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Integrated nutrient management for sustainable cultivation of okra (*Abelmoschus esculentus* L.) in northern Ganges River floodplain soils of Bangladesh

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ABSTRACT

Diminution of land and a decline in soil health with fertility due to intensive agricultural practices are the limiting factors for sub-tropical agriculture. Therefore, Integrated Nutrient Management (INM) is an option to fight against traditional farming practices by improving crop yields and managing soil fertility status for long-term sustainability through the combined and careful use of all possible sources of plant nutrients. This study, aimed to investigate the effects of INM tactics to maximize the vegetative and reproductive qualities of Okra under sub-tropical conditions. The entire study was performed in a pot experiment where replications were thrice with 12 INM treatments arranged in a completely randomized design. The results of our investigation revealed that combined application of inorganic fertilizer (75% recommended doses of NPK fertilizer) and 25% organic fertilizer (Compost + Vermicompost + Trichocompost). T_9 significantly enhanced the growth of okra plants at different stages as expressed in terms of numbers of flowers, fruits, average fruit weight, 100 seed weight and yield plant^{-1}. We also tested the physiochemical properties of the soil before planting and after the harvesting period. Profitability analysis was performed considering only the variable production costs. Our results suggest that the judicious combination of organic and synthetic fertilizers was more sustainable and productive than other studied treatments.

Keywords: integrated nutrient management, compost, vermicompost, trichocompost, profitability, sustainability

INTRODUCTION

The negative effects of environmental change can be managed by the appropriation of climate-smart agriculture. The adaptive smart agricultural approach can improve the productivity and profitability of farmers (FAO, 2016). In Bangladesh, socio-economic development and rural livelihood are becoming complex due to insecurity of food. Many factors such as climate change, depletion of soil organic matter, and decreased soil quality (soil fertility and crop productivity) have been regarded as the key concern for the agricultural sector to satisfy the demand of densely populated nations like Bangladesh. The Integrated Nutrient Management (INM) process visualizes the use of organic manures with chemical fertilizers (Sohel *et al.,* 2021). Hence, Nutrient supply from both organic and inorganic sources is important for crop yield and quality (Olaniyi *et al.,* 2010). "The INM helps to restore and sustain soil fertility and crop productivity" (Sachan *et al.,* 2017; Wagh *et al.,* 2014). Besides chemical fertilizers, the use of organic fertilizers like compost, vermicompost, rich compost helps to improve soil health and in turn, enhances the yield per unit of nutrient applied and thereby saving energy (Sohel and Ghosh, 2021; Kumar *et al.,* 2017; Sanwal *et al.,* 2007). Nath *et al.,* (2011) and Naidu *et al.,* (2002) suggested that sustainable and eco-friendly agriculture, which minimizes the use of harmful energy-intensive inputs is achievable through the use of organic and biofertilizers. Thus, INM involves chemical fertilizers along with organic manure, compost, and vermicompost are quite imperative for the maintenance of long-term soil health and productivity of crops (Sohel *et al.,* 2021; Bairwa *et al.*, 2013; Behera *et al.,* 2007). Nutrient use efficiency and soil fertility status may be accelerated due to the use of integrated nutrient sources which also helps to increase productivity and product quality simultaneously (Mondal *et al.,* 2016; Singh *et al.,* 2004; Nanjappa *et al.,* 2001). However, the most suitable combination of chemical fertilizers, organic manures, and biofertilizers for okra cultivation can enhance the growth and yield of studied crops (Wagh *et al.,* 2014; Haque *et al.,* 2012; El-Kader, 2010). Considering these contemporary researches, the current study was designed to screen out a suitable combination of chemical fertilizers and organic manures for sustainable okra cultivation in the northern Ganges floodplain soils of Bangladesh. The findings of our study may act as a guide for the management of soil health as well as for maintaining the optimum growth of okra without any yield penalty.

MATERIALS AND METHODS

The field laboratory of EXIM Bank Agricultural University Bangladesh was the experimental site for conducting the study. The geographical position of the study area was placed between the latitude 24'22 to 24'57 and longitude 87'23 to 88'23 (Wikipedia). The study site was dominated by sub-tropical climates and situated in the northwestern part of Bangladesh. The dry weather with moderate rainfalls was the predominant climatic feature of the study site. Generally, Chapainawabganj is dominated by the tropical wet and dry climate. The monsoon high temperature with high humidity and moderate rainfall is the predominant feature of the climate of Nawabganj. However, our studied okra plant was tolerant to moderately high temperatures (26.3^{0}C to 29.2^{0}C). The month with the highest relative humidity was June (79.50%). The month with the lowest relative humidity was February (37.40%).

Table 1. The treatments applied in the experiment

T_1 = Control (without fertilizer)	T_7 = Trichocompost + 75% RFD
T_2=100% Recommended Fertilizer Dose (RFD)	T_8 = Trichocompost + 100% RFD
T_3 = Compost + 75% RFD	T_9 = Compost + Vermicompost + Trichocompost + 75% RFD
T_4 = Compost + 100% RFD	T_{10} = Compost + Vermicompost + Trichocompost + 100% RFD
T_5 = Vermicompost + 75% RFD	T_{11} = Compost + Vermicompost + Trichocompost
T_6 = Vermicompost + 100% RFD	T_{12} = Farmer's practice

Management of field activities and plant protection

Suitable fertilizer doses were used followingthe Fertilizer Recommendation Guide (BARC, 2012). Proper Integrated Weed Management (IWM) was done to control the weed infestation in the pots. The modified and adapted weed control practice from the early

observation was scheduled in our present study according to Swanton and Murphy (1996).
The physical and yield parameters; plant height (cm), number of leaves, leaf length (cm), flower plant^{-1}, fruit plant^{-1}, average fruit length (cm), average fruit weight (g), 100 seed weight (g), yield plant^{-1} (g), yield (t ha^{-1}) was obtained during vegetative and reproductive stages, accordingly following the standard methods (Sayed *et al.,* 2020).The physical and chemical attributes of soil were tested in two different stages, 1. Before planting and 2 after the harvesting period of the crop the soil sample was collected from 0-15 cm depth of soil profile presented in Table 2 and Table 3. "The analysis of soil was accomplished following the standard analytical methods" (Page *et al*., 1982). The soil was collected from the 2 different AEZ (Agro-Ecological Zone) of the country: AEZ 10- Active Ganges Floodplain and AEZ 11- High Ganges River Floodplain for further testing. Net Returns (NR) were calculated by deducting the overall total variable cost (TVC) of cultivation from gross returns (GR) (NR = GR-TVC) (Parihar *et al.,* 2015; Das *et al.,* 2018). The benefit-cost ratio (BCR) is another fundamental indicator for measuring profitability. The equation used for calculating the benefit-cost ratio is BCR = GR/TVC."Mean comparisons between treatments were performed by the least significant difference (LSD) test. All statistical calculations were performed using the F-variance test, statistical significance was indicated at 1% & 5% level of probability" (SAS, 1993).

RESULTS AND DISCUSSION

Nutrient management practices demonstrated a significant effect on the fertility status of the test soil and a very significant effect on the soil's physical and chemical properties.

Table 2. Soil physical properties before planting and after harvesting of okra

Soil physical properties						
Treatments	Parameters	BD (g/cm^3)	PD (g/cm^3)	Porosity (%)	FC (%)	Texture
T_1	BP	1.50	2.00	24	29	Silty Clay Loam
	AH	1.75	1.90	26	27	
T_2	BP	1.45	2.20	38	33	
	AH	1.68	2.10	35	30	
T_3	BP	1.24	2.30	42	35	
	AH	1.55	2.10	36	29	
T_4	BP	1.59	1.90	39	32	
	AH	1.52	2.00	34	31	
T_5	BP	1.50	1.90	39	36	
	AH	1.52	2.00	33	34	
T_6	BP	1.55	1.98	29	28	
	AH	1.59	2.12	33	29	
T_7	BP	1.40	2.20	32	35	
	AH	1.55	2.18	35	28	
T_8	BP	1.18	2.40	40	36	
	AH	1.50	2.35	38	34	
T_9	BP	1.20	2.65	46	38	
	AH	1.00	2.75	48	40	
T_{10}	BP	1.50	2.50	40	35	
	AH	1.41	2.45	38	36	
T_{11}	BP	1.35	2.20	28	34	
	AH	1.32	2.30	29	33	
T_{12}	BP	1.56	1.88	29	25	
	AH	1.60	1.85	27	25	

Notes: *BD- Bulk Density; PD- Particle Density; FC- Field Capacity; BP-Before Planting; AH- After Harvesting.*

Soil physical properties like soil density, especially, the bulk density of surface soil decreased with the depth and organic matter present in soil and varied from 1.00 to 1.50 g/cm^3 in mineral soil. The highest bulk density (1.75 g/cm^3) was observed in T_1 (after harvesting) due to the compaction of the soil (Table 1) as compared to initial values (before planting) and the lowest bulk density was observed in T_9 due to high organic matter content of the soil. The highest field capacity (40 %) and porosity (48 %) were observed in T_9 and the lowest field capacity (25 %) and porosity (24 %) were found in T_{12} (Farmer's practice) and T_1 (control), respectively. The textural class of experimental soil was silty clay loam (Table 1). Similar findings were found in Sayed *et al.,* (2020).

Table 3. Soil chemical properties before planting and after harvesting of okra

Soil chemical properties										
Treatments	Parameters	Soil pH	OM (%)	EC (μs/m)	Available N (%)	K	P	S	B	Zn
						meq /100 ml			μg/g	
T_1	BP	6.50	0.30	126	0.08	0.04	04	10	0.02	0.60
	AH	6.40	0.20	116	0.05	0.03	02	08	0. 01	0.50
T_2	BP	6.50	0.80	135	0.30	0.16	10	25	0.10	1.80
	AH	6.20	0.65	129	0.12	0.10	09	25	0.10	1.65
T_3	BP	6.50	0.80	134	0.25	0.12	11	21	0.11	1.50
	AH	6.70	1.00	127	0.20	0.12	08	20	0.10	1.37
T_4	BP	6.50	1.20	133	0.21	0.13	15	19	0.11	1.90
	AH	6.60	1.20	127	0.10	0.12	12	14	0.10	1.70
T_5	BP	6.50	1.10	134	0.32	0.15	13	25	0.10	2.00
	AH	6.50	1.20	138	0.22	0.11	11	25	0.10	1.90
T_6	BP	6.50	1.50	135	0.33	0.14	12	23	0.09	2.20
	AH	6.60	1.60	135	0.17	0.13	10	19	0.07	2.00
T_7	BP	6.50	1.50	154	0.28	0.10	13	20	0.08	2.10
	AH	6.70	1.60	145	0.23	0.10	12	15	0.08	1.90
T_8	BP	6.50	1.45	139	0.20	0.12	13	24	0.10	2.25
	AH	6.40	1.50	132	0.12	0.12	11	22	0.10	2.20
T_9	BP	6.72	2.20	164	0.41	0.18	18	28	0.30	2.65
	AH	6.98	2.50	165	0.48	0.20	19	30	0.29	2.63
T_{10}	BP	6.50	2.20	135	0.40	0.12	14	25	0.21	2.60
	AH	6.76	2.20	132	0.20	0.12	16	25	0.10	2.70
T_{11}	BP	6.50	2.00	133	0.22	0.10	10	20	0.08	2.44
	AH	6.60	2.50	128	0.22	0.09	09	19	0.06	2.47
T_{12}	BP	6.50	0.70	120	0.12	0.05	07	18	0.04	1.00
	AH	6.30	0.60	111	0.12	0.05	06	12	0. 02	0.80
Critical level					0.12	0.20	14	14	0.20	2.0

Notes: *OM: Organic Matter, EC: Electrical Conductivity, BP: Before Planting, AH: After Harvesting*

The study demonstrated that chemical fertilizers along with organic manure and biofertilizer increased the soil pH cancelling the acidifying effect of chemicals in the soil (Table 2). Chemical fertilizers alone could not help much in improving the pH and fertility status of the experimental soil. Moreover, it marginally reduced the soil pH. After the end of the experiment, INM with compost + vermicompost + rich compost and chemical fertilizers significantly increased organic matter, available N, P, K, and S contents in soil over their initial values. The highest organic matter and available N, P, K, and S contents in soil were recorded from the pot having compost + vermicompost + rich compost and 75% chemical fertilizers (T_9) under the study. The electrical conductivity (EC), Zinc (Zn), and Boron (B) content before planting and after harvesting of soil were not significantly changed (Table 2).

Effect of treatment combinations on okra vegetative and reproductive growth

Vegetative parameters

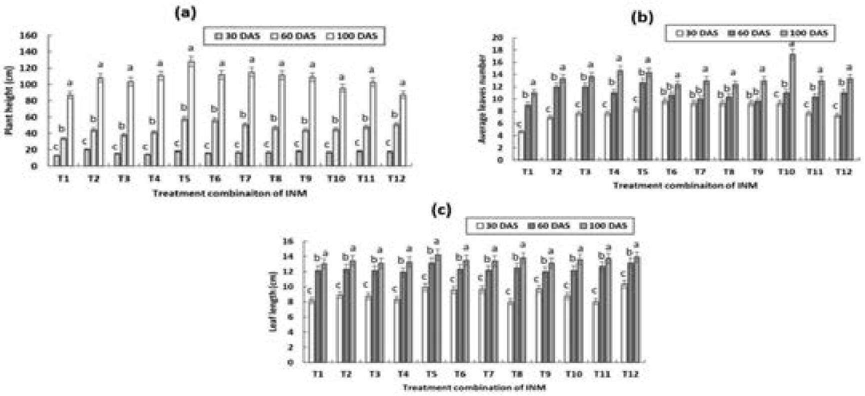

Figure 3. Effects of different treatment combinations of vegetative properties of okra a) plant height (cm) b) leaf number c) leaf length (cm). The lettering denotes the significance of the values at a 5% level of probability after Tukey's post hoc analysis among the treatments by DMRT test.

The vegetative parameters such as plant height, leaf length, and number of leaves were found significant at 30 DAS (Fig. 3). In those cases, the effect of chemical fertilizer on the plant height was found superior. The highest leaf length and number of leaves were observed in T_5 (vermicompost + 75% RFD) and T_6 (vermicompost + 100% RFD) treatment, respectively. In 60 DAS, the effect on plant height was found significant at a 1% probability level, on the other hand, the data for the leaf length and number of leaves were found significant at a 5% level of probability. In all the cases, vermicompost with 75% RFD was found superior. Our study results should correspond with the findings of Barani and Anburani (2004). The effect on leaf length was found statistically non-significant at 100 DAS but the data for the plant height and number of leaves were found significant at 5% and 1% probability level respectively. In these cases, the effect of vermicompost with 75% RFD on the plant height and leaf length was found superior whereas, compost, vermicompost, and trichocompost with 75% RFD produced the maximum number of leaves (Fig. 3). The use efficiency of inorganic fertilizers was also increased due to the controlled application of organic manures in the millet field of central Senegal (Tounkara *et al.,* 2020).

Plant height was documented at varying days after seeding (DAS) such as 30 DAS, 60 DAS, and 100 DAS. At 30 DAS, the height of the plant stood between 12.93 cm and 20.33 cm (Fig. 3a). The maximum height of the plant (20.33 cm) was determined from the T_2 treatment, and the minimal height of the plant was observed from T_1 (12.93 cm). The effect of chemical fertilizer on the plant height was found superior at 30 DAS. At 60 DAS, plant height varied from 33.67 cm to 58.07 cm.

The number of leaves/plants at different stages of growth showed significant variation with the different doses of manures and fertilizer used in the soil. At 30 DAS, the number of leaves plant^{-1} was found between 4.67 and 9.67. T_6 treatment showed the highest (9.67) number of leaves plant^{-1} at 30 DAS and the lowest (4.67) was in T_1 (control). At 60 DAS, it ranged from 9.00 to 12.67. The highest number of leaves (12.67) was recorded from T_5 and the lowest (9.00) was observed in T_1 (control). At 100 DAS, the maximum number (17.33) of leaves was recorded for the treatment of T_{10}, and the lowest 11.00 was found from T_1 (control) treatment (Fig. 3b).

The leaf length was significantly varied in different INM treatments. The maximum leaf length of 30 DAS (10.32 cm), 60 DAS (13.17 cm), and 100 DAS (14.22 cm) were recorded in the treatments T_{12}, $T_{12,}$ and T_5 respectively (Fig 3c). The minimum leaf length 30 DAS (8.000 cm), 60 DAS (11.92 cm), and 100 DAS (13.00 cm) were noted in the treatments T_8, T_4, and T_1 respectively (Fig. 3c)

Table 4. The reproductive parameters of the studied okra plant

Treatments	Number of flower plants^{-1}	Number of fruit plants^{-1}	Individual fruit length (cm)	Individual fruit wt. (gm)	100 seeds wt. (gm)	Yield plant^{-1} (gm)	Yield (t ha^{-1})
T_1	10.67	9.67	11.78	11.55	5.83	112.03	4. 67
T_2	29.00	27.33	11.85	13.68	5.73	373.63	15.57
T_3	27.67	27.33	11.54	13.15	5.38	359.73	14.99
T_4	26.00	25.67	11.70	13.19	5.69	339.83	14.16
T_5	20.00	19.33	13.30	15.30	5.88	297.68	12.40
T_6	25.67	24.00	11.59	13.08	5.32	313.84	13.08
T_7	21.67	21.00	11.06	13.78	5.14	290.78	12.12
T_8	19.00	19.00	11.13	12.72	5.81	228.96	10.54
T_9	30.00	29.33	12.15	14.78	5.89	388.38	16.18
T_{10}	24.00	23.67	10.56	11.46	5.31	271.69	11.32
T_{11}	26.67	26.33	10.45	13.24	4.75	348.82	14.53
T_{12}	20.33	19.67	11.63	12.11	5.64	239.34	9.97
LS	**	**	*	*	*	**	**
LSD at 5%	2.0057	3.2268	2.2055	2.4802	0.7120	69.727	69.727
CV	5.09	8.63	11.32	11.17	7.72	14.07	14.07

*DAS: Days After Sowing, LSD: Least Significant Difference, LS: Level of Significance, CV: Coefficient of Variation, NS: Non-Significant, * indicates 5% Level of Significance, ** indicates 1% Level of Significance.*

Vermicompost with 75% RFD was found superior in the case of individual fruit length and individual fruit weight (Sinha, 2009). But compost, vermicompost, and trichocompost with 75% RFD showed significantly better results in terms of the number of flowers, number of fruits, 100 seed weight, and yield. The data for the number of flowers, fruit, and yield was found statistically significant, whereas, the data for the individual fruit length, individual fruit weight, and 100 seeds weight was found non-significant (Table 4). The increase in yield of Okra was due to the combined application of organic manure and inorganic fertilizer is in line with the findings of Sanwal *et al.,* (2007) in turmeric, Patil *et al.,* (2004) in tomato, and Premsekhar and Rajashree, (2009) in Okra.

Assessment of yield and yield parameters

The number of fruits plant^{-1} also varied with different treatments. Fruits number varied from 9.67 to 29.33 with the highest number of fruits plant^{-1} (29.33) in T_9 and the lowest number of fruits plant^{-1} (9.67) in treatment $T_{1.}$ The effect of several fruits was found significant at the probability level of 1% (Table 4). Different treatments showed significant variation in the fruit length. The fruit length ranged from 10.45 cm to 13.30 cm. The highest fruit length (13.30 cm) was found in treatment T_5 (vermicompost + chemical fertilizer) and the lowest fruit length (10.45) was observed in treatment T_1 (control). The effect of fruit length was found significant at the 5% probability level (Table 3). The weight of the fruit varied significantly with different types of treatment techniques. The individual fruit weight was between 11.55 g and 14.78 g. The highest individual fruit weight (14.78 g) was found in treatment T_9 and the lowest value (11.55 g) was observed in treatment T_1. The effect of fruit length was found significant at the 5% probability level (Table 4).

The yield performance varied significantly in the dissimilar types of treatment. The cumulative yield ranged from 4.67 t/ha to 16.18 t/ha whereas the maximum yield (16.18 t/ha) was found in T_9 and the minimum yield (4. 67 t/ha) was observed in T_1 (control. The effect of yield performance of okra was significant at the probability level of 1% (Table 4). Our study result was also supported by the previous observations (Sachan *et al.,* 2017).

Economic analysis

Variable costs for production, Benefit Cost Ratio (BCR) of okra cultivation in the combined effect of different treatments. The cost currency is converted from BDT (Bangladeshi Taka) to USD ($) (1 BDT = 0.0125 $). The price of okra is $0.5/Kg. BCR is the ratio of variable costs and gross return.

Table 5. Costs in Treatment combination (USD), depending on the treatment applied

Cost items	Costs in Treatment combination (USD											
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Labors	270	295	275	269	270	277	275	273	275	273	278	209
Fuel	435	455	425	420	422	428	425	427	425	425	428	422
Manure	-	-	150	150	160	155	165	161	144	144	208	96
Urea	-	56.5	36.5	46.5	36.5	46.5	35.5	49	36.5	49.5	-	34
TSP	-	46	28	36	28	35	28	43	28	42	-	28
MP	-	60	34.5	44	34.5	44.5	34.5	47	34.5	46.5	-	31
Gypsum	-	23	08	12	08	13.5	09	9.92	12	16	-	11
Irrigation	260	285	242	238	242	245	242	239.32	242	243	277	240
Pesticide	225	195	165	166	165	156	163	160.77	167	175	173	195
TVC	1190	1415.5	1364	1381.5	1366	1400.5	1377	1410.1	1364	1414	1364	1267
GR	2335	7785	7495	7080	6200	6540	6060	5270	8090	5660	7265	4985
NR	1145	6369.5	6131	5698.5	4834	5139.5	4683	3859.9	6726	4246	5901	3718
BCR	1.96	5.50	5.49	5.12	4.54	4.67	4.40	3.74	5.93	4.00	5.32	3.93

Notes: TVC: Total Variable Costs, GR: Gross Return, NR: Net Return, BCR: Benefit Cost Ratio,BCR = GR/TVC

CONCLUSIONS

This study explains that inorganic and organic fertilizer combinations are higher in almost all vegetative and reproductive parameters of okra. The combination of 75% recommended inorganic fertilizers and 25% organic manures derived from compost, vermicompost, and trichocompost exhibited the best beneficial performance in terms of soil physiochemical, economical, and production perspectives during okra cultivation. Blended applications of organic and inorganic nutrient sources are more productive and support soil fertility. Further multi-site and multi-trial research should be carried out to suggest the most appropriate combinations of inorganic and organic fertilizers for maximum benefit. Therefore, integrated nutrient management can be employed as an economically viable technique for the governance of sustainable farming.

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