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Effect of integrated nutrient management strategies for sustainable Naga chilli (*Capsicum chinense* Jacq.) production in northeastern region of Bangladesh

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Abstract
A field experiment was conducted during the Rabi season of 2018-19 at the research field of the Citrus Research Station, Bangladesh Agricultural Research Institute (BARI), Jaintapur, Sylhet (25.13562ºN, 92.13217ºE, 36 m above sea level), to evaluate the impact of integrated nutrient management on the growth and yield of Naga chilli. The study included seven treatments: T_1 (100% Recommended Chemical Fertilizer, RCF), T_2 (100% RCF + 10 t/ha cow dung), T_3 (100% RCF + 15 t/ha cow dung), T_4 (120% RCF + 10 t/ha cow dung), T_5 (120% RCF + 15 t/ha cow dung), T_6 (80% RCF + 10 t/ha cow dung), and T_7 (80% RCF + 15 t/ha cow dung). The results showed that the highest fruit yield (9.11 t/ha) was achieved with treatment T_5 (120% RCF + 15 t/ha cow dung) followed by T_4 and T_7. The lowest yield was recorded in T_1 (100% RCF alone). Economically, T_5 also outperformed all other treatments, producing the highest gross income (Tk. 1,822,800/ha) and net income (Tk. 1,366,154/ha), along with the highest benefit-cost ratio (BCR) of 3.99. These findings suggest that the combination of 120% recommended chemical fertilizer with 15 t/ha cow dung (T_5) is the most effective in enhancing both yield and profitability of Naga chilli, making it a promising strategy for sustainable production and improved economic return.

Keywords: Benefit-cost, Naga chilli, cow dung, spices, fruit yield

1. Introduction

Naga chilli (*Capsicum chinense* Jacq.) is a significant fresh green fruit belonging to the Solanaceae family (Ince *et al*., 2009) [13]. It is also known as King chilli in Nagaland and Bhut Jolokia in Assam holds a special place among the hottest chillies in the world, and has recorded that it is hottest chilli with 1001304 SHU (Verma *et al*., 2013) [31] reported by Defence Research Laboratory, Tezpur, Assam, India. The naga chilli, an indigenous cultivar of northeast India, is predominantly cultivated in Nagaland, Assam, and Manipur with smaller scale farming in Mizoram, Arunachal Pradesh, Meghalaya and Bangladesh (Baruah *et al*., 2014) [3]. The demand for this fruit in the Bangladeshi market is growing day by day because of its distinctive aromatic flavor, pungency and high nutritional value (Elias and Hossain, 1984) [7]. During the growing season, the market price of green naga chilli typically ranges between Tk. 400-500 per kg. However, in the off-season, prices tend to rise significantly due to limited availability (Malangmeih and Rahaman, 2016; Meetei *et al*., 2016) [8, 23]. It has been reported that production of naga chilli is increased every year and exported to European markets annually (Hortex newsletter, 2009) [12].

Nowadays, consumers are increasingly seeking nutrient-rich products that offer greater health benefits. Naga chilli is rich in vitamin A, vitamin C, vitamin E, a good source of potassium and folic acid as well as contains a high concentration of antioxidants compound (Bosland and Votava, 2000) [6]. Naga Chilli has been used in various traditional medicinal treatments, such as relieving headaches, treating night blindness and spondylitis, improving digestive health, easing chronic respiratory congestion, pain relief, cancer prevention, weight reduction, gastrointestinal benefits, anti-inflammatory properties, antioxidant activity (Tolan *et al*., 2004; Sarwa *et al*., 2012; Bhagowati and Changkija, 2009) [30, 27, 4]. These medicinal qualities make it a promising source of capsaicin and dihydrocapsaicin for pharmaceutical applications (Malakar *et al*., 2019) [20]. In addition to its use in food, Naga Chilli is also applied as an antivenom for spider and snake bites and is used in defense spray formulations (Meetei *et al*., 2016) [23].

Naga chilli is grown successfully in North-eastern region of Bangladesh during the Rabi season (Bhuyan *et al*. 2015) [5]. The cultivation area of Naga chilli in Bangladesh remains unsatisfactory, mainly due to farmers' lack of awareness about modern production technologies. The average yield is only 4.5-5.5 tons per hectare, which is considerably lower than in other producing countries such as the UK (51.88 t/ha), Sweden (54.35 t/ha), Austria (56.70 t/ha), and Israel (64.20 t/ha), (FAO, 2000) [9]. One of the most effective ways to enhance yield is through integrated nutrient management, which supports healthy plant growth and maximizes productivity (Grewal and Trehan, 1979) [11].

Farmers typically rely on chemical fertilizers, which may lead to declining soil fertility, environmental degradation, and increased input costs. Integrated Nutrient Management (INM), which combines organic and inorganic, offers a promising approach to enhance crop productivity and sustainability. The use of organic fertilizers contributes to the improvement of soil structure, humus content, and water retention capacity, with a significant impact on the beneficial activity of macro-and micro-organisms (Laczi *et al*., 2016) [18].

Research has shown that combining organic manures like cow dung with inorganic fertilizers enhances soil quality and boosts the growth and yield of various vegetables, including chili peppers (Arancon *et al*., 2005) [1], tomatoes (Sharma *et al*. 2023) [28], Chinese cabbage (Wang *et al*., 2010) [32], and garlic (Argüello *et al*., 2006) [2]. However, there is still a lack of focused studies on how integrated nutrient management affects the growth, yield, and profitability of Naga chilli. To address this gap, the present study was conducted to evaluate the effectiveness and economic viability of using both organic and inorganic fertilizers in Naga chilli cultivation.

2. Materials and Methods

2.1 Description of the Research Site

The experiment was conducted at Spices Research field of Citrus Research Station, Bangladesh Agricultural Research Institute, Jaintapur, Sylhet, Bangladesh during October 2018 to March 2019. The experimental site was located at Latitude: 25.13562^{0}N and Longitude: 92.13217^0 E at an elevation of 36 m above mean sea level and it belongs to the Agro-ecological Zone-22 (northern and eastern piedmont plains). A baseline soil sample (0-15cm depth) was collected and tested at the Soil Resources Development Institute (SRDI), Sylhet, Bangladesh. The soil of the experimental plot was medium-high land with a sandy loam texture, acidic (pH of 4.5) in nature, having 1.12% organic matter, 0.071% total nitrogen (N), 0.28 meq/100g potassium (K), 28 µg/g phosphorus (P), 18 µg/g sulfur (S), 1.13 µg/g zinc (Zn), and 0.11 µg/g boron (B) which indicate that the soil was low in fertility. During crop growth period, Monthly weather data on temperature (maximum and minimum) and total precipitation (mm) were recorded (Figure 1). The experimental site experienced a hot and humid climate during the crop season (October 2018 to March 2019), with maximum temperatures between 25.84 °C and 31.53 °C, minimum temperatures from 8.84 °C to 19.03 °C, and total Precipitation of 8.85 mm.

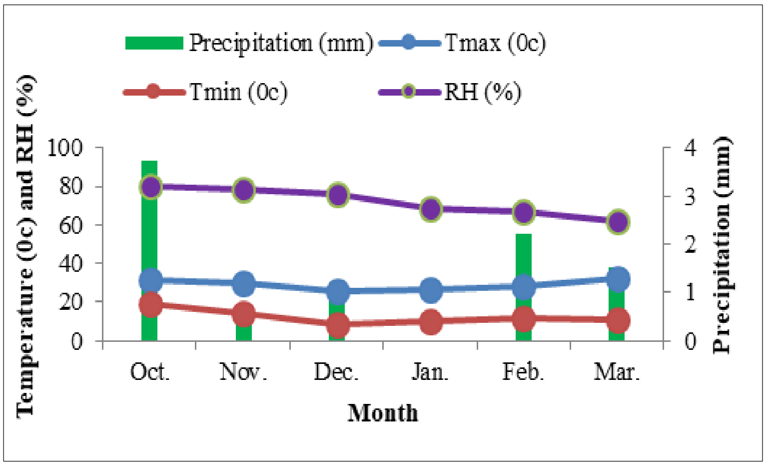

Fig 1: Meteorological observations during the Naga chilli growing period in northeastern region of Bangladesh

2.2 Experimental treatment, design and layout

The experiment was conducted using a randomized complete block design with seven treatments combination according to Fertilizer Recommendation Guide-2018 and replicated thrice. The plot size was 1.2×2m^2. Seven treatments *viz*., T_1: 100% Recommended Chemical Fertilizer (RCF), T_2: 100% RCF + 10t/ha cowdung, T_3: 100% RCF + 15t/ha cowdung, T_4: 120% RCF + 10t/ha cowdung, T_5: 120% RCF + 15t/ha cowdung, T_6: 80% RCF + 10t/ha cowdung, T_7: 80% RCF + 15 t/ha cowdung. In this study, the cow dung utilized had a nutritional composition of 18.6% organic matter, 2.8% nitrogen, 0.34% phosphorus, 0.48% potassium, 0.21% calcium, and 0.26% magnesium. The experimental field was ploughed and laddered for preparing the beds. The experimental area was divided into three blocks each consisted of 1.2×2 m^2 sized 7 unit plots. The blocks and plots were spaced at 0.5 m which was used as drain.

2.3 Crop Management

The experimental plot was prepared using a power tiller through ploughing and cross-ploughing, followed by laddering, to achieve a fine soil tilth suitable for planting. Naga chilli advanced line CC Jai-010 was used for this experiment. Seeds were initially sown in a seed bed, and after 7 days, the seedlings were transferred into poly tubs (3×5") on 15th October, 2018 and 50g of Furadan was applied as an insecticide. Seedlings emerged within 5 to 8 days after sowing. To prevent disease, Diathane M-45 was sprayed in the pot @ 2 g/l. Proper irrigation, mulching, and weeding practices were maintained throughout the growing period. Seedlings of 45 days old were planted in the experimental field on 29st November 2018 maintaining 60 cm × 65 cm spacing according to treatments. All chemical fertilizers were distributed uniformly and well incorporated into the soil. The source of N, P, K, S, Zn, and B were urea, triple super phosphate (TSP), Muriate of potash (MoP), gypsum, zinc sulphate, and boric acid, respectively. Organic manure cowdung was applied in the plot 5-7 days before planting and mixed thoroughly with the soil. N was applied around the plant as a top dressing at 15, 30, 50, and 70 DAT under moist soil conditions and mixed thoroughly with the soil as soon as possible. After each urea application, four irrigations were provided. Hand weeding was conducted twice, at 25 and 50 days after transplanting (DAT). Stalking of each plant was performed as needed, particularly during the vegetative and fruit-setting stages, to prevent the plants from leaning. Since Naga chili plants are semi-indeterminate and continuously produce new stems, leaves, and fruits. So fruits of the plants were harvested when the fruits turned into deep green color. Experimental Data were recorded from 30 days after transplanting and continued until last harvest. Data were collected on plant height, branch count at various days after transplanting (30, 60, 50, 90 DAT and harvest) and yield related attributes. The collected data were analyzed using Statix10 software, and mean comparisons were made using Fisher's LSD test (Gomez and Gomez 1984) [10].

2.4 Economic Analysis

The economic analysis was conducted based on the current market prices. The cost of cultivation included all expenditures associated with crop production. Gross income (Tk. /ha) was calculated by multiplying the yield per hectare from each treatment with the market price. Net income (Tk./ha) was obtained by deducting the cultivation cost from the gross income of each treatment. The Benefit: Cost ratio was determined using the formula

$$\text{Benefit: Cost Ratio} = \frac{\text{Gross income}}{\text{Cost of Cultivation}}$$

3. Results and Discussion

Growth parameters

Integrated management for nutritional balance had a significant effect on plant height and number of branches at all growth stages of Naga chilli. At 30, 60, 90 DAT and at harvest, the highest plant height was 28.79, 57.43, 84.46 and 88.8cm, respectively was recorded in T_5 (120% recommended chemical fertilizer +15 t/ha cow dung) followed by T_3 (100% recommended chemical fertilizer +15 t/ha cowdung. On the other hand, the lowest plant height was recorded in T_1 (Figure 2).

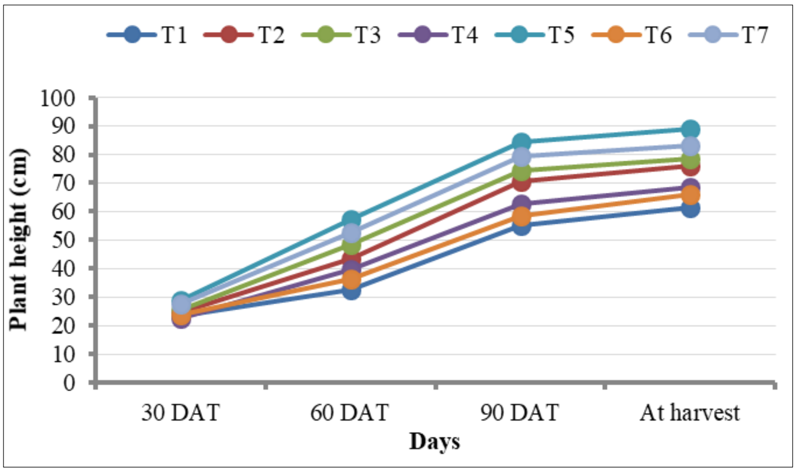

Fig 2: Effect of fertilizer treatments on plant height of naga chilli at different days

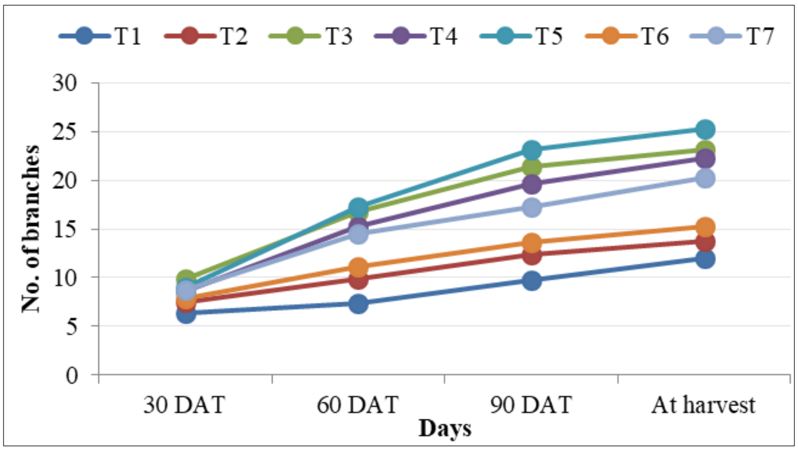

Fig 3: Effect of integrated nutrient management on number of branch/plants of naga chilli at different day

The maximum plant height was observed in the combination of both organic and inorganic fertilizers, might be due to the quick availability of nutrients especially nitrogen, the chief nutrient of protein for the formation of protoplasm which leads to cell division and cell enlargement. Similar results were found by Muradi *et al.* (2023) [24], Mart Handan and Sundar lingam, (2016) [22] and Jamir *et al.*, (2017) [14] that the interaction effect of organic and inorganic fertilizers could be

attributed the growth of the plant. The highest number of branches/plant was recorded in treatment T_5 whereas the lowest number was in T_1 (Figure 3). Treatment T_5 demonstrated that combining organic and inorganic nutrients enhances the physical properties of the soil, a finding that aligns with the results reported by Kumar *et al*. (2008) [17].
Significant differences were observed in the days to first flowering, 50% flowering, first harvest, and final harvest of Naga chilli across the various fertilizer treatments (Figure 4). The time to first flowering ranged from 39.88 to 47.53 days after transplanting (DAT). The longest period to reach first flowering was recorded in treatment T_2 (47.53 DAT), which was significantly longer than in T_1. In contrast, the shortest duration (39.88 DAT) was observed in T_5. In terms of days to 50% flowering, the highest days (65.24 DAT) took the 50% flowering observed in T_2 which was statistically same result to T_1. On the other hand, the lowest days (57 DAT) took in T_5, which was which was statistically similar to T_4, T_6 and T_7. Similar patterns were observed in the days to first harvest and days to complete harvest. Earliness in plants is influenced by nutrient availability, as nutrients aid in the production of hormones such as auxins, gibberellins, and cytokinins, which trigger early flowering. Cow dung, rich in essential nutrients and beneficial microbes, not only supports overall plant growth but also enhances hormone production through microbial metabolism. This, along with rapid vegetative growth, likely leads to early transformation of buds into flowers and earlier fruit harvest. Similar results were observed by Khurshid *et al*. (2021) [16], Pariari and Khan (2013) [26] in chilli and Jamir *et al*. (2017) [14] in sweet pepper.

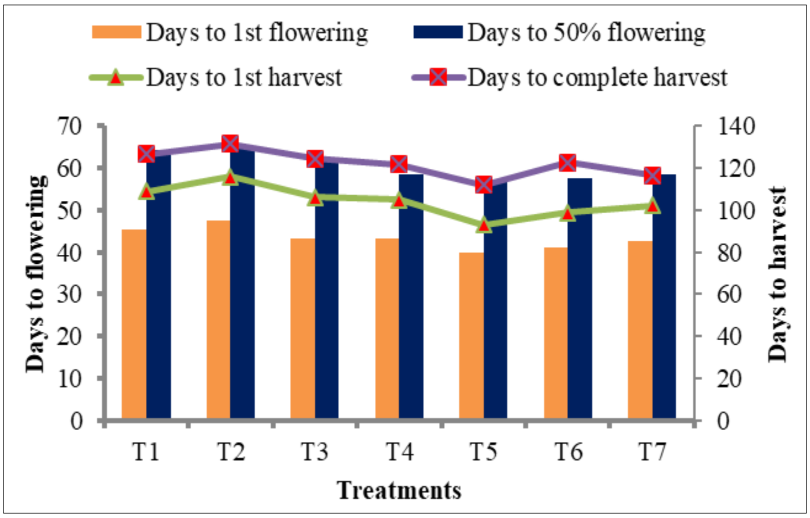

Fig 4: Effect of Integrated nutrient management on days to 1st flowering, days to 50% flowering, days to 1st harvest and days to complete harvest of Naga chilli

Yield and yield related parameters
The combined application of chemical fertilizers and organic manures led to a significant improvement in the yield and yield related traits of Naga chilli compared to Treatment T_1 (Figure 5). The treatment involving 120% of the recommended chemical fertilizer along with 15 t/ha of cow dung (T_5) showed the highest values for yield attributes such as fruit length (6.18 cm), fruit breadth (3.00 cm), and single fruit weight (4.56 g). In contrast, the highest number of fruits per plant was recorded under the treatment with 120% recommended chemical fertilizer and 10 t/ha of cow dung (T_4). The results indicate that combining chemical fertilizers with cow dung has a favorable impact on Naga chilli production. The integrated use of organic manure and inorganic fertilizers enhanced the availability of NPKS nutrients, improved soil fertility, and boosted overall productivity, which likely contributed to the improvement in yield-attributing traits. Furthermore, the increased availability of micronutrients through the addition of cow dung may have also played a crucial role in enhancing the yield characteristics of Naga chilli. The highest yield per hectare (9.11t) was observed in the treatment with 120% of the recommended chemical fertilizer combined with 15 t/ha of cow dung (T_5), which was significantly superior to all other treatments, including T_3 and T_7. The lowest yield was recorded in T_1. Notably, the application of 120% recommended chemical fertilizer along with 15 t/ha cow dung resulted in a 44% increase in yield compared to the treatment (T_1) with 100% recommended dose of chemical fertilizer alone. The increase in naga chilli fruit size and weight can be attributed to the balanced carbon nitrogen ratio and enhanced nutrient availability resulting from the application of organic manures. These conditions promote better decomposition, mineralization, and solubilization of nutrients, which in turn improve physiological processes. This leads to the accumulation of food reserves, efficient nutrient distribution to developing fruits, and improved root growth. Together, these factors support better nutrient uptake and carbohydrate synthesis, ultimately contributing to higher fruit yield. Similar results were reported by Khurshid *et al*. (2021) [16], Madhukumar *et al*. (2018) [19], Reddy *et al*. (2017) [29].

Economic analysis of Naga chilli
The economic analysis of the various treatments is comprehensively presented in Table 1. The results clearly indicated that the highest gross income (Tk. 1,822,800 ha^{-1}) and net income (Tk. 1,366,154 ha^{-1}) were recorded in treatment T_5, which involved 120% of the recommended chemical fertilizer combined with 15 t/ha of cow dung. This treatment also yielded the highest benefit-cost ratio of 1:3.99. The next best was treatment T_4 (120% RCF + 10 t/ha cow dung), with a benefit-cost ratio of 1:3.84. On the other hand, the lowest economic return was observed in T_1 (100% recommended chemical fertilizer), with a gross income of Tk. 805,000 ha^{-1}, net income of Tk. 410,006 ha^{-1}, and benefit-cost ratio of 1:2.04

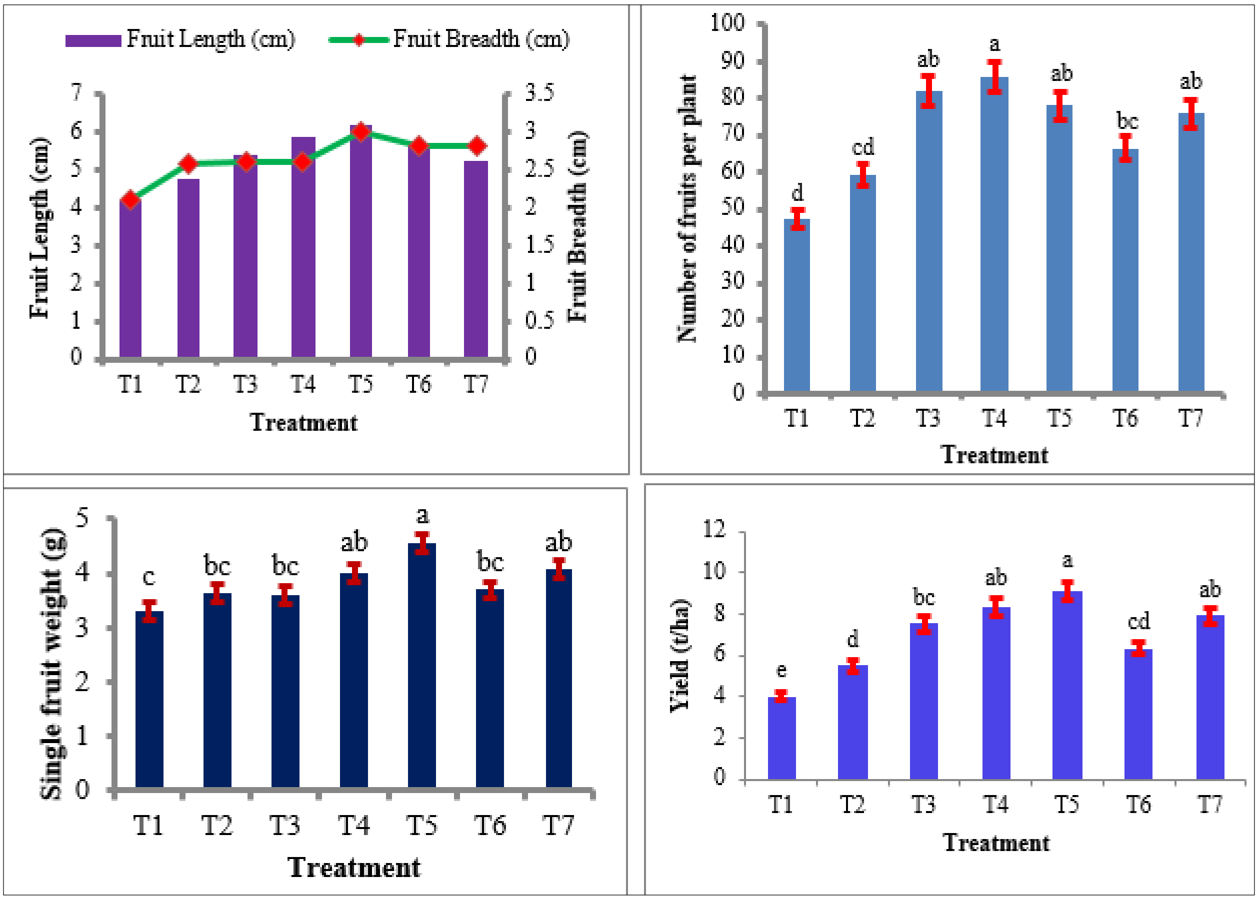

Fig 5: Effect of integrated nutrient management on yield and yield related attributes of Naga chilli

Table 1: Effect of integrated nutrient management on economic indices in Naga chilli

Treatment	Fixed cost (Tk.)	Treatment cost (Tk.)	Total cost (Tk.)	Yield (kg/ha)	Gross income (Tk./ha)	Net income (Tk./ha)	Benefit Cost Ratio
T_1	375000	19994	394994	4025	805000	410006	2.04
T_2	376858	49994	426852	5503	1100600	673748	2.58
T_3	377452	64994	442446	7559	1511800	1069354	3.42
T_4	379865	53992	433857	8336	1667200	1233343	3.84
T_5	387654	68992	456646	9114	1822800	1366154	3.99
T_6	375853	45995	421848	6358	1271600	849752	3.01
T_7	375976	60995	436971	7924	1584800	1147829	3.63

Input and output price per kg: Urea = Tk. 16, TSP = Tk. 22, MoP = Tk. 15, Gypsum = Tk. 12, Zinc sulphate =Tk.200, Boric acid = Tk. 250, Cow dung = Tk. 3, Naga chilli seed =Tk.800, Naga chilli selling price = Tk.200.

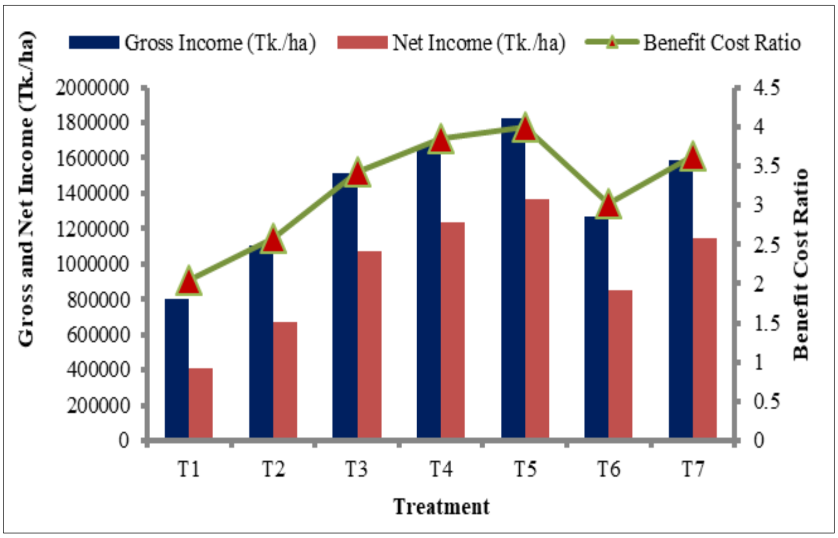

Fig 6: Effect of integrated nutrient management on economic indices in Naga chilli

4. Conclusion

The findings of the present study clearly indicate that the integrated application of organic and inorganic fertilizers has a significant positive effect on the growth and yield performance of Naga chilli. This approach enhances nutrient availability, uptake, and overall utilization, contributing to improved plant development and productivity. Among the treatments, the combination of 120% recommended chemical fertilizer with 15 t/ha of cow dung (T_5) was the most effective. Agronomically, it resulted in the highest growth and yield attributes, while economically, it achieved the maximum gross income (Tk. 1,822,800 ha^{-1}), net income (Tk. 1,366,154 ha^{-1}), and benefit-cost ratio (1:3.99). These results underscore the potential of integrated nutrient management for maximizing both yield and profitability in Naga chilli cultivation.

5. Acknowledgement

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