International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(4): 295-299
www.biochemjournal.com
Received: 18-01-2024
Accepted: 21-03-2024

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Enhancing nutrient utilization in eggplant (*Solanum melongena* L.) through integrated management approaches

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DOI: https://doi.org/10.33545/26174693.2024.v8.i4d.973

Abstract
The research named "Integrated Nutrient Management in Eggplant (*Solanum melongena* L.)" was carried out in the 2017–18 academic year at SKUAST–J Chatha's Experimental Farm I, Division of Vegetable Science. The experiment used a Randomised Block Design with 14 treatments that were repeated three times. It included three levels of inorganic fertilizer (PKA, 75%, and 100%), two biofertilizers (Azotobacter and Phosphorus solubilizing Bacteria), and two organic sources (FYM and Vermicompost). Several growth, productivity, quality, and economics-related criteria were evaluated. Among all treatment combinations, the combination of T_{13} produced the tallest plant height (101.55 cm) and the most leaves per plant (93.31). In addition, the greatest number of branches (6.74) were formed by T_{11}. Furthermore, of all the treatments, T_{13} produced the maximum fruit yield per hectare (450.20 q), the heaviest fruit weight (64.90 g), the longest fruit length (18.66 cm), the largest fruit diameter (5.14 cm), and the maximum fruit count (20.30). This resulted in the highest fruit yield per plant (1.29 kg). It is interesting to note that fruits with the highest sugar content (11.53% for both total and reducing sugars) and the highest vitamin C content (26.23 mg/100 g) were produced by T_{11}. About economics, the treatment T_{13} had the greatest Cost-benefit ratio (2.87), with T_{11} coming in second with a B: C ratio of 2.83.

Keywords: Bio-fertilizers, cost-benefit ratio, INM, vermicompost

Introduction
One of the most important vegetable crops in the world is aubergine (*Solanum melongena* L.), which is a member of the Solanaceae family. Its height typically ranges from 40 to 150 cm, and it grows in an erect or semi-spreading manner. This versatile crop can flourish in a variety of climates and offers a high output per unit area. Extensively grown in countries like the US, France, Bulgaria, Italy, India, Japan, Indonesia, and many African nations (Kalloo, 1993) [12], it is the third most important vegetable crop in the Solanaceae family, producing 269,654 million tonnes of vegetables annually over 1,853,340 hectares (Anonymous, 2014a) [2]. To reach desired productivity levels, integrated plant nutrition management maintains appropriate soil fertility and plant nutrient supply through the synergistic utilization of organic, inorganic, and biological components. By employing locally accessible resources, balancing the application of organic and inorganic sources improves soil health and increases productivity, providing an economically viable method of nutrient supply. It's possible that soil health cannot be maintained for long-term productivity by using chemical fertilizers alone. Vermicompost, for example, provides minerals such as calcium, magnesium, soluble potassium, exchangeable phosphorus, and nitrates in easily absorbed forms (Edward and Burrows, 1988) [10]. Bio-fertilizers have become essential parts of “Integrated Nutrient” Supply Systems, and have the latent to increase productivity through improved nutrient supply (Hegde *et al.*, 1999) [11]. These beneficial microorganisms help biological processes convert essential elements from insoluble to soluble forms. Similar to Pseudomonas strata, Phosphate Solubilizing Bacteria (PSB) are essential for solubilizing fixed phosphorus in soil so that plants can access it. Beneficial bacteria such as Azotobacter and PSB found in biofertilizers improve nutrient uptake by changing nutrients into soluble forms (Bhattacharya *et al.*, 2000) [5].

According to Bahadur *et al*. (2003) [4], organic nutrient sources like vermicompost, farmyard manure, and biofertilizers affect nitrogen availability and uptake, which in turn promotes crop growth and yield. Because year-round eggplant agriculture is supported by the subtropical plains and intermediate zones of the Jammu division, it is necessary to standardize Integrated Nutrient Management approaches that combine synthetic fertilizers with locally sourced organic sources. This becomes especially important because eggplants require more nutrients to produce their best yields. To tackle this, a study was designed with the dual goals of assessing the potential for eggplant production under different combinations of FYM, Vermicompost, and Biofertilizer treatments and investigating the viability of lowering the amount of inorganic fertilizer used by combining FYM, Vermicompost, and Biofertilizer treatments.

Materials and Methods

The experimental site in Chatha, Jammu, and Kashmir, sits at 32˚-29 North latitude and 74˚-48˚ East longitude, with an elevation of 332 meters above mean sea level. The climate of the Jammu plains, where the field study was conducted, is subtropical, characterized by hot, dry summers, heavy rainfall during the monsoon season, and mild to severe cold spells and frosts in winter. The investigation into the effects of integrated nutrient management strategies was carried out during the 2017 Kharif season. The soil nursery underwent thorough spading and pulverization, with complete removal of weeds and plant debris, and was generously supplied with well-decomposed farmyard manure. Punjab Sadabahar brinjal variety seeds were used for seedling cultivation, placed in nursery beds of practical size (2x2 m). Two days after seeding, light watering was applied to the beds using a rose can. After ten days, when maximum germination was observed, the straw cover was removed, and all necessary precautions were taken to ensure seedling health, including alternate-day light irrigation. FYM, vermicompost, and bio-fertilizers (Azotobacter and PSB), along with urea, DAP, and MOP, were administered according to treatment protocols. Before transplanting, each treatment received a unique fertilizer combination with predefined proportions of nitrogen, phosphorous, potassium, FYM, and vermicompost. The recommended amount of inorganic fertilizer (100:60:30) in the form of urea, DAP, and MOP was applied. Azotobacter slurry, prepared by mixing Azotobacter @ 1kg/ha (0.5 kg jaggery per 2-3 liters of water in the slurry), served as a seedling root dip, while PSB was integrated into organic sources (FYM and vermicompost) and applied as per treatment criteria. After 30 days, when seedlings reached the required size and stockiness (6-8 cm in height), irrigation was briefly suspended for 2-3 days to harden them. To prevent seedling uprooting, nursery plots were irrigated a few hours before transplanting. Transplanting was followed by six days of morning irrigation with a "Rose can" until plants were fully established, followed by an initial gentle flooding of water. Plant protection measures were implemented following approved crop health procedures, including pest and disease control techniques outlined in the Package of procedures for Vegetable Crops (Anonymous, 2016) [3]. The study meticulously recorded various parameters, including average plant height (cm), number of branches per plant, number of leaves per plant, number of fruits per plant, fruit diameter (cm), fruit length (cm), fruit weight (g), fruit yield/plant (kg), fruit yield (q/ha), total soluble solids (Brix°), total sugar (%), reducing sugar (%), vitamin C (mg/100 g), gross return, net return, and benefit-cost ratio.

Results and Discussion

Growth Characteristics

The number of leaves per plant and the average height of plants (measured in centimetres) did not differ considerably across the Integrated Nutrient Management (INM) techniques shown in Table 1. While the control treatments, T_1 and T_3, had the lowest average plant height (100.65 cm) and leaf count per plant (85.06), treatment T_{13} had the tallest average plant height (101.55 cm) and the highest leaf count per plant (93.31). Integrated nutrient management had a major impact on the number of branches per plant (Table 1). There were 6.74 branches per plant in treatment T_{13}, compared to 4.61 in treatment T_1, the control. By promoting microbial activity and biomass, vermicompost raises soil organic carbon levels. These factors are essential for nutrient recycling and the enhancement of native plant growth regulators, which leads to an increase in plant height. This observation is consistent with the research conducted by Samadhiya *et al*. (2015) [23] and Agrawal and Sharma (2014) [1]. The increased root uptake of macro- and micronutrients, which promotes vegetative development and amplifies photosynthetic activity, is probably the cause of the larger leaf count per plant. Similar findings were published by Ogundare *et al*. (2015) [20] and Kashyap *et al*. (2015), showing that the metrics related to tomato development were not significantly affected by nutrients given. Nonetheless, the positive association between inorganic, organic, and biofertilizer sources may be responsible for the incremental increase that was seen in comparison to the control, indicating an improvement. Growth-promoting compounds generated by biofertilizers may be the cause of the greater influence on growth metrics compared to the control. These molecules may facilitate better root development, water uptake conveyance, and nutrient deposition. Brinda was found to grow best when treated with NPK + FYM + Azospirillum + PSB by Nanthakumar and Veeraragathatham (2001) [19], whereas (2012) found that 50% NPK + 50% FYM + Bio-fertilizers produced the best growth in brinjal, tomato, and king chilli.

Yield and yield contributing characters

As Table 1 shows, INM approaches have a considerable impact on yield as well as yield-contributing components. Fruits/plant 20.30, fruit diameter 5.14 cm, fruit length 18.66 cm, fruit weight 64.90 g, fruit yield per plant 1.29 kg, and fruit yield per hectare 450.20 q/ha were the highest metrics for treatment T_{13}. In contrast, fruits/plant 17.50, fruit diameter 3.13 cm, fruit length 14.90 cm, and fruit weight 64.90 g were the lowest values for treatment T_1 (100% NPK + FYM). The number, length, and diameter of fruits rose as a result of the enhanced vegetative growth, which probably made it easier for more food to be synthesised and transferred into developing fruits (Chumei and Singh, 2013) [8]. This can be attributed to the positive impacts of organic manures, which provide vital nutrients in a balanced ratio, enhancing the physical-chemical and biological characteristics of soil, facilitating better nutrient uptake and utilization by plants, and ultimately raising parameters that contribute to yield. Having more leaves (the "food factory") encourages strong plant growth, which in turn produces more fruits per plant. According to Maghfoer *et al*. (2014) [16], a higher yield of aubergine was obtained by applying 75% NPK in addition to other organic manures and biofertilizers, suggesting greater synchronization than the control. The highest yield of eggplants is produced when the 75% NPK fraction satisfies the chemical nutritional need early in growth. The combined effects of nutrients on vegetative growth, which result in increased photosynthetic activities, improved nitrogen and carbohydrate metabolism, and enhanced water metabolism and relations in plants, may be responsible for the increased fruit yield (Reddy *et al*., 2002; Kumar and Gowda, 2010; Mujawar, 2012; Kashyap *et al*., 2014; Laxmi *et al*., 2015) [22, 14, 17, 13, 15]. By lowering the risk of nitrogen loss and improving soil properties, a 25% reduction in the amount of inorganic fertilizer and a 25% substitution with stable manures (organic + biofertilizers) could increase the efficiency of nitrogen absorption by plants (Ullah *et al*., 2008) [26].

Quality parameters

In response to integrated nutrition management (INM) methods, all quality metrics showed notable improvements. Total Soluble Solids (TSS) for treatment $T_1$4 (50% NPK + Vermicompost + Azotobacter + PSB) in Table 1 were 5.16, the greatest, whereas T_2 (75% NPK + FYM + Azotobacter) showed the lowest (4.16). Notably, the information shown in Tables 13 and 14 revealed that T_4 (75% NPK + FYM + PSB) showed the lowest total sugar content (8.49%) and lower sugar content (8.10%), while treatment T_{11} showed the greatest (total sugar content 11.53%) and (reducing sugar content 11.13%). Additionally, treatment T_{13} showed the maximum vitamin C content (26.23 mg/100g), whereas treatment T_{11} presented the lowest. Table 15 illustrates the beneficial outcomes of INM procedures about vitamin C content. The nutrients used had a substantial impact on total soluble solids, a measure of sweetness, it is also the same as the findings of Kamili *et al* (2002) [28]. Other quality metrics that responded well to INM approaches were vitamin C and total and decreasing sugar levels. The treatment with the highest sugar concentration was 75% NPK + Vermicompost + PSB, while the treatment with the highest vitamin C content was 75% NPK + Vermicompost + Azotobacter + PSB. Comparable results were noted by Chattoo *et al*. (1997) [6] in knol-khol and Balakrishnan (1988) in chilies. The physiological effects of both organic and inorganic nutrient sources on enzyme activity, as well as the brinjal fruit's increased availability of energy and nutrients as a result of enhanced vegetative growth, could be responsible for the fruit's elevated levels of total and reducing sugars. Similar results were reported by Chitesh (2005) [7] and Nandani (2006) [18] for a variety of vegetables, including tomatoes. On the other hand, Patil *et al*. (2004) [21] pointed out that the treatment that received only 100% NPK + FYM (control) produced lower total and reducing sugars, probably as a result of decreased nutritional content and subsequent shortages in plants. Because vermicompost and biofertilizers work synergistically to improve soil physical conditions and nutrient solubilization while also providing essential major and micronutrients, it is possible to attribute the increase in ascorbic acid and sugar contents in treatment combinations of inorganic, organic, and biofertilizers over the control. The increased sugar content in treatment combinations with 75% NPK, vermicompost, and PSB may be related to growth hormones such cytokinins and IAA that are produced by Azotobacter. Biofertilizers produce growth hormones that encourage the growth of leaf area and the synthesis of carbohydrates (Subbiah, 1992) [25].

B: C Ratio

The goal of brinjal growers directly corresponds to yield per rupee invested, therefore farmers and producers stand to gain a great deal from a thorough review of economic research, especially considering how perishable brinjal is. Table 2 offers a thorough examination of applied nutrition economic research, emphasizing differences in the Cost: Benefit ratio. The ratio of benefit to cost varied between 2.20 and 2.87. With a B: C ratio of 2.87, treatment T_{13} (Vermicompost + Azotobacter + PSB + 75% NPK) produced the highest net returns, totaling Rs. 38,963.11. Treatment T_{11} (Vermicompost + PSB + 75% NPK) produced net returns of Rs. 38,467.68 with a B: C ratio of 2.83, placing it in second place. In contrast, treatment T_1, which was the control and included FYM together with inorganic fertilizers, had the lowest B: C ratio (2.20). Because pests and illnesses cause less yield loss in INM plots than in control plots, the net returns in INM plots are higher. Furthermore, higher costs for plant protection and inorganic fertilizers were the cause of the higher costs seen in control plots. According to Chumei *et al*. (2013) [8], a treatment combination consisting of 50% NPK + 50% FYM + biofertilizers produced a B: C ratio of 1.92, whereas a combination consisting of 50% NPK + 50% pig manure + biofertilizers produced a B: C ratio of 1.55, most likely as a result of higher yields and lower input costs. These results are consistent with their research. Chumyani *et al*. (2012) [9], Sentiyangla *et al*. (2010) [24], and Vimera *et al*. (2012) [27] found similar results in treatments of tomatoes, radish, and chillies with mixtures of 50% NPK + 50% FYM + biofertilizers, highlighting the financial advantages of such approaches.

Table 1: Influence of integrated nutrient management on the growth, yield, and quality of brinjal.

Notation	Treatments	Average plant height (cm)	No. of branches/ Plant	No. of leaves/ plant	No. of fruits/ plant	Fruit diameter (cm)	Fruit length (cm)	Fruit weight (g)	Fruit yield/ plant (Kg)	Fruit yield (q/ha)	TSS (brix°)	Total sugar (%)	Reducing sugar (%)	Vitamin C (mg/100 g)
T_1	100%NPK + FYM (control).	100.65	4.61	91.84	17.50	3.13	14.90	50.20	0.90	325.36	4.66	9.50	9.00	24.72
T_2	75% NPK + FYM + Azotobacter	101.44	5.38	85.54	19.30	3.34	16.53	52.39	1.00	360.37	4.16	10.90	10.50	25.53
T_3	50% NPK + FYM + Azotobacter	101.33	5.94	85.06	17.90	3.51	18.63	51.10	0.92	335.20	4.63	9.46	9.13	23.26
T_4	75% NPK + FYM + Phosphorus solubilising Bacteria	101.10	6.10	92.27	19.50	4.10	16.89	62.11	1.10	370.00	5.10	8.49	8.10	24.02
T_5	50% NPK + FYM + Phosphorus solubilising Bacteria	100.88	6.09	91.60	19.12	3.89	17.36	60.19	1.12	390.20	5.03	9.86	9.46	24.30
T_6	75% NPK + FYM + Azotobacter + Phosphorus solubilising Bacteria	100.77	6.46	90.93	19.70	4.30	17.46	63.12	1.16	400.12	5.10	9.20	8.50	25.83
T_7	50% NPK + FYM + Phosphorus solubilising Bacteria	100.66	6.46	92.90	19.23	4.02	18.36	62.90	1.20	420.19	5.13	9.86	9.40	26.02
T_8	100%NPK + Vermicompost	101.10	6.45	97.55	19.11	3.82	17.66	59.10	1.14	419.10	4.96	8.83	8.33	26.20
T_9	75% NPK + Vermicompost + Azotobacter	100.66	5.76	83.88	19.10	3.81	18.06	60.13	1.13	416.20	4.86	10.00	9.40	23.36
T_{10}	50% NPK + Vermicompost + Azotobacter	100.88	6.42	92.56	18.94	3.63	18.30	60.11	1.24	420.12	4.46	10.96	10.50	24.13
T_{11}	75% NPK + Vermicompost + Phosphorus solubilising Bacteria	100.66	6.74	92.30	20.10	4.86	18.63	63.16	1.22	430.12	4.53	11.53	11.13	23.20
T_{12}	50% NPK + Vermicompost + Phosphorus solubilising Bacteria	100.55	6.39	86.65	19.80	4.69	18.33	63.13	1.29	428.18	4.53	9.50	9.50	23.70
T_{13}	75% NPK + Vermicompost + Azotobacter + Phosphorus solubilising Bacteria	101.55	5.71	93.31	20.30	5.14	18.66	64.90	1.29	450.20	4.26	10.36	10.36	26.23
T_14	50% NPK + Vermicompost + Azotobacter + Phosphorus solubilising Bacteria	100.33	6.37	92.64	20.23	4.90	17.66	63.59	1.28	443.20	5.16	9.06	8.70	25.26
	SEm(±)	1.40	0.11	2.39	0.29	0.04	0.24	1.02	0.01	5.40	0.06	0.15	0.14	0.36
	CD (P=0.05)	NS	0.22	NS	0.85	0.14	0.71	3.00	0.03	15.79	0.20	0.45	0.43	1.06

Table 2: Influence of integrated nutrient management on the economic aspects of brinjal

	Treatments	Cost of Cultivation (Rs)	Gross Returns (Rs)	Net Returns (Rs)	B: C
1	Control= 100% NPK + FYM	266700.00	586740.00	320040.00	2.20
2	75% NPK + FYM + Azotobacter	238363.64	576840.00	338476.36	2.41
3	50% NPK + FYM + Azotobacter	233110.88	578115.00	345004.11	2.48
4	75% NPK + FYM + Phosphorus solubilising Bacteria	221256.00	553140.00	331884.00	2.50
5	50% NPK + FYM + Phosphorus solubilising Bacteria	212961.25	577125.00	364163.74	2 .71
6	75% NPK + FYM + Azotobacter + Phosphorus solubilising Bacteria	232464.14	583485.00	351020.85	2.51
7	50% NPK + FYM + Azotobacter + Phosphorus solubilising Bacteria	234755.90	596280.00	361524.09	2.54
8	100% NPK + Vermicompost	209638.68	574410.00	364771.31	2.74
9	75% NPK + Vermicompost + Azotobacter	220876.38	598575.00	377698.61	2.71
10	50% NPK + Vermicompost + Azotobacter	217408.39	569610.00	352201.60	2.62
11	75% NPK + Vermicompost + Phosphorus solubilising Bacteria	210217.31	594915.00	384697.68	2.83
12	50% NPK + Vermicompost + Phosphorus solubilising Bacteria	218361.11	589575.00	371213.88	2.70
13	75% NPK + Vermicompost + Azotobacter + Phosphorus solubilising Bacteria	208358.88	597990.00	389631.11	2.87
14	50% NPK + Vermicompost + Azotobacter + Phosphorus solubilising Bacteria	210561.15	585360.00	374798.84	2.78

Recommended dose: 100:60:30 kg NPK/ha.

Inputs

FYM- Rs 16500/ha, Azotobacter = Rs. 1000/ha. Vermicompost= Rs. 18000/ha, Urea = Rs 7.5/kg Phosphorus Solubilising Bacteria (PSB) = Rs 1000/ha, DAP= Rs. 23/ kg, MOP= Rs. 6/kg

Conclusion

In conclusion, the integrated nutrient management (INM) techniques employed in this study exhibited significant impacts on growth characteristics, yield, quality parameters, and the cost-benefit ratio (B: C) of brinjal cultivation. Despite minimal differences in plant height and leaf count per plant across various treatments, INM significantly influenced the number of branches per plant, likely due to enhanced microbial activity and biomass promotion, as evidenced by previous research. Moreover, INM approaches led to increased yield and yield-contributing factors, such as fruit size and weight, attributed to improved vegetative growth and nutrient uptake facilitated by organic manures and biofertilizers. Quality parameters like Total Soluble Solids (TSS), sugar content, and vitamin C levels also showed notable improvements under INM treatments, indicating enhanced nutritional value. Additionally, the economic analysis revealed favorable B: C ratios for INM treatments compared to conventional methods, highlighting the financial benefits of adopting integrated approaches in brinjal cultivation. These findings underscore the importance of INM strategies in optimizing brinjal production while ensuring economic viability and sustainability for growers and producers.

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