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Ensuring High Productivity and Net Income to the Farmers through Integrated Nutrient Management (INM) in Brinjal

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ABSTRACT

The application of inorganic fertilizer enhanced plant yield by more than 50% by providing essential nutrients. However, it has resulted in long-term negative consequences on soil, aquatic life, the environment and human health. Integrated use of inorganic fertilizers with biofertilizers and micronutrients can potentially improve the yield and maintain the nutritional balance in the soil. The current study evaluated the efficacy and economic viability of integrated nutrient management in brinjal. The highest yield, gross returns, net profit and benefit: cost ratio were noticed due to the application of nitrogen through 75% of RDF (recommended dose of fertilizers) with *Azotobacter chroococcum* as an N-fixer, phosphorus and potassium as RDF which was at par with the application of nitrogen and phosphorus through 75% of RDF with *A. chroococcum* as an N-fixer, *Aspergillus niger* as P-solubilizer and potassium as RDF. The foliar spray of $ZnSO_4$ (0.5%) and borax (0.2%) was reported to have a significant interaction effect on yield and economics of brinjal cultivation.

Key words: Biofertilizers, *Azotobacter chroococcum*, *Aspergillus niger*, N-fixer, P-solubilizer

INTRODUCTION

Crop production worldwide is driven by the extensive use of chemicals in the form of inorganic fertilizers, pesticides, fungicides, etc. to ensure high-yield and marketable quality produce. It is necessary to maintain the soil's nutrient level to harvest good yields and to secure food and nutrition availability for the growing global population. Mineral nutrition to plants through inorganic fertilizer has enhanced yield by more than 50% in the 20th century (Krasilnikov *et al*., 2022). However, it has long-term negative consequences on soil, aquatic life, the environment and human health. The excessive use of inorganic fertilizers has adverse effects on soil health viz., depletion of microbial diversity, degradation of soil structure, nutrient imbalance, etc. Due to their high solubility, the inorganic fertilizers are susceptible to leaching and contaminating groundwater. Especially nitrate leaching has caused the contamination of drinking water which has adverse effects on human health, particularly infants and pregnant women. Excessive use of fertilizers also results in heavy metal accumulation and eutrophication in water bodies severely affecting aquatic life (Jote, 2023). Further, the volatility of nitrogenous fertilizers contributes to the greenhouse effect and increases respiratory problems. To meet the global demand for fertilizers, the fertilizer-producing industries also contribute to environmental pollution and fossil fuel depletion.

Considering the adverse impact of enhancing crop productivity through the chemical approach, various authors recommend the application of organic nutrient sources and biofertilizers. Krause *et al*. (2024) reported greater microbial biomass in the soil through biodynamic agricultural practices followed by bioorganic practices. Gamage *et al*. (2023) advocated for strategies to improve the efficacy of conventional agricultural practices and to restructure organic farming systems through integration with improved sludge, biochar, bio fertilizers, organ minerals and digital technology to improve the efficacy of organic farming. Giri and Pokhrel (2022) reviewed the role of organic farming in sustainable agriculture and reported the improvement in soil fertility and nutrient management through

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organic practices and environment-friendly practices. Combining conventional practices with organic agriculture can enhance the ecological balance and reduce agriculture's climate effects. However, the sustainability of organic farming in the long run has also been questioned in terms of soil nutrient management, productivity and economic viability. Reimer *et al*. (2023) elaborated on the pros and cons of the European Commission's target of raising the area of organic agriculture to 25% by 2030. As per the principle of organic agriculture, it is independent of the external supply of nutrients as synthetic nutrient sources. The soil fertility and biological activities can be maintained by crop rotation, application of farm yard manures and use of leguminous crops for biological nitrogen fixation. However, there is always a key concern regarding the economic viability of organic agricultural practices due to low yield and high operational costs (Riar *et al*., 2024). The concern of high operation cost can be minimized through reduced tillage intensity and a diversified crop rotation while the low gross returns due to low yield can be resolved by growing high value crops (Dayananda *et al*., 2021). Integrating different nutrient sources including biofertilizers and micronutrients with inorganic fertilizers can be an economically viable approach towards sustainable agriculture in terms of production, soil and environmental health and economic feasibility. The current study was designed to evaluate the viability of integrated nutrient management in brinjal for high yield and economic benefits to the farmers.

MATERIALS AND METHODS

The experiment was conducted at the Crop Research Center of ITM University, Gwalior, M.P. The field of research farm having homogenous fertility and uniform textural makeup was selected for the field experimentation. The total rainfall received during the crop season from November 2020 to April 2021 and November 2021 to April 2022 was 5 and 7 mm, respectively. The percentage of sand was more (59.6%) than other fractions viz., clay (22%) and silt (18.4%) so the soil was categorized as sandy clay loam with low aggregation. The soil bulk density was 1.32 and 1.35 g/cm^3, particle density was 2.50 and 2.53 g/cm^3 and porosity was 48.1 and 48.5%. The chemical composition of the experimental field soil during two consecutive years of work, collected from 0-15 cm depth, exhibited that the soil of the experimental field was rich in potash content (240.50 and 230.60 kg/ha), but low in organic carbon (0.40 and 0.44%), available nitrogen (168.50 and 160.50 kg/ha) and medium in available phosphorus (14.2 and 15.2 kg/ha). It was slightly alkaline in reaction and had moderate cation exchange capacity (16.19 and 16.21) with saline pH (7.50 and 7.64) and electrical conductivity (0.40 and 0.42 dS/m at 25^{o}C).

The experiment was laid out in a factorial randomized block design with three replications and two factors; factor F as combinations of inorganic and biofertilizers sources of nutrients at four levels (F_0: 100% RDF, F_1: 75% RDN+100% RDP+100% RDK+N-fixer, F_2: 100% RDN+75% RDP+100% RDK+P-solubilizer, and F_3: 75% RDN+75% RDP+100% RDK+N-fixer+P-solubilizer) and factor M as foliar spray of micronutrients (M_0: Control, M_1: $ZnSO_4$ (0.5%), M_2: Borax (0.2%) and M_3: $ZnSO_4$ (0.5%)+Borax (0.2%)). The recommended dose of fertilizer (RDF) was 150: 50: 50 kg of NPK/ha. *Azotobacter chroococcum* was used as N-fixer, while *Aspergillus niger* was used as P-solubilizer. The allocations of treatments to different plots were done randomly in a given replication.

The field was prepared with a moldboard plow by two cross harrowing with the tractor to obtain a well-pulverized condition. After this, the field was divided into three replications. In each replication, 16 plots equal to the number of treatments were made, each of size 22.68 m^2 (5.40 x 4.20 m).

The total weight of brinjal fruits harvested at every picking was recorded and divided by the total number of fruits of all the harvests to compute the mean fruit weight in grams.The number of fruits was counted during each picking and the average was expressed as the number of fruits per plant. The total weight of all fruits harvested at every picking was recorded and divided by the total number of plants of all the harvests to compute the mean fruit yield per plant in grams. The total weight of all fruits harvested at every picking was recorded from each plot and was expressed as kg per plot. The total yield per plot was used to estimate the yield per hectare.

The cost of cultivation for each treatment was determined based on different inputs used for raising the crop under different treatments for one hectare area. The variable cost of all the inputs viz., labour, seed, manures, fertilizers, pesticides and irrigation charges and the fixed costs as rent, depreciation, etc. were considered while estimating the cost of cultivation. Gross returns were the total monetary value of economic produce and by-products obtained from the crop raised in the different treatments and were estimated based on the local market prices of the produce. Net monetary returns (Rs/ha) were computed by subtracting the cost of cultivation from gross returns. It is a good indicator of the suitability of a cropping system since this represents the actual income of the farmer.

Net monetary returns (Rs./ha) = Gross returns (Rs./ha) – Total cost of cultivation (Rs./ha)

The B:C ratio is the ratio of net returns to the cost of cultivation. It is expressed as returns per rupee invested.

$$\text{B: C ratio} = \frac{\text{Net monetary returns (Rs/ha)}}{\text{Total cost of cultivation (Rs/ha)}}$$

The data obtained on various parameters during 2021-22 and 2022-23 were tabulated and the pooled data were subjected to statistical analysis using OPSTAT software. The hypotheses about each treatment effect were tested using F-statistics at a 5% significance level. The resource use efficiency for the cultivation of brinjal crops was analyzed using the Cobb-Douglas production function. The correlation analysis, regression coefficient analysis, significance and coefficient of multiple determinations (R^2) were estimated to analyze the resource use efficiency for each input.

RESULTS AND DISCUSSION

Though the interaction effect was not significant, the impact of both factors was substantial on the number of fruits per plant in brinjal after applying fertilizer biofertilizer combinations and micronutrients (Table 1). The highest number of fruits per plant (8.471) was noted in F_1 followed by F_3 and F_2, while the minimum (7.719) was in F_0 (control). The maximum number of fruits per plant was recorded in micronutrient level M_3 (8.828) followed by micronutrient levels M_2 and M_1,

Table 1. Effect of NPK sources and micronutrient application on number of fruits and fruit yield/plant

Factors	Number of fruits/plant				
	M_0	M_1	M_2	M_3	Mean (F)
F_0	6.027	7.893	8.240	8.717	7.719[B]
F_1	7.567	8.543	8.407	9.367	8.471[A]
F_2	6.943	7.800	8.040	8.443	7.807[B]
F_3	7.700	8.643	8.557	8.783	8.421[A]
Mean (M)	7.059[C]	8.220[B]	8.311[A]	8.828[A]	
Factors	C.D.	SE(d)±	SE(m)±	P-value	
Factor (F)	0.538	0.262	0.186	0.0095	
Factor (M)	0.538	0.262	0.186	< 0.01	
Factor (F X M)	NS	0.525	0.371	0.594	
Factors	**Fruit yield per plant (g per plant)**				
	M_0	M_1	M_2	M_3	Mean (F)
F_0	694.63[e]	1047.87[c]	1057.41[c]	1453.31[ab]	1063.31[D]
F_1	1105.56[c]	1331.48[b]	1392.78[b]	1551.76[a]	1345.39[A]
F_2	888.15[d]	1162.78[c]	1084.44[c]	1517.59[a]	1163.24[B]
F_3	859.08[d]	1291.85[b]	1309.35[b]	1514.81[a]	1243.77[B]
Mean (M)	886.85[C]	1208.49[B]	1211.00[B]	1509.37[A]	
Factors	C.D.	SE(d)±	SE(m)±	P-value	
Factor (F)	57.83	28.18	19.93	< 0.01	
Factor (M)	57.83	28.18	19.93	< 0.01	
Factor (F X M)	115.65	56.36	39.85	< 0.01	

Where F_0: RDF (150:50:50 Kg NPK /ha), F_1: N as 75% of RDF + P and K as RDF + *A.r chroococcum* (N- fixer), F_3: P as 75% of RDF + N and K as RDF + *A. niger* (P-solubilizer), F_3: N and P as 75% of RDF + K as RDF + N-fixer + P-solubilizer; M: Micronutrients levels [M_0: control, M_1: $ZnSO_4$ (0.5%), M_2: borax (0.2%), M_3: $ZnSO_4$ (0.5%) + borax (0.2%); RDF recommended dose of fertilizers.

while the minimum (7.059) in M_0. The interaction between various levels of fertilizers and micronutrient levels did not show any statistical difference. The average fruit yield per plant was also influenced by both the factors as well as interactions (Table 1) and the highest fruit yield per plant (1345.39 g) was noted in F_1 followed by F_3 and F_2, while the minimum (1063.31 g) in F_0 (control). The maximum fruit yield per plant was recorded in micronutrient level M_3 (1509.37 g) followed by micronutrient levels M_2 and M_1, while the minimum (886.85 g) was in M_0. The interaction effect reflected the highest in treatment combination F_1M_3 (1551.76 g) followed by the other combinations, while minimum in M_0F_0.

The fruiting parameter was significantly influenced by different levels of fertilizers and the maximum number of fruits and the fruit yield per plant after application of nitrogen as 75% of RDF in combination with *A. chroococcum* as N-fixer could be associated with balance fertilization at reduced inorganic form of nitrogen and the continuous supply of nitrogen. This might be due to nitrogen as an important component for plant metabolisms like synthesis of the DNA, RNA, ribosomes, new tissues, amino acids and proteins. Nitrogen is important for synthesizing chlorophyll porphyrin rings (Padhiary and Dubey, 2020). Further, the plants receiving nitrogen and phosphorus as 75% of RDF in combination with *A. chroococcum* as N-fixer, while *A. niger* as P-solubilizer as well as the treatments receiving phosphorus as 75% of RDF in combination with *A. niger* as P-solubilizer were also at par in the performance. The current finding confirms the requirement that the integrated application of biofertilizers as N-fixers and P-solubilizers with reduced doses of nitrogen and phosphorus has a positive effect on the yield of brinjal. Application of N-fixers and P-solubilizers microbial formulation could be responsible for the continuous supply of nutrients at various growth and development stages of brinjal plants, supply of plant growth-promoting substances like auxins, cytokinins and gibberellic acid which could have improved the availability of photo assimilates (Singh *et al*., 2020; Rathore *et al*., 2023). The application of micronutrients such as $ZnSO_4$ and borax are involved in many of the metabolic processes viz., cell division, photosynthesis, protein synthesis and expansion of shoot and root growth in plants, and have an active role during vegetative growth and crop productivity. These micronutrients are responsible for increased nutrient use efficiency which could be the reason behind the increased yield of brinjal per plant in terms of the number of fruits and fruit weight (Saha *et al*., 2023).

The effect of both factors as well as the interaction effect on the brinjal fruit yield per unit area was substantial after the application of fertilizer biofertilizer combinations and micronutrients (Table 2). The maximum fruit yield per plot (41.69 kg) was noted in F_1 followed by F_3 and F_2, while the minimum (33.81 kg) was in F_0 (control). Further, the maximum fruit yield per plot was recorded in levels M_3 (47.22 kg/plot) followed by micronutrient levels M_2 and M_1, while the minimum (27.41 kg/plot) in M_0. The maximum fruit yield per plot was highest in treatment combination F_1M_3 (48.09 kg) followed by the rest of the combinations, while the minimum was in M_0F_0. The maximum fruit yield per hectare (33.09 t) was noted in F_1 followed by F_3 and F_2, while the minimum (26.83 t) was in F_0 (control). Further, maximum fruit yield per hectare was recorded in micronutrient levels M_3 (38.17 t) followed by micronutrient levels M_2 and M_1, while minimum (21.75 t) in M_0. The maximum fruit yield per hectare was observed in treatment combination F_2M_3 (40.43 t) followed by rest of the combinations, while minimum in M_0F_0.

The maximum fruit yield per unit area was noted after the incorporation of *A. chroococcum* as N-fixer with nitrogen as 75% of RDF or in combination with phosphorus as 75% of RDF and *A. niger* as P-solubilizer (Paswan *et al.*, 2022). This might be responsible for improving soil health in the rhizosphere resulting in better mobilization and uptake of nutrients by the plants ensuring enhanced synthesis of carbohydrates and proteins which could have translocated to the storage tissues (fruits) (Devi *et al*., 2022). The synthesis of all essential amino acids was possible in this condition only because the *Azotobacter* produced plant growth-promoting substances and that is responsible for the highest yield. The N-fixer and P-solubilizer are siderophore-secreting microorganisms that make Fe^{2+} ions available to the plants which could be responsible for active uptake and utilization during photosynthesis ensuring a greater level of carbohydrates in leaves as well as in fruits (Timofeeva *et al*., 2023). The micronutrients

Table 2. Effect of NPK sources and micronutrient application on fruit yield per plot and per ha

Factors	Fruit yield/plot (kg/plot)				
	M_0	M_1	M_2	M_3	Mean (F)
F_0	20.93^{f}	33.77^{d}	35.64^{d}	44.88^{b}	33.81^{C}
F_1	34.35^{d}	40.84^{c}	43.31^{b}	48.27^{a}	41.69^{A}
F_2	27.01^{e}	35.18^{d}	36.68^{d}	47.44^{ab}	36.58^{C}
F_3	27.35^{e}	39.11^{cd}	39.84^{c}	48.29^{a}	38.65^{B}
Mean (M)	27.41^{D}	37.23^{B}	38.87^{B}	47.22^{A}	
Factors	C. D.	SE(d)±	SE(m)±	P-value	
Factor (F)	1.47	0.71	0.51	< 0.01	
Factor (M)	1.47	0.71	0.51	< 0.01	
Factor (F × M)	2.93	1.43	1.01	< 0.01	

Factors	Yield/ha (t/ha)				
	M_0	M_1	M_2	M_3	Mean (F)
F_0	16.61^{f}	26.80^{d}	28.28^{d}	35.61^{b}	26.83^{C}
F_1	27.26^{d}	32.43^{c}	34.37^{bc}	38.31^{a}	33.09^{A}
F_2	21.44^{e}	27.92^{d}	29.11^{d}	40.43^{a}	29.73^{B}
F_3	21.71^{e}	31.04^{cd}	31.61^{c}	38.32^{a}	30.67^{B}
Mean (M)	21.75^{D}	29.55^{C}	30.85^{B}	38.17^{A}	
Factors	C. D.	SE(d)±	SE(m)±	P-value	
Factor (F)	1.19	0.58	0.41	< 0.01	
Factor (M)	1.19	0.58	0.41	< 0.01	
Factor (F × M)	2.39	1.16	0.82	< 0.01	

Where, F_0: RDF (150:50:50 kg NPK/ha), F_1: N as 75% of RDF+P and K as RDF+*A.r chroococcum* (N-fixer), F_2: P as 75% of RDF+N and K as RDF+*A. niger* (P-solubilizer), F_3: N and P as 75% of RDF + K as RDF+N- fixer+P-solubilizer, M: Micronutrients levels [M_0: Control, M_1: $ZnSO_4$ (0.5%), M_2: borax (0.2%), M_3: $ZnSO_4$ (0.5%)+borax (0.2%), RDF-Recommended dose of fertilizers.

are involved in many of the metabolic processes viz., cell division, photosynthesis, protein synthesis and expansion of shoot and root growth in plants, and have an active role during vegetative growth. The accumulation of total photosynthates in leaves is translocated by boron from sink to source like leaves to fruits. Further, foliar application of micronutrients (Zn and B) could be associated with the various metabolic processes viz., cell division, photosynthesis, protein synthesis and expansion of shoot and root growth in plants which is responsible for the regulation of the uptake of nutrients by the plants resulting in increased plant growth and biomass or dry matter production suggesting the enhanced photosynthetic process and carbohydrate accumulation (Vera-Maldonado *et al.*, 2024). Zinc is involved in Zn-dependent signalling which regulates gene expression, cell division and plant-stimuli interactions required for photosynthesis and protein synthesis. Further, boron interaction with other macro and micro-elements can improve cellular metabolism and the ability to resist biotic and abiotic stresses resulting in enhanced photosynthetic activities and crop yield (Long and Peng, 2023).

The calculation of the cost of cultivation of brinjal under different treatments ranged from Rs. 71178.00 to 81960.00 depending on all the expenditures spent during the experiment including fixed cost and variable costs (Table 3). The variation in the cost of cultivation might be due to variations in nutrient sources as per the treatments. The selling of fruit after harvesting was calculated as a gross return. The highest gross returns (Rs. 323440.00) and net returns (Rs. 241480.00) were mathematically calculated in the treatment F_2M_3 as compared to rest of the treatments. Concerning the benefit: cost ratio, the highest value (2.94) was found in treatment F_2M_3, and the minimum benefit: cost ratio (0.86) was calculated in treatment F_0M_0.

The variation in treatments might be responsible factors for significant variability in yield and production cost of brinjal which could be accountable for variation in benefit: cost ratio. The present finding confirms the suitability of integrated nutrient management practices including the use of biofertilizers and micronutrients for farmers with medium and large farm holdings (Sharma and Singh, 2020; Shedge *et al.*, 2021). The substantial increase in the B:C ratio in the current study is associated with good yield and quality produce due to the supply of balanced nutrients through integrated nutrient management. The quality produce can get premium prices resulting in high gross returns and so a good profit for the producer (Reddy *et al.*, 2022).

The production functions were analyzed using Cobb-Douglas model and it was observed that

Table 3. Effect of NPK sources and micronutrient application on economics

Factor (F)	Factor (M)	Fruit yield (t/ha)	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	Benefit: cost ratio
F_0	M_0	16.61	71178	132880	61702	0.86
	M_1	26.80	76178	214400	138222	1.81
	M_2	28.28	75178	226240	151062	2.00
	M_3	35.61	80177	284880	204703	2.55
F_1	M_0	27.26	72358	218080	145722	2.01
	M_1	32.43	77358	259440	182082	2.35
	M_2	34.37	72758	274960	202202	2.78
	M_3	38.31	81358	306480	225122	2.76
F_2	M_0	21.44	72358	171520	99162	1.37
	M_1	27.92	77958	223360	145402	1.86
	M_2	29.11	75958	232880	156922	2.06
	M_3	40.43	81960	323440	241480	2.94
F_3	M_0	21.71	72558	173680	101122	1.39
	M_1	31.04	76958	248320	171362	2.22
	M_2	31.61	75958	252880	176922	2.32
	M_3	38.32	80958	306560	225602	2.79

Where, F_0: RDF (150:50:50 kg NPK/ha), F_1: N as 75% of RDF+P and K as RDF+*A.r chroococcum* (N-fixer), F_2: P as 75% of RDF+N and K as RDF+*A. niger* (P-solubilizer), F_3: N and P as 75% of RDF+K as RDF+N-fixer+P-solubilizer; M: Micronutrients levels [M_0: Control, M_1: $ZnSO_4$ (0.5%), M_2: borax (0.2%), M_3: $ZnSO_4$ (0.5%)+borax (0.2%) and RDF: Recommended dose of fertilizers.

this model was fit for the current study due to the high value of R^2 (0.875) which showed that 87.5% of the variation in yield was substantially explained by the variables under study (Table 4). Among these input variables, nitrogen, phosphorus, potassium, biofertilizers, micronutrients and the number of irrigations were statistically significant which confirm the efficient resource utilization due to the application of biofertilizers and micronutrients (Table 5). The correlation study of the different variables indicated that all parameters had substantially affected the B:C ratio of the brinjal cultivation. The parameters like fruit yield per plant (g per plant), fruit yield per plot (kg per plot), fruit yield (t/ha), gross returns (Rs./ha) and net returns (Rs./ha) had strongly influenced the benefit:cost ratio.

Table 5. Correlation of B:C ratio with other variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	1.00							
X_2	0.89	1.00						
X_3	0.91	0.99	1.00					
X_4	0.89	0.98	1.00	1.00				
X_5	0.75	0.82	0.83	0.84	1.00			
X_6	0.89	0.98	1.00	1.00	0.84	1.00		
X_7	0.89	0.98	1.00	1.00	0.83	1.00	1.00	
X_8	0.89	0.97	0.99	0.99	0.74	0.99	0.99	1.00

Where, X_1: Number of fruits/plant, X_2: Fruit yield/plant (g/plant), X_3: Fruit yield/plot (kg/plot), X_4: Fruit yield (t/ha), X_5: Cost of cultivation (Rs./ha), X_6: Gross returns (Rs./ha), X_7: Net returns (Rs./ha) and X_8: Benefit:cost ratio.

CONCLUSION

The current study revealed that application of 75% RDN+P and K as RDF+N-Fixer (*Azotobacter chroococcum*) and 75% RDN, 75% RDP+K as

Table 4. Regression coefficient of different production functions and their significance in cultivation of brinjal

Variables	Regression coefficient	Standard error	t-value	R^2
Seed (g)	0.412	0.057	1.13	0.875
Nitrogen (kg)	0.143*	0.038	0.15	
Phosphorus (kg)	0.324*	0.152	1.05	
Potassium (kg)	0.286*	0.074	2.23	
Biofertilizers (kg)	0.323*	0.216	2.43	
Micronutrients (g)	0.432*	0.182	1.72	
Labour requirement (No. of man days)	0.316	0.182	1.53	
Tractors (h)	-0.143	0.403	-0.537	
Irrigations (No.)	0.175*	0.307	2.435	
Insecticide sprays (No.)	0.23	0.106	1.502	
Weeding (No.)	0.362	0.043	1.36	

*Significant at 5% level of significance.

RDF+N-Fixer (*A. chroococcum*), P-solubilizer (*Aspergillus niger*) was most economically viable treatment when applied in combination with $ZnSO_4$ (0.5%) and borax (0.2%). These treatments resulted in higher yield of brinjal in terms of number of fruits per plant, fruit yield per plant, fruit yield per hectare, gross returns, net income and the B:C ratio.

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