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Fertilizer recommendation for puddling garlic cultivation: An approach to optimize fertilizer use and enhance sustainable yield and income

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ABSTRACT

The experiment was implemented in the farmers' field of Shibpur, Puthia, Rajshahi during three consecutive years at rabi season (October-March) of 2017-18, 2018-19 and 2019-20 to find out a suitable combination of different fertilizers for puddling garlic production. The experiment was laid out with six dispersed replications and four fertilizer doses *viz.* T1 = Soil test based (STB) fertilizer dose for high yield goal, T2 = 20% higher NPK than STB, T3 = 40% higher NPK than STB supplemented with 5 t ha^{-1} cowdung and T4 = Farmers dose. Three tones per hectare of rice straw was used as mulch with all the fertilize doses. Garlic variety BARI Rasun – 2 was used as test crop. Among the treatments, the highest average yield was obtained from T3 = 40 % higher NPK than STB (9.57 t ha^{-1}) which was similar to T4 = Farmers practice (9.52 t ha^{-1}). Nutrient addition was very much unbalanced in T4. Maximum gross return (574200 Tk ha^{-1}), net return (328465Tk ha^{-1}) and BCR (2.34) were found in T3 treatment. The treatment T3 produced the lowest break-even price (25.68 Tk kg^{-1}) and the highest sustainability index (85.5%). Considering all these facts, the treatment T3 (40% higher NPK than STB = 220-18-84-34-2.5-3 kg ha^{-1} NPKSZnB, respectively) may be recommended for puddling garlic cultivation in High Ganges River Floodplain Agro-ecological zone (AEZ-11) in Bangladesh.

Keywords: Garlic, puddling, fertilizer, yield, net return, sustainability

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1 Introduction

Garlic (*Allium sativum* L) is an aromatic annual spice crop belongs to the family Alliaceae. It is the second most extensively cultivated bulb crops after onion in world (Bozzini, 1991). The garlic bulb consists of numerous cloves enclosed with dry papery leaf sheaths and best grown in dry and mild winter (Brewster, 2008). A fresh bulb is a good source of carbohydrates, Vitamin C, Selenium, Manganese and Phosphorus comprises about 62.8% moisture, 6.3% protein, 0.1% fat, 0.8% fiber (Pamplona-Roger, 2001). Garlic is a popular spices crop and used in different foodstuffs in Bangladesh. The area, production and annual demand of garlic was about 71255 hectares, 462000 metric tons and 1.1-1.2 million metric tons in the year of 2017-18 in Bangladesh (BBS, 2018), respectively. Continuous cropping without the appropriate use of fertilizers cause intensely reduction in crop yield, hence the major nutrients particularly nitrogen, phosphorus and potash must be provided through fertilizer application for increasing the garlic growth and yield (Abbas et al., 2006). Nitrogen is a main component of pro-

teins part of chlorophyll and nucleic acid molecules. Phosphorus is vital component of phospholipids, nucleic acids, and many enzymes. It is also essential for the transfer of energy in the plant body and is positive role in its various metabolic activities. Phosphorus has its valuable consequence on early plant growth, root development, quality and yield (Verma, 1993). Inadequate phosphorus in bulb crops reduced leaf growth, root growth, delayed maturation, bulb size and yield (Greenwood, 2001). Potassium plays a dynamic role in photosynthesis, regulation of plant pores, translocation of photosynthates, activation of plant catalyst and increase resistance against diseases and pests in plant. Colour, dry matter accumulation, shininess and storage quality of the crop were improved by potassium (Domis et al., 2002). Garlic is generally cultivated with conventional land preparation and zero tillage (dibbling with the wet soil) with straw mulch methods in low lying areas after harvest of broadcasting/transplanting Aman rice. Another method, puddling (ploughing followed by irrigation) with straw mulch is getting acceptances due to its higher yield over conventional method (Kabir et al., 2016). In Bangladesh, crop competition for land is higher in winter and puddling is the opportunity to increase total production without increasing the area of garlic. Soil degradation is common in Bangladesh caused mainly by imbalanced use of fertilizer (BRAC, 2018), cultivation of modern varieties and increasing cropping intensity (Jahan and Gurung, 2017). Garlic is produced as cash crop and there is no fertilizer recommendation for puddling method and the use of imbalanced fertilizer reduces the garlic yield and degrading soil health and quality. Neither fertilizer nor manure alone can guarantee sustainable crop productivity, their integration is important to achieve sustainable crop yield without reducing soil fertility. Therefore, this trial was undertaken to determine optimum dose of fertilizers for sustainable garlic production at puddling condition in Bangladesh.

2 Materials and Methods

2.1 Study site

The experiment was conducted during the winter season of 2017-18, 2018-19 and 2019-20 at farmer's field of Shibpur, Puthia, Rajshahi to determine optimum dose of fertilizers for sustainable garlic production at puddling condition in Bangladesh. It belongs to the High Ganges River Floodplain Agro-ecological Zone of Bangladesh (AEZ-11). The site is located at 24°22′59.4″ N, 88°46′4.4″ E. The altitude of the study area is 20 m from sea level. The sub-tropical monsoon and uneven (unimodal) rainfall around year is the climatic characteristics of the experimental site. The most of the rainfall was concentrated during the months of May to September and rest of the months received very less rainfall. The total rainfall of the consecutive three years (November to March) was 46 mm, 132.2 mm and 50.1 mm, respectively and mean monthly minimum and maximum temperature decreased up to January and then increased in every crop season (Fig. 1). The soil samples were collected initial from experimental field and analyzed following standard laboratory processes and are compiled in Table 1. The experimental soil was silty loam and slightly alkaline (8.42) having low organic matter (1.72%). The soil contained 0.08% total N (very low), 24.12 ppm available P (optimum), 0.166 meq (%) exchangeable K (low), 15.47 ppm available S (low), 0.20 ppm available B (low) and 0.70 ppm available Zn (low).

2.2 Experimental details

The rates of the fertilizers requirements for different treatments were computed using soil test values based (STB) for high yield goal following Fertilizer Recommendation Guide (FRG, 2012). There were four fertilizer treatments *viz*. T1 = STB fertilizer dose for high yield goal, T2 = 20% higher NPK than STB, T3 = 40% higher NPK than STB and T4 = Farmers dose (Average of 25 farmers') were presented in Table 2. The experiment was laid out in Randomized Complete Block Design with six dispersed replications. Unit plot size was 8 m $\times$ 5 m. The land was puddled well (2 ploughing followed by irrigation) and seed cloves were dibbling at a spacing of 10 cm $\times$ 10 cm on 14 November 2017, 7 November 2018 and on 8 November 2019, respectively. The garlic variety was BARI Rashun-2 and the seed rate was 800 kg ha^{-1}. Straw mulch @ 3000 kg ha^{-1} was used after dibbling of cloves. All fertilizers with carbofuran @ 15 kg ha^{-1} were applied as basal during puddling except urea. Urea was top dressed at 25, 40 and 60 days after planting of cloves. Land was irrigated six times in which two times during puddling and four times after planting. The crop was spot weeded one time. Emidachloprid (Emitaf) @ 0.5 mL L^{-1} water and Rovral (Epridion) @ 2 g L^{-1} of water were applied four times for controlling insects and disease, respectively. The bulbs were harvested on 01 April 2018, 22 March 2019 and 20 March 2020. Harvesting was done at almost 70% of the leaves senesced or dried; garlic was harvested by hand pulling of individual plants (bulbs). The harvested bulbs were cured for a week in a shade at ambient condition.

2.3 Statistical analysis

The collected data were statistically analyzed for analysis of variance (ANOVA) by using MSTAT-C computer software. Analysis of variance techniques were used to test the overall significance of the data. The least significant difference (LSD) test ($P \leq 0.05$) was

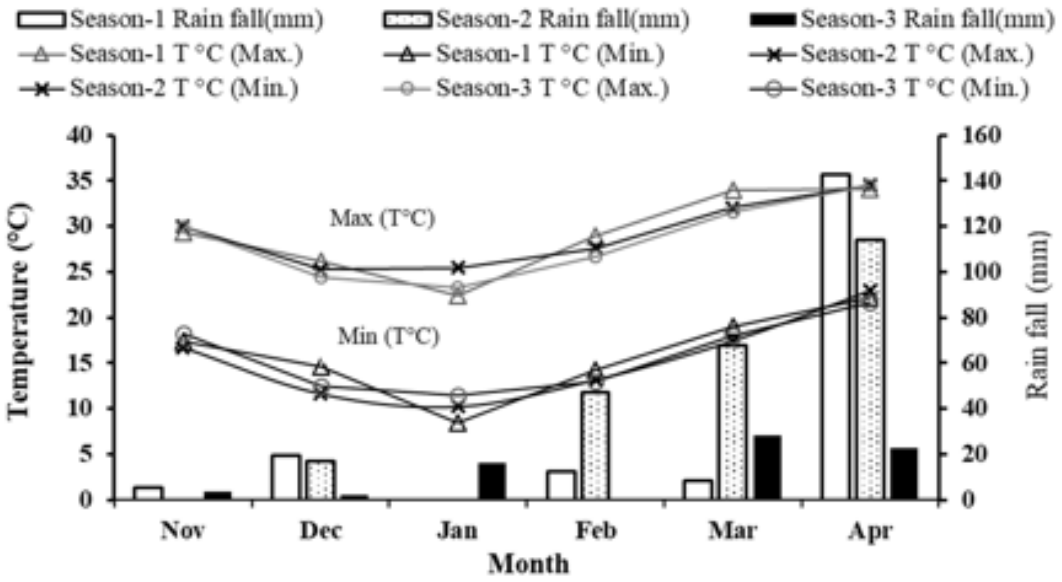

Figure 1. Monthly (crop season only) average maximum and minimum temperature, and rainfall during the period from 2017–2018 (season 1), 2018–19 (season 2), and 2019–2020 (season 3)

also used to comparison among treatment means. The nutrient composition of garlic was collected from available literatures of Mardomi (2017) and Lorenz and Maynard (1988) for the calculation of apparent nutrient balance. Sustainable Yield Index (SYI): It was calculated by the following formula suggested by Krishana and Reddy (1997).

$$SYI = \frac{Y_{\text{mean}} - SD}{Y_{\text{max}}} \times 100 \quad (1)$$

where, Y_{mean} = Mean yield from a treatment over years, SD = Standard deviation of the treatment, and Y_{max} = Maximum yield obtained in the treatment.

Break-even price was calculated by using this following formula :

$$BE_{\text{price}} = \frac{F_C}{P} + V_C \quad (2)$$

where BE_{price} = Break even price (Tk ha^{-1}), F_C = fixed cost (Tk ha^{-1}), P = quantity produced (kg ha^{-1}), and V_C = variable cost unit-1 produced (Tk ha^{-1}).

3 Results

3.1 Yield and agronomic traits

The pooled data presented in table 3, revealed the significant variations in case of main effects as well as interactions in respect of plant height. The increasing tendency of the plant height was noticed (66.7 cm -71.3 cm) with the increasing level of STB doses of fertilizers from T1 to T3 (71.3 cm). The T4 (71.0 cm) known as farmers' dose produced the similar plant height with T3. The highest significant mean plant height was achieved in the year Y2 (73.3 cm) followed by Y3 (68.9 cm) and the lowest was produced in Y1 (65.3 cm). The plant height varied from 61.3 cm to 75.4 cm in different fertilizer doses and year combinations. The maximum and similar plant height was recorded in T4Y2 (75.4 cm), T3Y2 (75.3 cm) and T4Y2 (73.1 cm) as compared to the lowest plant height under T2Y1 (61.3 cm) combination. In response to plant population (m2), the significant variations were observed among fertilizer doses, year and their interactions. The highest and similar number of plant m^{-2} was recorded in similar Y3 (85.8) and Y2 (83.9) followed by Y1 (64.5). The highest number of plant m^{-2} was recorded in statistically similar T3 (80.5) and T4 (80.3) as compared with T2 (76.2) and T1 (75.2). In different combinations of year and fertilizer doses, the maximum number of plant m^{-2} was counted in T3Y3 (89.8), T4Y2 (89.7), T4Y3 (87.7) and T3Y2 (87.3) which were similar to each other. All the fertilizer doses produced the lowest and insignificant plant m^{-2} when they were combined with Y1. In case of individual bulb weight (IBW) the significant variation was observed in individual means and interaction effect. The significantly highest IBW was attained in Y1 (16.12 g) as compared to Y2 (14.98 g) and Y3 (14.98 g). The IBW was increased with the increasing rate of fertilizers in different package of STB dose. The heaviest bulb was produced in T3 (16.66 g) which was statistically similar to farmers' package; ie T4 (16.39 g). The fertilizer packages T2 (14.45 g) and T1 (13.94 g) produced the similar lowest values in respect of IBW. The maximum IBW was recorded in T4Y1 (18.07 g) and T3Y1 (17.7 g) followed by T3Y3 (16.62 g) as compared to least IBW in T1Y3 (13.57 g). The yield of garlic bulb varied significantly with main effects only

and the interaction combinations failed to produce any significant influence. The mean highest yield was produced by Y3 (9.08 t ha^{-1}) and Y2 (8.81 t ha^{-1}) which were similar to each other. The lowest yield was produced in Y1 (7.30 t ha^{-1}). The yield trend was increased with the increasing amount of fertilizers dose in STB. The highest yield was recorded in T3 (9.57 t ha^{-1}) and T4 (9.52 t ha^{-1}) followed by T2 (7.67 t ha^{-1}). The lowest yield was produced in T1 (6.82 t ha^{-1}).

3.2 Nutrient balance

The apparent nutrient uptake and balance was presented in Table 3. The nitrogen balance was calculated assuming 40% nitrogen use efficiency of the crop. The highest P (78 kg ha^{-1}), K (180 kg ha^{-1}) and S (40 kg ha^{-1}) and the lowest N (137 kg ha^{-1}) were added in T4. The T3 package added the highest dose of N (245 kg ha^{-1}). The total nutrients uptake in T3 and T4 was almost same due to their similar yield and the lowest was in T1. In apparent balance of nutrients N was negative in all STB packages where N of T4 (Farmers' dose) was too much negative than STB. P and K were positive in T1, T2 and T3 but huge accumulation in T4. The S also showed positive balance in all packages. T3 package used not only balanced fertilizers (Both organic and inorganic combined) to produced similar yield with T4 but also saved considerable amount of inorganic (P and K) fertilizes compare to T4 that can be used for other crops to increase food security and income.

3.3 Cost and return analysis

The findings obtained from Table 5, indicated the marked variation among treatments in respect of added cost where fertilizers and labor (only for fertilizer application) were involved. The maximum added cost was found in T4 (29707 Tk ha^{-1}) followed by T3 (25109 Tk ha^{-1}) as compared to the lowest added cost in T1 (16052 Tk ha^{-1}). The findings from Table 6, the maximum total variable cost (TVC) was computed in T4 (205963 Tk ha^{-1}) followed by T3 (201362 Tk ha^{-1}) as compared to the lowest in T1 (192308 Tk ha^{-1}). The same trend was found in case of total cost of production where T4 (250333 Tk ha^{-1}) produced the highest total cost of production followed by T3 (245735 Tk ha^{-1}) and the lowest was in T1 (236678 Tk ha^{-1}).

The findings observed from the Table 7, indicated that the clear variation among fertilizer packages in respect of gross return, net return, BCR, break-even price and sustainable yield index. The maximum gross return was achieved in T3 (574200 Tk ha^{-1}) followed by T4 (571200 Tk ha^{-1}) and T2 (460200 Tk ha^{-1}) against the lowest gross return in T1 (409200 Tk ha^{-1}). In case of net return, the highest value was incurred from T3 (328465 Tk ha^{-1}) followed by T4 (320867 Tk ha^{-1}) and T2 221756 Tk ha^{-1}) as compared to the lowest T1 (172522 Tk ha^{-1}). The highest benefit cost ratio (BCR) was recorded in T3 (2.34) followed by T4 (2.28) and T2 (1.93) as compared to the lowest BCR in T1 (1.73). The maximum break-even price was recorded in T1 (34.7 Tk kg^{-1}) followed by T2 (31.09 Tk kg^{-1}) and T4 (26.3 Tk kg^{-1}). The lowest break-even price was achieved in T3 (25.68 Tk kg^{-1}). In context of sustainable yield index (SYI), the highest SYI was achieved in T3 (85.5 %) followed by T1 (81.2 %) and T2 (79.8 %) as compared to the lowest in T4 (79.3 %).

4 Discussion

In this experiment, puddling combined with straw mulch creates the ideal condition in soil for crop growth by accumulating more organic matter in soil Kabir et al. (2016) and straw mulch decrease the soil temperature (Azam, 2005) and conserve soil moisture for all treatments. Thus the significant effect on these traits, as consequence of increased inorganic fertilization was endorsed to the increased nutritional condition of soil causing into increased growth and yield of garlic. Most of the traits reached their extent at the level of higher fertilizers. In harmony with the study, Karim et al. (2011) reported that application of N P K increased individual bulb and total bulb yield and plant height also gradually increased with the increase in the doses of NPKS up to 140:50:150:30 kg ha^{-1}. Interestingly it was observed that yield and other traits jumped where increased rate of chemical fertilizers supplemented with organic manure (cowdung). This might be contributed to advantageous consequence of organic manure on microbial activity and root multiplying in soil which caused solubilizing effect on native macro (nitrogen, phosphorus, potassium), micronutrients and other nutrients. The result of integrated use of inorganic and organic fertilizers and manures were in close similarity with the observation of Patil et al. (2007) reported that combined use of organic and inorganic manures and fertilizers improved organic carbon, available N, S, Mn and Fe thus, enhanced soil fertility. In the study, maximum plant height, individual bulb weight and bulb yield were achieved by 40% higher STB fertilizers with 5 t ha^{-1} cowdung supplement and also in farmers' package. This might be due to the facts that increase in fertility levels, helped in enlargement of leaf area and increased in chlorophyll content which together might have enhanced the photosynthetic rate and sequentially increased the production of carbohydrates to the plants. The use of 40% higher STB dose of N P K supplemented with 5 t ha^{-1} cowdung might be helped the metabolic and auxin activities in the plant and finally caused in increased plant height, IBW and

Table 1. Chemical properties of soil (0-15 cm depth) of the experimental field at Shibpur, Puthia, Rajshahi

Parameter	Soil pH	OM (%)	TN (%)	P (ppm)	K (meq/100g soil)	S (ppm)	Zn (ppm)	B (ppm)
Value	8.42	1.72	0.08	24.12	0.166	15.47	0.7	0.2
Critical level	–	–	0.12	10	0.12	10	0.2	0.2
Interpretation	Al	L	VL	O	M	L	L	L

OM = organic matter, TN = total nitrogen, VL = very low, M = medium, H = high, L = low, Al = alkaline and O = optimum

Table 2. Different fertilizer treatment packages (kg ha^{-1}) for puddling garlic production at MLT site, Shibpur, Puthia, Rajshahi

Treatment †	N	P	K	S	Zn	B	Mg	CD
T1 = STB fertilizer dose for high yield goal	157	13	60	34	2.5	3	–	–
T2 = 20% higher NPK than STB	188	16	72	34	2.5	3		
T3 = 40% higher NPK than STB	220	18	84	34	2.5	3		5 t ha^{-1}
T4 = Farmer's practice	137	78	180	40	6.5	2	–	3 t ha^{-1}

† Fertilizer doses are in kg ha^{-1}, if not specified; STB fertilizer dose = soil test based fertilizer dose

Table 3. Effect of fertilizer packages on yield and traits of garlic (pooled for three seasons)

Year/ Treatments	Plant height (cm)	Plant population (m^{-1})	Ind. bulb weight (g)	Bulb yield (t ha^{-1})
Y1	65.3 c	64.5 b	16.12 a	7.30 b
Y2	73.3 a	83.9 a	14.98 b	8.81 a
Y3	68.9 b	85.8 a	14.98 b	9.08 a
$LSD_{0.05}$	1.73	2.77	0.5	0.54
T1	66.7 b	75.2 b	13.94 b	6.82 c
T2	67.7 b	76.2 b	14.45 b	7.67 b
T3	71.3 a	80.5 a	16.66 a	9.57 a
T4	71.0 a	80.3 a	16.39 a	9.52 a
$LSD_{0.05}$	1.48	2.42	0.53	0.41
T1 × Y1	64.8 f	65.5 e	14.03 ef	5.69
T2 × Y1	61.3 g	64.5 e	14.67 de	6.54
T3 × Y1	67.1 d-f	64.3 e	17.70 a	8.52
T4 × Y1	68.0 de	63.7 e	18.07 a	8.2
T1 × Y2	69.5 cd	78.3 d	14.23 ef	7.07
T2 × Y2	73.1 ab	80.3 cd	14.67 de	8.11
T3 × Y2	75.3 a	87.3 ab	15.67 c	10.2
T4 × Y2	75.4 a	89.7 a	15.37 cd	9.86
T1 × Y3	65.9 ef	81.7 cd	13.57 f	7.45
T2 × Y3	68.6 d	83.8 bc	14.02 ef	8.37
T3 × Y3	71.5 bc	89.8 a	16.62 b	10
T4 × Y3	69.7 cd	87.7 ab	15.73 bc	10.5
$LSD_{0.05}$	2.57	4.19	0.92	NS
CV (%)	3.19	4.62	5.13	7.19

Means followed by the same letters within a column are not significantly different at 5% level of significance; CV- coefficient of variation; LSD- Least Significant Difference; NS- Non Significant

Table 4. Nutrient addition, apparent uptake and balance in soil during puddling garlic cultivation

Treatment	Nutrient uptake (kg ha^{-1})				Nutrient added† (kg ha^{-1})				Apparent balance ‡ (kg ha^{-1})			
	N	P	K	S	N	P	K	S	N	P	K	S
T1	89.3	10.4	27.4	4.8	157	13	60	34	-26.5	2.6	32.6	29.2
T2	100.5	11.7	30.8	5.4	188	16	72	34	-25.3	4.3	41.2	28.6
T3	125.1	14.6	38.3	6.7	245	25.5	95.5	34	-27.1	10.9	57.2	27.3
T4	124.7	14.6	38.1	6.7	152	82.5	187	40	-63.9	67.9	148.9	33.3

† Organic + inorganic; ‡ Assumed 40% nitrogen use efficiency

Table 5. Cost added from different fertilizer packages in puddling garlic cultivation

Treatments	Fertilizer cost † (Tk ha^{-1})	No. of labourer involved ‡ (ha^{-1})	Labour cost (Tk ha^{-1})	Added cost (Tk ha^{-1})
T1	13652	8	2400	16052
T2	15418	8	2400	17818
T3	22109	10	3000	25109
T4	26707	10	3000	29707

† Organic + inorganic; ‡ Basal application + top dressing

Table 6. Cost of cultivation in different fertilizer packages during puddling garlic production

Treatments	Fixed cost (Tk ha^{-1})	Variable cost (Tk ha^{-1})	Added cost (Tk ha^{-1})	TVC † (Tk ha^{-1})	Total cost of production (Tk ha^{-1})
T1	45000	176256	16052	192308	236678
T2	45000	176256	17818	194074	238444
T3	45000	176256	25109	201365	245735
T4	45000	176256	29707	205963	250333

† Total variable cost; Urea: 16 Tk kg^{-1}, TSP: 22 Tk kg^{-1}, MoP: 15 Tk kg^{-1}, gypsum: 7 Tk kg^{-1}, zinc sulphate: 120 Tk kg^{-1}, boric acid: 150 Tk kg^{-1}, furadan: 150 Tk kg^{-1}, Garlic seed: 110 Tk kg^{-1}, Tillage cost (one pass) :1875 Tk ha^{-1}, irrigation (1 time): 1875 Tk ha^{-1} and Labour: 300 Tk d-1 (6 h)

Table 7. Economics and sustainable yield index (SYI) of puddling garlic production in different fertilizer packages

Treatments	Pooled yield (t ha^{-1})	Gross return (Tk ha^{-1})	Total cost (Tk ha^{-1})	Net Return (Tk ha^{-1})	BCR	Break-even (price Tk kg^{-1})	SYI (%)
T1	6.82	409200	236678	172522	1.73	34.7	81.2
T2	7.67	460200	238444	221756	1.93	31.09	79.8
T3	9.57	574200	245735	328465	2.34	25.68	85.5
T4	9.52	571200	250333	320867	2.28	26.3	79.3

BCR = Benefit Cost Ratio; SYI = Sustainable Yield Index; Garlic bulb @ 60 Tk kg^{-1}

finally the total yield than only chemical fertilizer packages. These findings were in conformity with those of Patil et al. (2007) and Singh et al. (2012) in garlic. They observed that the integrated use of organic and inorganic fertilizers increased the yield contributing traits and lastly the total yield in garlic. Later on it was confirmed as well by the observation of Yadav et al. (2017) and Kumar et al. (2013) in garlic. Though the farmers' package produced the similar yield with T3, it is not recommended for use due to its higher accumulation of nutrients in soil that may produce toxic effect in soil in the long run. Thangasamy and Chavan (2017) stated that garlic crop removed 56.3 kg N, 13.5 kg P, 65.8 kg K, 30.6 kg S, 110.3 g Zn, 116.9 g Mn, 724.9 g Fe, and 26.2 g Cu to produce 6.7 t garlic bulbs ha^{-1}. Sustainable yield index was also higher in T3 indicating that more sustainable yield produced over the year that may be due to the balanced use of fertilizers combined with manure. The result was supported by Wanjari et al. (2004) and stated that maximum SYI (0.37–0.62) attained in 100% NPK + FYM treatment indicating that combined use of inorganic and organic nutrients sustained higher crop productivity by correcting marginal nutrients deficiencies in rice-wheat and fingermillet-maize cropping system.

5 Conclusions

Judicious application of fertilizers is important for yield and income maximization of garlic. From the findings of the study, it is concluded that the treatment T3 (40% higher NPK than STB = 220-18-84-34-2.5-3 kg ha^{-1} NPKSZnB, respectively) supplemented with 5 t ha^{-1} cowdung gave best results for plant height, individual bulb weight, yield, net economic return and sustainability compared to other treatments. This fertilizer package could be recommended for wide extension for puddling garlic production in the High Ganges River Floodplain Agro-ecological zone (AEZ-11) in Bangladesh.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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