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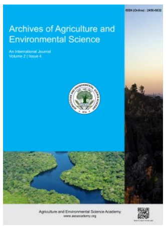

ORIGINAL RESEARCH ARTICLE

CrossMark

Integrated nutrient management improves the nutritional quality and yield of black rice

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ABSTRACT

Integrated nutrient management combining inorganic and organic fertilizers is a promising approach to sustain crop production and soil health. As a premium rice type, integrated nutrients to cultivate black rice are rarely studied in Bangladesh. So, this research was conducted to identify the best combination of inorganic fertilizer (IF) and cow dung (CD) for maximizing the yield and nutritional quality of black rice. The experiment was conducted in the field laboratory of the Department of Agronomy, Bangladesh Agricultural University, Mymensingh following a Completely Randomized Design with four replications. Six treatments with single and combining IF and CD viz., 0% IF + 0% CD (IF_0CD_0), 100% IF + 0% CD ($IF_{100}CD_0$), 75% IF + 25% CD ($IF_{75}CD_{25}$), 50% IF + 50% CD ($IF_{50}CD_{50}$), 25% IF + 75% CD ($IF_{25}CD_{75}$), and 0% IF + 100% CD (IF_0CD_{100}) were applied. A significant variation was found among different treatments concerning plant growth, yield contributing characters, yield, and nutritional composition of black rice. Overall, a better performance was obtained from the application of 75% IF and 25% CD ($IF_{75}CD_{25}$) concerning most of the studied parameters with few deviations. The highest number of tillers hill^{-1}(8.33), effective tillers hill^{-1} (7.33), panicle length (25.97 cm), spikelet's panicle^{-1} (22.87), grains panicle^{-1} (129.7), grain yield (4 t ha^{-1}), protein (9.71%), and potassium (0.58%) were found at the treatment $IF_{75}CD_{25}$. The overall results suggest that 25% cow dung combined with 75% recommended inorganic fertilizers can be applied to achieve maximum yield and nutritional quality of black rice in non-calcareous soil.

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INTRODUCTION

The majority of the world's population depends on a staple food named rice (*Oryza sativa* L.). Rice thrives well under irrigated conditions and is predominantly cultivated in lowland ecosystems. Within the realm of rice varieties, black rice, also known as "purple rice", emerges as a remarkable member of the *Oryza sativa* L. species (Ton-ogan & Banoc, 2020). This rice species is glutinous and has a high level of nutrients, cultivated mainly in Asia. The outer part known as the pericarp of this rice kernel is black due to the presence of anthocyanin pigments and antioxidants. Black rice has several varieties and they have a long cultivation history in Southeast Asian countries like India, China, and Thailand (Kushwaha, 2016). In contrast to white rice, there are several forms of black rice including short-grain, long-grain, and glutinous varieties which are similar to brown rice. Beyond its striking appearance, black rice serves a wide array of nutritional advantages and accelerates aerial levels of protein, vitamins, and minerals (Suzuki *et al*., 2004). Depending on the soil used for cultivation and the variety of rice, black rice is particularly high in micronutrients and mineral contents viz., iron (Fe), zinc (Zn), manganese (Mn), and phosphorus (P). Moreover, it contains carbohydrates, fiber, vitamins, microelements, and amino acids (Nashrurrokhman *et al*., 2019). Furthermore, it also increases immunity, improves liver function, prevents impaired kidney function, and cleans cholesterol in the blood (Kumari, 2020). Beyond its nutritional value, black rice is important in many other ways too. It was seen that the flavor, color, and nutritional quality were improved when black rice and white rice were mixed (Yang *et al*., 2008). Furthermore, substantial health benefits are achieved by incorporating black rice into the diet (Asem *et al*., 2015). In Bangladesh, a significant portion of the population depends on rice as a staple food to meet their nutritional needs. It is worth mentioning that the climate of Bangladesh is suitable for growing rice year-round and there are three distinct rice growing seasons namely *aus*, *aman*, and *boro*. Black rice can also be cultivated year-round in plain land in Bangladesh (Rahman *et al*., 2020).

In Bangladesh, farmers generally apply chemical fertilizers in most cases overdose than the recommended dose to produce rice. Though chemical fertilizers application significantly increases crop yield, on the other hand, if chemical fertilizer application is increased continuously, its utilization efficiency deteriorate and crop yield eventually diminish along with declination of soil physicochemical, biological, and overall soil health properties (Guo *et al*., 2010; Bailey-Serres *et al*., 2019; Anisuzzaman *et al*., 2021). Nutrient losses resulted from the additional fertilizer application and greenhouse gas emissions will be amplified. In addition to raising production costs and wasting resources, long-term application of chemical fertilizers has significant detrimental effects on the environment (Wang *et al*., 2014; Huang *et al*., 2015). However, the use of integrated nutrient management, which makes the most of both organic and inorganic fertilizers, appears to be a promising strategy for preserving soil sustainability, crop productivity, and soil health (Yuniarti *et al*., 2019).

Organic fertilizers contain higher organic matter and have several nutrients. Increasing soil structure and decreasing bulk density improves the physicochemical and biological properties of soil (Guo *et al*., 2019; Iqbal *et al*., 2019). Nevertheless, the nutrient content of organic manure is often low, and its rate of release is generally too sluggish to rapidly meet the needs of plants. Therefore, applying chemical fertilizers and organic manure together has shown to be a more viable option than applying either supplement alone for enhancing and preserving soil fertility and crop productivity (Kumar *et al*., 2018; Iqbal *et al*., 2021). Anisuzzaman *et al*. (2021) reported that the combined application of chemical fertilizer and organic manure showed a significant increase in rice growth, yield contributing parameters and nutrient (N, P, K) concentration.

As an agrarian country, there have been a lot of commercial cattle farms as well as domesticated cattle. Available cow dung manure has been utilized efficiently through proper application methods and timing along with integrated nutrient management practices that combine inorganic fertilizers with organics like cow dung, which has the ability to increase yields while minimizing nutrient losses and optimizing nutrient supply. Thus, it is necessary to compare the productiveness of black rice through inorganic, organic, and integrated (organic+ inorganic) nutrient management practices. Given this context, the current study explores the output of cow dung and various chemical fertilizer dosages in a single and integrated manner. The objective of this study is to elucidate the advantages of utilizing cow dung and inorganic fertilizers in enhancing the growth, yield, and nutritional profile of black rice.

MATERIALS AND METHODS

Experimental setup details

The pot experiment was executed in the field laboratory of the Department of Agronomy, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. Geographically the experimental site was located at an altitude of 18 m above sea level at 24°43'09.5' N latitude and 90°25'42.1' E longitude. The soil is under the Agro-Ecological Zone of Old Brahmaputra Floodplain (AEZ-9) with characteristics of Non-calcareous Dark Grey Floodplain soil. The experimental area experiences a sub-tropical climate. This sub-tropical climate is marked by limited rainfall, low humidity, low temperature, and short days during the *Rabi* season (October to March) and relatively moderate to high temperatures, high rainfall, high humidity, and relatively long days during the *Kharif* season (April to September). Non-calcareous soil was collected to a depth of 0-15 cm from the selected area. Then the collected soil was meticulously cleaned to get rid of any plant residues and other unwanted materials. Afterward, they were air-dried, ground, and passed through a 2 mm sieve. From this processed soil, 500 g were separated and stored for physico-chemical analysis which was done by following standard methodologies (Page *et al*., 1982; Tandon, 2005). The physico-chemical properties of soil are presented in Table 1. Twenty-four plastic pots, 30 cm in height with a top diameter of 24.50 cm and a bottom diameter of 20 cm, were filled with 10 kg of processed soil, leaving a 2 cm gap from the top. Inorganic fertilizers viz., N, P, K, S, Zn, and B @ 200, 100, 120, 110, 3, and 1 kg ha^{-1} were applied from urea, triple superphosphate, muriate of potash, gypsum, zinc sulfate, and boric acid, respectively; cow dung was applied @ 5 ton ha^{-1}. There were six treatments of this experiment comprised of control and integration of various levels of inorganic fertilizer (IF) and cow dung (CD) presented in Table 2. The well-decomposed CD was mixed thoroughly with the soil during pot preparation seven days before transplanting. Thirty-five days old seedlings of black rice were transplanted with two seedlings in each pot. The experiment was conducted with four replications following a Completely Randomized Design (CRD).

Data collection and chemical analyses

Measurement of plant height and counting of total tillers $hill^{-1}$ and fertile tillers $hill^{-1}$ was done at the physiological maturity of rice. Again, panicle length, spikelet's $panicle^{-1}$, grains $panicle^{-1}$, 1000 grain weight, grain yield, and straw yield were measured after harvesting of rice. The grain and straw yield were expressed on a dry basis. The starch content of black rice grain was determined using the enthrone reagent (Subroto *et al*., 2020).

Table 1. Physical and chemical properties of collected experimental soil.

Parameters	Value	Parameters	Value
Textural class	Silty loam	Total N	0.08%
Bulk density	1.29 g cm^{-1}	Available P	2.92 µg g^{-1}
Soil class	Inceptisol	Available S	3.89 µg g^{-1}
pH	6.6	Available K	2.19 meq 100 g^{-1}
Total C	0.43%	Available Ca	3.99 meq 100 g^{-1}
Organic matter	0.74%	Available Mg	2.82 meq 100 g^{-1}

Table 2. Treatments description.

S. No.	Treatments	Symbol
1.	0% IF + 0% CD	IF_0CD_0
2.	100% IF + 0% CD	$IF_{100}CD_0$
3.	75% IF + 25% CD	$IF_{75}CD_{25}$
4.	50% IF + 50% CD	$IF_{50}CD_{50}$
5.	25% IF + 75% CD	$IF_{25}CD_{75}$
6.	0% IF + 100% CD	IF_0CD_{100}

Nitrogen content in the grains was determined using the *Kjeldahl* method as described by Page *et al.* (1982). This nitrogen content was then converted into protein percentage (%) by multiplying it with a conversion factor of 5.85. The mineral nutrients of grain were determined after the preparation of extract using di-acid mixture composed of HNO_3 and $HClO_4$ at a ratio of 2:1. Phosphorus was determined using a spectrophotometer (T60U, UK) by developing a color solution (Jackson, 1973). Potassium concentration was measured using flame photometry (JENWAY -PFP7) as described by Tandon (2005). Calcium concentration was measured using the complexometric method of titration by using Na_2EDTA as a complexometric or chelating agent (Page *et al*., 1982). Finally, the atomic absorption spectrophotometric method was used to determine the Fe, and, Zn using an atomic absorption spectrophotometer (Shimadzo, AA7000, Japan).

Statistical analysis

Statistical analysis was performed using Manitab 2017 version 17.0, a statistical software provided by Manitab Inc. Analysis of variance (ANOVA) was performed on the calculated means for each treatment for each of the measurable attributes. The collected data were checked for normality and equal variance using the Kolmogorov-Smirnov test and modified Levene's test before the ANOVA. Tukey's HSD test was used to find significant differences and a number of comparisons among the various treatments.

RESULTS AND DISCUSSION

Growth, yield attributes, and yield

The data presented in Table 3 demonstrated that the height of the plants was significantly influenced ($p<0.05$) by the different treatment combinations. The single and combined application of IF and CD significantly increased plant height than the control treatment. The highest plant height was recorded in the treatment labeled $IF_{100}CD_0$, reaching 116 cm which was identical to the $IF_{75}CD_{25}$ treatment. Plant height of $IF_{75}CD_{25}$ treatment was identical to $IF_{50}CD_{50}$, and $IF_{25}CD_{75}$, respectively. Sole application of CD (IF_0CD_{100}) showed the lowest performance among all the fertilizer treatments, whereas sole application of IF ($IF_{100}CD_0$) showed the highest performance among all the treatments. In this experiment plant height was higher in IF treatment than in pure CD or its combination with IF treatments. Fortunately, plant height of only IF treatment showed statistical similarity with $IF_{75}CD_{25}$ treatment. The higher plant height at only IF treatment is mainly due to the rapid release of fertilizer nutrients especially fertilizer N than CD treatments or its combination with IF. This evidence is consistent with the study of Wang *et al.* (2023). In this 9-year study, they found that the agronomic trait of rice was relatively lower at organic manure treatments during the early years of study but middle to last years of study partial substitution of chemical fertilizers with organic manures showed better performance than chemical fertilizers alone. In this experiment, though plant height was slightly lower at 25% substitution of IF by CD but the decrease was not significantly lower.

All the yield contributing parameters were significantly influenced the single and combined application of IF and CD except panicle length and 1000-grain weight (Table 3). All the fertilized treatments showed a significantly higher tiller number $hill^{-1}$ than the control treatment. The highest tiller was found at $IF_{75}CD_{25}$ treatment which was identical to $IF_{100}CD_0$, $IF_{50}CD_{50}$, and $IF_{25}CD_{75}$ treatments, respectively. Like the tiller number fertile tiller $hill^{-1}$ was also highest in $IF_{75}CD_{25}$ treatment that showed statistical similarity to $IF_{50}CD_{50}$ treatment. Again, fertile tillers $hill^{-1}$ of $IF_{50}CD_{50}$, $IF_{100}CD_0$, and $IF_{25}CD_{75}$ were identical among them. The panicle length was unaffected by different treatments but the highest length was found at the $IF_{75}CD_{25}$ treatment followed by $IF_{100}CD_0$, $IF_{50}CD_{50}$, $IF_{25}CD_{75}$, and IF_0CD_{100}, treatments, respectively. Control treatment showed the lowest panicle length. The different treatments had a highly significant effect on the number of spikelet $panicle^{-1}$. The treatment $IF_{75}CD_{25}$ produced the maximum number of spikelet $panicle^{-1}$ which was statistically indistinguishable from $IF_{100}CD_0$ followed by $IF_{50}CD_{50}$ and $IF_{25}CD_{75}$, respectively. On the other side, the minimum number of spikelet $panicle^{-1}$ was recorded from the control treatment (IF_0CD_0) which showed similarity to IF_0CD_{100} where only CD was applied. Inorganic fertilizer alone or in combination with CD had a significant effect on the number of grains $panicle^{-1}$ over control but only CD application did not show any significant effect of grains $panicle^{-1}$ over control. The highest number of grains $panicle^{-1}$ was observed at the treatment $IF_{75}CD_{25}$ and was statistically higher than all other treatments. The second highest grain $panicle^{-1}$ was found at $IF50_0CD_{50}$ treatment which was identical to $IF_{100}CD_0$, and $IF_{25}CD_{75}$ treatments, respectively. Again, grains $panicle^{-1}$

Table 3. Integrated effects of inorganic fertilizer and cow dung on the yield attributes of black rice cv. *Kongnam ene.*

Treatments	Plant height (cm)	Total tillers hill^{-1} (No.)	Fertile tillers hill^{-1} (No.)	Panicle length (cm)	Spikelet's panicle^{-1} (No.)	Grains panicle^{-1} (No.)	1000 grain weight (g)
IF_0CD_0	90d	5.0d	4.3d	22.9	15.9c	104.9d	18.8
$IF_{100}CD_0$	116a	7.6ab	6.0b	25.6	21.2a	122.9bc	19.5
$IF_{75}CD_{25}$	113ab	8.3a	7.3a	25.9	22.8a	129.7a	19.4
$IF_{50}CD_{50}$	109b	7.0b	6.6ab	24.5	20.3ab	125.8b	20.6
$IF_{25}CD_{75}$	100bc	5.6bc	5.0bc	23.4	18.9b	115.7c	19.2
IF_0CD_{100}	97c	5.3c	4.6cd	22.9	16.7c	100.5d	19.1
Sig. Level	**	**	**	NS	**	**	NS
CV	3.7	3.0	3.6	3.4	5.5	3.8	-
SE ±	4.1	0.5	0.4	0.5	1.0	4.8	0.2

Figures In a column, having the same letter (s) do not differ significantly; * = Significant at 5% level of Significance; ** = Significant at 5% and 1% level of Significance; NS= non-significant.

Table 4. Integrated effects of inorganic fertilizer and cow dung on the protein and nutrient content of Black rice cv. *Kongnam ene.*

Treatments	N (%)	P (%)	K (%)	Ca (%)	Fe (ppm)	Zn (ppm)
IF_0CD_0	1.1c	0.3c	0.3b	0.4b	19.1d	13.2d
$IF_{100}CD_0$	1.6a	0.5ab	0.5a	0.6a	25.9c	20.4c
$IF_{75}CD_{25}$	1.5ab	0.5ab	0.5a	0.6a	39.8b	25.8bc
$IF_{50}CD_{50}$	1.5ab	0.6a	0.4a	0.5ab	46.6ab	30.2b
$IF_{25}CD_{75}$	1.3b	0.4b	0.4a	0.5ab	50.4a	34.3b
IF_0CD_{100}	1.3b	0.3c	0.4a	0.4b	51.2a	42.6a
Sig. Level	**	**	*	*	**	**
CV	2.5	4.0	3.0	7.9	6.9	4.5
SE ±	0.07	0.04	0.03	0.03	5.4	4.2

Figures In a column, having the same letter (s) do not differ significantly; * = Significant at 5% level of Significance; ** = Significant at 5% and 1% level of Significance; NS= non-significant.

$IF_{100}CD_0$ treatment was identical to $IF_{25}CD_{75}$ treatment. Though different treatments did not significantly influence 1000 grain weight, the highest 1000 grain weight was found at the $IF_{50}CD_{50}$ treatment followed by $IF_{100}CD_0$, $IF_{75}CD_{25}$ $IF_{25}CD_{75}$, and IF_0CD_{100} treatments, respectively; the lowest 1000 grain weight was found at the control treatment. The overall effect of IF and CD on yield contributing parameters focuses on the combination of 25% CD with 75% IF showed better performance than all other combinations though there was some deviation in the case of some parameters. This effect may be due to successful utilization of nutrients under 25% CD and 75% IF applications than all other combinations. Several previous studies demonstrated that nutrient loss is very high under the sole application of IF especially nitrogen loss (Moe *et al*., 2019). A combination of 25% CD with 75% IF reduces nutrient losses as CD has the capability to adsorb and retain nutrients (Raj *et al*., 2014). Again, the slow release of nutrients from CD synchronized the nutrient supply along with rice demands resulting in higher nutrient availability and uptake by rice throughout the whole growing season (Iqbal *et al*., 2021); consequently, yield contributing parameters positively increased under this combination. However, lower performance under the increasing dose of CD with IF is mainly due to the slow release of nutrients that are already addressed to justify plant height. Our findings are justified by the experiment of Kakar *et al.* (2020); where they found maximum tiller number hill $^{-1}$, leaf number plant^{-1}, panicle length, panicle number hill^{-1}, spikelet number panicle $^{-1}$, and 1000-grain weight of rice under the application of animal manure and 50% recommended dose of chemical fertilizers.

Different treatments showed significant variation in grain yield (Figure 1). Among the different treatment combinations, the highest grain yield was recorded from the treatment $IF_{75}CD_{25}$ reaching 4 t ha^{-1} which was statistically indistinguishable from the treatment $IF_{50}CD_{50}$ followed by $IF_{100}CD_0$ treatment, respectively. The grain yield of $IF_{25}CD_{75}$ treatment showed similarity to $IF_{50}CD_{50}$ and $IF_{100}CD_0$, respectively. On the contrary, the lowest grain yield was recorded in the treatment IF_0CD_0 reaching 2.29 t ha^{-1}. The straw yield of black rice showed a distinct pattern due to the combined application of inorganic fertilizers and cow dung (Figure 2). There was a significant increase in straw yield observed with the treatment $IF_{100}CD_0$ (8.4 t ha^{-1}) which was identical to $IF_{50}CD_{50}$. Again, the straw yield of $IF_{50}CD_{50}$ was statistically similar to the treatment $IF_{75}CD_{25}$, and $IF_{25}CD_{75}$, respectively. The lowest straw yield was recorded at the control treatment (4.58 t ha^{-1}). Yield is positively correlated to yield contributing parameters and it is mainly determined by yield contributing parameters (Sui *et al.*, 2013). In this experiment, yield contributing parameters were better at 25% CD and 75% IF application and resulted in higher grain yield than all other treatment combinations. However, the deviation of straw yield at 25% CD and 75% IF application and higher at 100% IF application may be attributed to environmental variation or very rapid vegetative growth of rice at the early stage of development as nutrients were very high then under IF application than the combination of IF and CD; but grain yield is a consistent parameter than straw and mainly depends on nutrients supply during the reproductive period. This result is in line with the findings of Peng *et al.* (2023), where they found higher grain yield of rice under the application of NPK and cow manure than NPK application only.

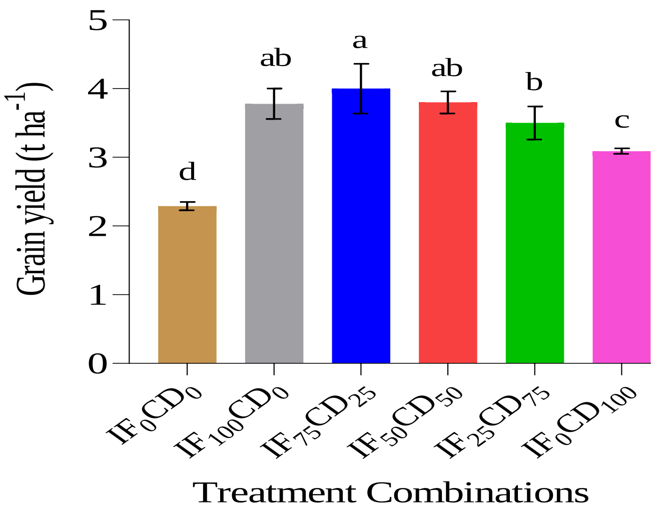

Figure 1. *Integrated effects of inorganic fertilizer (IF) and cow dung (CD) on the grain yields of black rice cv. Kongnam ene.*

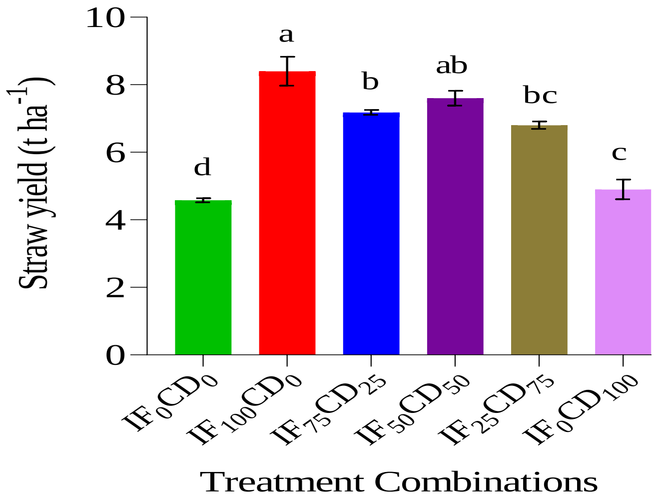

Figure 2. *Integrated effects of inorganic fertilizer (IF) and cow dung (CD) on the Straw yields of black rice cv. Kongnam ene.*

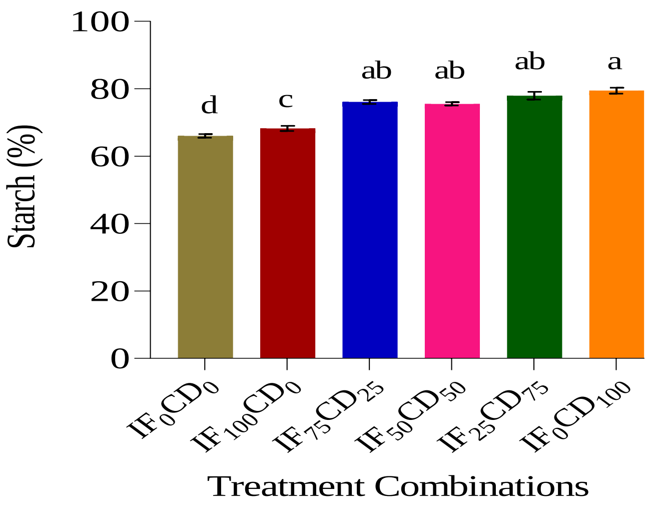

Figure 3. *Integrated effects of inorganic fertilizer (IF) and cow dung (CD) on the starch content of black rice cv. Kongnam ene.*

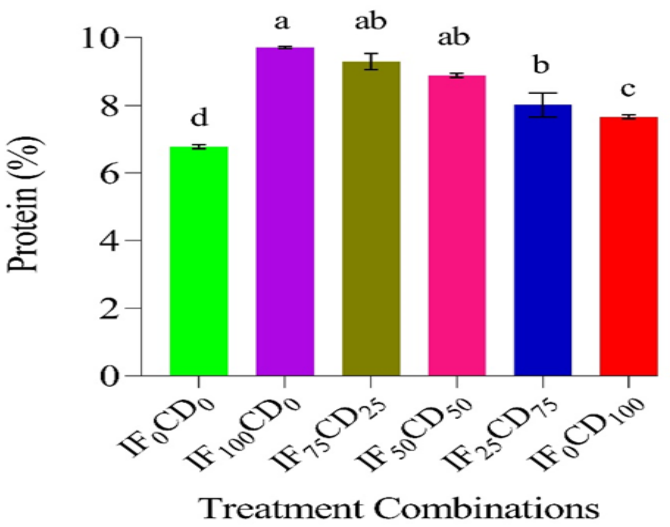

Figure 4. *Integrated effects of inorganic fertilizer (IF) and cow dung (CD) on the protein content of black rice cv. Kongnam ene.*

Biochemical and chemical parameters

Different combinations of inorganic fertilizers and cow dung exhibited a significant influence ($P<0.05$) on starch percentage (Figure 3). The amount of starch significantly increased in the single and combined application of IF and CD over control treatment. However, the highest starch content was found at $IF_{0}CD_{100}$ (79.45%) which was identical to all other treatments except $IF_{100}CD_{0}$ and control ($IF_{0}CD_{0}$) treatments, respectively. The result displayed in Figure 4 revealed that the amount of protein was significantly influenced ($P<0.05$) by the application of varied levels of inorganic fertilizers and cow dung. The highest amount of protein was recorded in the $IF_{100}CD_{0}$ treatment reaching 9.71% which was statistically similar to $IF_{75}CD_{25}$ and $IF_{50}CD5_{0}$ treatments, respectively. The significantly lowest protein was found at control treatment than all other treatments. The sole application of CD significantly reduced the protein content than all other fertilizer treatment combinations.

Whosoever, all the mineral nutrient concentrations were significantly ($P<0.05$) influenced by different treatments (Table 4). The plant treated with 100% inorganic fertilizers ($IF_{100}CD_{0}$) exhibited the highest amount of N concentration which was statistically indistinguishable from the treatment $IF_{75}CD_{25}$ and $IF_{50}CD_{50}$, respectively. Again, the N concentration of $IF_{25}CD_{75}$ and $IF_{0}CD_{100}$ was identical between them. A significantly lower N concentration was recorded with the treatment $IF_{0}CD_{0}$ than all other treatments. A significantly higher P was recorded with the treatment $IF_{50}CD_{50}$ which was similar to $IF_{75}CD_{25}$ and $IF_{100}CD_{0}$ treatments, respectively. Control treatment showed the lowest P concentration similar to $IF_{0}CD_{100}$ treatments only. The maximum amount of K was recorded from the treatment $IF_{75}CD_{25}$ which was statistically similar to all other fertilizer treatments except the control treatment. Without any significant difference, there was a gradual increase in K percentage with a decrease in inorganic fertilizers up to a certain level and then decreased. The highest Ca was observed at $IF_{100}CD_{0}$ and $IF_{75}CD_{25}$ treatments which was identical to $IF_{50}CD_{50}$ and $IF_{25}CD_{75}$ treatment, respectively. The lowest quantity of Ca was observed at the control ($IF_{0}CD_{0}$) treatment and that was identical to $IF_{0}CD_{100}$, $IF_{50}CD_{50}$, and $IF_{25}CD_{75}$ treatments, respectively. Different combinations and levels of cow dung and chemical fertilizer exhibited a significant influence on the amount of Fe content. The highest Fe content was found in the plant treated with 100% cow dung (IF_0CD_{100}) which was identical to $IF_{50}CD_{50}$, and $IF_{25}CD_{75}$ treatments, respectively. There was a gradual decrease in Fe content with a gradual increase in the amount of inorganic fertilizer. A significantly lower amount of Fe was recorded with the treatment IF_0CD_0 than all other treatments. Zinc concentration was significantly higher at IF_0CD_{100} than all other treatments. The second highest Zn concentration was found at $IF_{25}CD_{75}$ treatment which was identical to $IF_{50}CD_{50}$ and $IF_{75}CD_{25}$ treatments, respectively. A significantly lower Zn was recorded in the control treatment than all other fertilizer treatments. The overall biochemical and nutritional parameters showed a variable response under single and combined application of IF and CD. Starch content did not vary among different treatments but a single application of IF showed a decrease in starch concentration might be due to the variation of environmental factors or asynchronization of nutrient supply during the grain filling stage. However, protein and N concentration was significantly influenced by different treatments where 100% IF application showed the highest N and protein concentration but identical to 75% IF + 25% CD and 50% IF+ 50% CD application. A slight increase of N and protein concentration at 100% IF application is unknown to us; it may vary due to environmental factors. Phosphorus concentration was also significantly varied and 50% IF+ 50% CD application resulted from the mainly beneficial effect of the combined application of IF and CD. Though K and Ca concentrations did not vary so prominently among different treatments but higher concentrations were found in a higher share of IF treatment reflecting the lower availability of these elements at higher doses of CD with IF. Interestingly, Fe and Zn concentration was high at 100% CD treatments; may be due to the higher biological activity as they related to microbial secretion and siderophores. Also, CD itself is a rich source of micronutrients (Raj *et al.*, 2014). Our results reflect the findings of Iqbal *et al.* (2021) where they found a higher N concentration in rice grain due to co-application of manure and chemical fertilizers than chemical fertilizers. Again, Anisuzzaman *et al.* (2021) found higher P, and K concentrations in rice grain under the application of chicken manure and recommended dose of chemical fertilizers than chemical fertilizers alone. Again, Zhao *et al.* (2022) observed an increase in leaf Fe concentration in various crops with the application of greater amounts of cow dung.

Conclusion

Combined application of cow dung and inorganic fertilizers showed a substantial influence on the growth, yield, and nutritional quality of black rice. The highest values of most of the studied parameters were obtained from the combined application of 75% inorganic fertilizers along with 25% cow dung. On the other hand, the maximum plant height and straw yield were obtained from the 100% inorganic fertilization. Furthermore, 1000 grain weight was the highest in the treatment $IF_{50}CD_{50}$, and Fe and Zn content was the maximum in the treatment IF_0CD_{100}. Considering the overall performance, 25% cow dung may be applied along with 75% recommended inorganic fertilizers to obtain better grain yield, protein content, and nutrient concentrations of black rice in non-calcareous soil.

DECLARATIONS

Author contribution statement

Conceptualization: M.AH.C., R.R., M.B. and B.K.S.; Methodology: M.AH.C., R.R., M.B. and B.K.S.; Investigation: M.AH.C., R.R., M.B. and B.K.S.; Software and validation: M.AH.C.; Data curation: M.AH.C.; Writing-original draft preparation: M.AH.C.; Review and editing: R.R. M.B.; Supervision: B.K.S.

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