	
Treatments \ Seasons	2023/24	2024/25	2023/24	2024/25	2023/24	2024/25	2023/24	2024/25
$CF_{100\%}$	186.98	190.25	32.23	33.47	283.26	283.46	11.68	11.89
TRI	159.89	156.22	28.72	29.58	217.21	219.55	9.99	9.76
FMC	162.89	165.11	28.32	28.19	222.96	219.17	10.18	10.32
TRI + $CF_{75\%}$	173.98	177.95	27.12	27.28	230.25	233.11	10.87	11.12
TRI + $CF_{50\%}$	164.13	164.36	26.49	26.61	227.03	224.09	10.26	10.27
FMC + $CF_{75\%}$	185.58	183.50	33.44	34.04	277.48	278.13	11.60	11.47
FMC + $CF_{50\%}$	178.35	174.65	29.30	28.56	269.10	270.53	11.15	10.92
FMC + TRI + $CF_{75\%}$	220.46	210.16	35.02	34.49	285.27	290.35	13.78	13.13
FMC + TRI + $CF_{50\%}$	179.38	183.17	33.36	32.77	232.73	235.03	11.21	11.45
$LSD_{0.05}$	16.64	19.16	3.59	2.83	4.31	3.69	1.04	1.20

CF: chemical fertilizer, FMC: filter mud cake and TRI: Trichoderma.

3.4. Economic evaluation

3.4.1. Total Costs (EGP)

Data presented in Tables (6 and 7) indicate that the application of NPK fertilizers (CF), Trichoderma (TRI), filter mud cake (FMC), and their combinations affected the total costs (EGP) in both 2023/24 and 2024/25 growing seasons. A clear trend was observed; increasing the rate of chemical fertilizers from 50% to 75% and up to 100% of the recommended dose led to a progressive rise in total costs per feddan. The highest total cost was recorded in the treatment of $CF_{100\%}$, reaching 16,336 EGP in the both seasons, respectively. In contrast, the lowest total cost was observed in the TRI (Trichoderma alone) treatment, recording 13,850 EGP in both seasons. Treatments including FMC also showed higher total costs than control due to the additional cost of filter mud cake (1,400 EGP), especially when combined with CF or TRI. This cost increase reflects the combined effect of added inputs (organic/biological amendments, fertilizers), preparation, and labor.

3.4.2. Gross Income (EGP)

Gross income, calculated as yield (ton/fed) × market price (15,000 EGP/ton), varied significantly across treatments and between seasons. In both seasons, the maximum gross income was recorded for the FMC + TRI + $CF_{75\%}$ treatment, with 63,525 EGP and 64,170 EGP, respectively. Conversely, the lowest gross income was from the TRI only treatment, with values of 42,900 EGP and 42,810 EGP. Treatments that included combinations of organic and biological components with reduced fertilizer doses also performed economically well, such as FMC + TRI + $CF_{50\%}$, which yielded 60,030 EGP and 60,435 EGP in both seasons. These results reflect the positive influence of integrated fertilization strategies on productivity and revenue.

3.4.3. Net Profit (EGP):

Net profit (Gross income -Total costs) reflected the real economic gain per treatment. FMC + TRI + $CF_{75\%}$ recorded the highest net profit of 46,073 EGP and 46,718 EGP in the first and second seasons, respectively. The lowest net profit was again seen with the TRI only treatment: 29,050 EGP and 28,960 EGP. This trend underscores the importance of balancing input costs with productivity outputs to maximize profitability (Fig 1).

3.4.4. Benefit/Cost Ratio (BCR)

The Benefit/Cost Ratio (BCR) expresses the return per unit of cost invested. The highest BCR was recorded in the FMC treatment: 3.75 and 3.78 in the first and second seasons, respectively. The lowest BCR was observed in the TRI only treatment: 3.10 and 3.09. All treatments recorded BCR values greater than 1, indicating their economic feasibility. However, integrating FMC with Trichoderma and 75% of the recommended chemical fertilizer showed a consistently high return per Egyptian pound spent across both seasons, making it one of the most efficient and sustainable fertilization strategies (Fig 1).

Table 6. Economic evaluation of pea productivity under different treatments of Trichoderma, filter mud cake and chemical fertilizer at 2023/2024 season

Treatment	Yield (ton/fed)	Total Cost (EGP)	Gross Income (EGP)	Net Profit (EGP)	Benefit-Cost Ratio (BCR)
$CF_{100\%}$	4.044	16,336	60,660	44,324	3.71
TRI	2.860	13,850	42,900	29,050	3.10
FMC	3.704	14,800	55,560	40,760	3.75
TRI + $CF_{75\%}$	3.519	16,052	52,785	36,733	3.29
TRI + $CF_{50\%}$	3.383	15,318	50,745	35,427	3.31
FMC + $CF_{75\%}$	3.960	17,002	59,400	42,398	3.49
FMC + $CF_{50\%}$	3.712	16,268	55,680	39,412	3.42
FMC + TRI + $CF_{75\%}$	4.235	17,452	63,525	46,073	3.64
FMC + TRI + $CF_{50\%}$	4.002	16,718	60,030	43,312	3.59

CF: chemical fertilizer, FMC: filter mud cake and TRI: Trichoderma.

Table 7. Economic evaluation of pea productivity under different treatments of Trichoderma, filter mud cake and chemical fertilizer at 2024/2025 season

Treatment	Yield (ton/fed)	Total Cost (EGP)	Gross Income (EGP)	Net Profit (EGP)	Benefit-Cost Ratio (BCR)
$CF_{100\%}$	4.025	16,336	60,375	44,039	3.70
TRI	2.854	13,850	42,810	28,960	3.09
FMC	3.725	14,800	55,875	41,075	3.78
TRI + $CF_{75\%}$	3.501	16,052	52,515	36,463	3.27
TRI + $CF_{50\%}$	3.403	15,318	51,045	35,727	3.33
FMC + $CF_{75\%}$	3.943	17,002	59,145	42,143	3.48
FMC + $CF_{50\%}$	3.652	16,268	54,780	38,512	3.37
FMC + TRI + $CF_{75\%}$	4.278	17,452	64,170	46,718	3.68
FMC + TRI + $CF_{50\%}$	4.029	16,718	60,435	43,717	3.61

CF: chemical fertilizer, **FMC**: filter mud cake and **TRI**: Trichoderma.

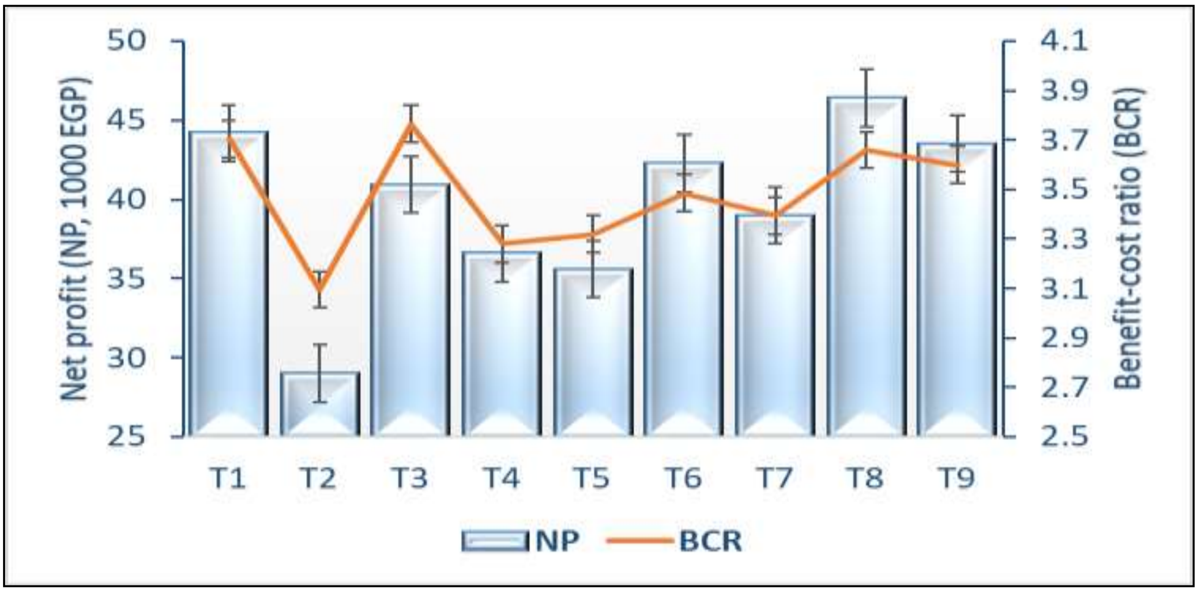

Fig. 1. Net profit (1000 EGP) and benefit-cost ratio of pea production under different treatments of Trichoderma, filter mud cake and chemical fertilizer on average of both 2023/2024 and 2024/2025 seasons.

4. Conclusion

The study examined the effects of different treatments involving chemical fertilization (CF), *Trichoderma viride* (TRI) and filter mud cake (FMC) on growth parameters, yield components, and chemical constituents as well as protein content in pea plants at two winter seasons (2023/2024 and 2024/2025). The performance of the FMC + $CF_{75\%}$ and FMC + TRI + $CF_{75\%}$ treatments further supports the importance of organic amendments in nutrient management. The presence of FMC (a rich organic source of nutrients) contributed to the steady release of essential elements, improving plant nutrition even when chemical fertilizer levels were reduced. The $CF_{100\%}$ treatment, which ranked second in most traits, indicates that the recommended dose of chemical fertilization alone can effectively supply essential nutrients, but it may not be as efficient as integrated approaches that involve organic amendments and biofertilizers. This suggests that excessive reliance on chemical fertilizers without biological support may lead to nutrient losses due to leaching or reduced microbial activity in the soil. These findings confirm that an integrated fertilization method, combining moderate levels of chemical fertilizers (75%) with biofertilizers and organic amendments**,** is the most effective strategy for optimizing vegetative growth, yield, nutrient content and protein synthesis in pea plants. This approach not only enhances plant growth and yield but also promotes sustainable agricultural practices by reducing chemical fertilizer dependence and improving soil health. Regarding economic evaluation, the combined use of 75% NPK + Trichoderma + Filter Mud Cake gave the best economic returns in both seasons. It produced the highest yield, gross income, net profit, and benefit/cost ratio, suggesting this combination is the most cost-effective and sustainable practice for maximizing productivity and profitability in pea cultivation under Sohag Governorate conditions.

5. Recommendation

The FMC + TRI + CF_{75}% and FMC + CF_{75}% treatments is recommended as a promising alternative to full chemical fertilization (CF_{100}%), as it produced competitive results across all studied traits while reducing dependence on chemical fertilizers. Among the tested treatments, FMC + CF_{75}% emerged as the best choice for achieving high yield and maintaining optimal pea plant growth with reduced chemical input. Furthermore, integrating TRI with FMC + CF_{75}% further enhanced plant performance, making it a viable partial substitute for CF_{100}%. This combined treatment significantly improved nutrient absorption, soil fertility, and overall crop productivity, contributing to sustainable agricultural practices with minimized chemical fertilizer use by 25%.

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