Optimizing Nutrient Recommendations for Bottle Gourd Crop by Formulation of Targeted Yield Equations in an *Inceptisols*of Odisha

Abstract

A field experiment was conducted to formulate targeted yield equations for Bottle gourd under arice-vegetable cropping system in an *Inceptisol* of Odisha. The experiment started with the creation of three soil fertility gradient stripes by applying no fertilizer, recommended dose and double the recommended dose of fertilizer in rice (cv. Lalat) during the *kharif* season. Each fertility gradient strip was divided into 24 sub-plots and superimposed with 21 different combinations of nutrients containing N, P, and K; FYM in two plots at 5t and 10t $ha^{-1}$and one plot was kept as absolute control following which, bottle gourd was grown during the *rabi* season. The highest yield (116.3q ha^{-1}) of bottle gourd was achieved in S-III with an application of 70, 100, and 100 kg N, P_2O_5, and K_2O per hectare, respectively. The nutrient requirement (NR) for producing one quintal of bottle gourd yield was 0.30, 0.20, and 0.30 kg N, P_2O_5 and K_2O. The effect of graded doses of fertilizers on nutrient requirement, yield and nutrient uptake of bottle gourd were studied and subsequently, fertilizer prescription equations were derived for targeted yield of bottle gourd. A ready reckoner chart has also been prepared for facilitating farmers to achieve the desired yield target of bottle gourd by applying the required quantity of plant nutrients in the existing soil fertility level. The equations provide a basis for site-specific nutrient management based on desired yield targets under varying soil fertility conditions.

Keywords: Bottle gourd, targeted yield, fertilizer prescription equations, *Inceptisols*, STCR-IPNS

Introduction

Bottle gourd [*Lagenariasiceraria* (Molina) Standl.] is a fast-growing*monoecious* annual climber in the family *Cucurbitaceae*. Bottle gourd fruit is rich in carbohydrates, protein, fat, and minerals including essential elements such as calcium and phosphorus.Thisnutritionally rich vegetable needs to be cultivated with balanced fertilization so that maximum yield can be achieved with optimum use of externally applied nutrients(Lokya *et al*., 2020; Kishore *et al.*, 2022).Moreover, the site-specific application of nutrients has become increasingly important in present-day precision agriculture, which is based on theneed-based precise application of agricultural inputs (Dash *et al*., 2022a; Dash, 2024).

Application of site-specific balanced nutrients on crops can be achieved with fertiliser prescription equations through a targeted yield approach as described by Ramamoorthy *et al*. (1967). The targeted yield approach considers not only the nutrient status of the soil but also the targeted yield for the determination of the amount of nutrients to be added through external sources (Ranjan *et al.*, 2018). Fertilizer application based on the targeted yield equation approach is an effective way to obtainhigher yield, net benefit,enhanced nutrient use efficiencies, and fertilizer savingsover general fertilizer recommendation (Pande and Singh, 2016).

Bhatt *et al.* (2021) observed that the targeted yield model for Brinjal was better than the general recommendations in terms of net savings on fertilizers. Recently, Murthy *et al.* (2023) concluded that the targeted yield equation approach was the most suitable and effective approach for fertilizer recommendation for finger millet crops.Eunice *et al.* (2023) while generating targeted yield equations for the Amaranthus crop concluded that fertilizer and manure recommendations based on STCR (Soil Test Crop Response)-targeted yield equations not only improved crop yield but also improved the soil quality.Further, Goyal *et al.* (2023) validated the targeted yield equations for Bt. Cotton in farmers' fields and observed the said approach to be superior to farmer's practice and general recommended dose.Keeping the above factsin view,a field experiment was conducted to formulate targeted yield equations for Bottle gourd under a rice-vegetable cropping system in an *Inceptisol* of Odisha.

Materials and Methods

The study area

The experiment was conducted at E block of the Central Research Farmof OUAT, Bhubaneswar, which comes under the East and Southeastern Coastal Plain agroclimatic zone of Odisha (latitude: 20.266829°, longitude: 85.795856°, elevation: 175 ft above mean sea level). The climate of the study site is hot and humid characterized by hot summer and dry winter with mean annual rainfall, maximum and minimum temperatures of 1,657.8 mm, 33°C, and 22.4°C, respectively.

Soil characteristics

Before the development of the fertility gradient, composite soil samples were taken and analyzed for initial soil properties using standard procedures.The experimental site was characterized by medium land, sandy loam in soil texture, acidic (pH 5.67) in soil reaction and medium (5.5 g kg^{-1}) in soil organic carbon content. The Cation Exchange Capacityof the surface soil was 4.5 cmol $(p^{+})kg^{-1}$with 65percentof base saturation. The experimental site was low (117 kg ha^{-1}) in average soil available nitrogen (N), medium (36 kg ha^{-1}) in average available phosphorus(P),and low (87 kg ha^{-1}) in average available potassium (K). The soil has beenclassified as fine, mixed, hyperthermic, *VerticUstochrepts* as per USDA soil taxonomy.

Creation of fertility gradient

The experimentstarted with the creation of three soil fertility gradient strips in*Kharif*, 2019. Three strips were created by applying no N, P, K fertilizers in S-I, the recommended dose of fertilizers (N:P: K::80:40:40) in S-II and double of the recommended dose (N:P:K::160:80:80) in S-III strip.

Rice (cv. Lalat) crop was grown so that fertiliser could interact with soil constituents, plant rhizosphere and thus become part of the soil system.After the harvest of paddy, grain and straw yields were recorded.

Test crop experiments

After the harvest of the paddy crop, each of the three fertility gradient strips was subdivided into 24 sub-plots.In each strip, out of 24 sub-plots, 21 sub-plots were superimposed with different graded doses of N, P, and K fertilizers(Table 1) in different combinations; two sub-plots (22nd and 23rd) were applied with FYM at 5 t and 10 t ha^{-1}, respectively and the 24th plot was kept as absolute control.The subplots were created in such a way that all 24 treatments were present in all three strips.Thereby, a total 72 numbers of subplots were created, and 72 numbers of soil samples from the subplots were collected and analyzed in the laboratory to determine the soil test value. Bottle gourd (cv. *Kaveri*) was grown as the test crop during the following *rabi* season. Sources of nutrients were fertilizer urea, diammonium phosphate and muriate of potash. Nitrogen was applied in split dose i.e., 50% N was applied as basal dose and the rest 50% was applied at the time of flowering. Full doses of P, K and FYM were applied at the time of sowing as basal dose. Standard agricultural practices of bottle gourd were adopted during its cultivation.

Soil and plant analysis

The soil samples collected after the harvest of paddy crop and before planting of bottle gourd crop were analysed to determine soil organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1956), phosphorous (Bray and Kurtz, 1945) and potassium (Hanway and Heidel, 1952) as outlined by Jackson (1973).After completion of the bottle gourd crop cycle, yield information was recorded, and laboratory analysis of post-harvest soil samples, fruit and vine samples was performed.For analysis of total N, P and K content in fruit and vine,representative plant samples were collected and after proper processing, wet oxidation of samples wasdone by using the diacid digestion mixture (HNO_3:$HClO_4$::9:4) for determination of total P andK content. Total N content was determined using the micro-Kjeldahl's method(Jackson 1973). Uptake of N, P and K was computed by using yield data and the total N, P and K content of the plant samples.

Formulation of targeted yield equations

The factors required for targeted yield equations such as nutrient requirement (NR), soil efficiency (Cs), fertilizer efficiency (Cf), and organic matter efficiency (Co) were calculated following Ramamoorthy's inductive cum targeted yield model as given below.

$$\text{NR (kg/ q)} = \frac{\text{Uptake of nutrient by bottle gourd (kg/ ha)}}{\text{Yield of bottle gourd (q/ ha)}}$$

$$\text{Cs (\%)} = \frac{\text{Uptake of nutrient in absolute control plot } \left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Initial soil test value of a particular nutrient in control plot } \left(\frac{\text{kg}}{\text{ha}}\right)} x100$$

$$\text{Cf}\ (\%) = \frac{\text{Uptake of nutrient in fertilizer treated plot (kg/ ha)} - [\text{Initial soil test value} \times \text{Cs}/100]}{\text{Nutrient applied through fertilizer (kg/ha)}} x100$$

$$\text{Co}\ (\%) = \frac{\text{Uptake of nutrient in organic matter treated plot} - (\text{Initial soil test value of control plot with FYM} \times \text{Cs}/100)}{\text{Nutrient applied through organic matter (kg/ha)}}$$

All the required parameters were calculated and combined for formulating the targeted yield equations with and without FYM as follows:

$$\text{FD}_{\text{without FYM}} = \frac{\text{NR} \times 100 \times \text{T}}{\text{Cf}} - \frac{\text{Cs} \times \text{STV}}{\text{Cf}}$$

$$\text{FD}_{\text{with FYM}} = \frac{\text{NR} \times 100 \times \text{T}}{\text{Cf}} - \frac{\text{Cs} \times \text{STV}}{\text{Cf}} - \frac{\text{Co} \times \text{nutrient} \left(\frac{\text{kg}}{\text{t}}\right) \text{in FYM x FYM} \left(\frac{\text{t}}{\text{ha}}\right)}{\text{Cf}}$$

Where, FD = fertilizer dose (kg ha^{-1}),T = targeted yield (q ha^{-1}), and STV = soil test value.

Results and Discussions

Effect on yield of paddy crop

Three fertility gradient stripes rice crop was cultivated by applying no fertilizer in the S-I block (N_0: P_0: K_0), the recommended dose of fertilizer in S-II (N_{80}: P_{40}: K_{40}) and double of the recommended dose of fertilizer in S-III block (N_{160}: P_{80}: K_{80}). Data showed that the highest grain yield (45.2 q ha^{-1}) of rice was achieved in S-II block followed by S-III (42.9 q ha^{-1}) and S-I (29.6 q ha^{-1}) blocks (Table 2). On the other hand, the highest straw yield was recorded (53.4 q ha^{-1}) in the S-III block followed by the S-II (51.7 q ha^{-1}) and S-I (33.8 q ha^{-1}) blocks. Both grain and straw yield of rice were lowest in S-I (control). Data clearly indicated that the application of a recommended dose of fertilizers (S-II) resulted in 52% more grain yield and 53% more straw yield compared to the control strip ($N_0P_0K_0$). However, the S-III strip showed 44% more grain yield and 57% more straw yield thanthecontrol strip.The results clearly showed that higher doses of fertilizer in S-III increased the vegetative growth of rice which was reflected in straw yield. Excess use of fertilizers often delays the maturity of the crop (Gogoi *et al.*, 2011; Mishra *et al.*, 2013).

Effect on soil fertility status

The experimental result showed that the highest soil nutrient was built up in the S-III strip among the three fertility gradient stripes. The mean values of soil available NPKincreasedwith an increase in fertilizer doses from the S-I to S-III strip. The mean available soil N was found to be 117.3, 135.9 and 145.6 kg ha^{-1}, that of P_2O_5 was 34.2, 41.8 and 64.5 kg $ha^{-1}$and the mean available K_2O was 87.1, 66.8 and 99.3 kg ha^{-1} in S-I, S-II, and S-III stripes, respectively (Table 3). Higher soil fertility status was observed in the S-III strip as the highest quantities of fertilizers were applied for rice during *kharif*and a large amount of applied nutrients might have remained unutilized after the harvest of the crop (Ammal *et al.*, 2020; Singh *et al.*, 2022). Similar results are recently being reported by Pandey *et al.*, (2023) while formulating targeted yield equations for Sesame.

Effect on fruit yield

Results indicated that the fruit yield of bottle gourd in S-I, S-II and S-III was found to vary from 52.9 to 92.5, 73.6 to 106.3 and 95.1 to 116.3 q ha^{-1} with the average yield of 77.5, 87.3 and 103.5 q ha^{-1}, respectively (Table 3). The lowest yield of bottle gourd was observed in the absolute control plot in all three fertility gradient stripes as it did not receive any fertilizer. The highest fruit yield was achieved in S-III strip with a fertilizer dose of 70:100:100 kg N: P_2O_5: K_2O and this graded dose of fertilizer recorded the highest yield in all the stripes (supplementary material). In contrast, the lowest yield was found in the S-I as no fertilizer was applied to rice during *kharif*.The percentage increase of bottle gourd fruit yield in S-II and S-III as compared to S-I was observed to be 12% and 33%, respectively. Similar observations have also been reported forFrench bean(Pogula*et al.*, 2016),greengram(Saren*et al.*, 2018), coriander (Singh *et al.*, 2020), forage oat (Jhinkwan*et al.*, 2021), and rice (Mondal *et al.*, 2020). Thus, higher nutrient content in soil resulted in higher yield of bottle gourd.

Effect on biomass (vine)yield

The biomass (leaves and vine) yield in S-I, S-II and S-III was found to range between 32.8 to 55.8, 41.0 to 60.2 and 53.7 to 68.4 q $ha^{-1}$with average values of 44.7, 49.9 and 58.9 q ha^{-1}, respectively (Table 3; Fig.1). The highest biomass production was observed to follow the same trend of fruit yield i.e., biomass yield also increased from S-I to S-III. Similar observations were also recorded in different crops by the earlier workers (Gogoi *et al.*, 2011; Mishra *et al.*, 2016).

Effect on nutrient uptake

The uptake of N, P and K shows an increasing trend with an increase in artificially created fertility gradient stripes from S-I to S-III. The mean uptake of nitrogen was 26.6, 30.8 and 42.1 kg ha^{-1}, that of phosphorus was 13.8, 19.4 and 30.3 kg ha^{-1} andmean potassiumuptake was 24.5, 32.6 and 44.3 kg ha^{-1} in S-I, S-II, and S-III stripes, respectively (Table 3). Thus, the uptake of major nutrients increased with the applied nutrients and nutrients present in the soil. Higher plant nutrient uptake corresponded to a higher yield of both fruit and biomass. The uptake of N, P and K was found to be highest in the fertilizer dose of 70:100:100 kg N: P_2O_5: K_2O ha^{-1} in all fertility gradient stripes (supplementary material).Among 21 fertilizer treatment plots, one of each of the nutrients i.e., N, P and K was not applied (supplementary material). Both nutrient update and yield drastically reduced where a single nutrient was not applied. Such type of treatment combinations in the present investigation showed the importance of any particular macronutrienton the yield and uptake of the crop.

Formulation of targeted yield equation and ready reckoner for bottle gourd

The nutrient requirement (NR) for producing one quintal of bottle gourd was 0.3kg N, 0.2kg P_2O_5 and 0.3kg K_2O. Soil efficiency (Cs) was found to be 15, 21 and 21per cent; fertilizer efficiency (Cf) was 28, 15 and 22per cent and organic matter efficiency (Co) was 7.6, 9.8 and 7.8per cent for N, P_2O_5 and K_2O, respectively (Table 4). Such low efficiencies of nutrients in both soil and fertilizer sources could be because of persistent high levels of soil acidity prevailed in the study area since soil acidity is associated with poor nutrient availability and poor nutrient use efficiencies (Digal *et al.*, 2018). Soil acidity has been reported in several other studies in the state of Odisha (Dash *et al.*, 2019; Sethy *et al.*, 2019; Singh *et al.*, 2021;Dash *et al.*, 2022b; Pattnaik*et al.*, 2023).

Targeted yield equations for bottle gourd (*cv. Kaveri*) were thus formulated (Table 5). In the equations, the yield target (T) was fixed based on the yield potential of the crop.In the equations, SN, SP_2O_5 and SK_2O values stand for available soil nitrogen, soil phosphorus and soil potassium, respectively. Similarly, ON, OP_2O_5 and OK_2O values stand for nitrogen, phosphorus, and potassium through organic sources. The amount of fertilizer to be added is dependent on the status of soil nutrients and the yield target. The equations show that if a part of the nutrient requirement is filled up by the application of FYM, there will be a net saving on the cost of fertilizers. Similar findings were also reported by Singh *et al.* (2017). A ready reckoner for fertilizer doseswas prepared to facilitate farmers to achieve the desired yield target of bottle gourd by applying the required quantity of plant nutrients in different existing soil fertility levels (Table 6). A higher yield target of the crop suggested more nutrient requirements. On the other hand, lower nutrient content in the soil needed higher nutrients to achieve the desired yield target. In case, when soil nutrient content is high and the yield target is low, the required fertilizer as per the equations will be very low or in some cases, values might be negative. In that case, only a maintenance dose of 25% of the recommended dose of fertilizer is recommended to avoid nutrient mining from the soil. Thus, in soils with higher initial nutrient content, unnecessary application of fertilizers can be checked by using the targeted yield equation approach.

Conclusion

Fertilizer recommendation based on targeted yield equations is a scientific way of precise and need-basednutrient management. This study has led a path towards adopting site-specific nutrient management in bottle gourd crop. This will not only supply the required quantity of nutrients to achieve a specific yield target but also will help in maintaining soil fertility status overthe long run.For further validation, in future,the equations need to be tested at farmers' fields at multiple locations with varying levels of soil fertility status and yield targets. For effective adaptation of these equationsamong the farmers, initial soil testing must be promoted as a first step. The targeted yield equations prepared in this study will especially be useful to increase the production and productivity of bottle gourd crop in red, laterite and yellow soils of Odisha (*Inceptisols* and *Alfisols*) and similar soils of our country. Integrating the application of FYM along with inorganic sources of nutrients will help curtail the amount of inorganic nutrients to be applied. Thus, thetargeted yield equation approach can be effectively utilized for improving bottle gourd yieldand saving costs on fertilizers, besides having environmental benefits by avoiding over-application of chemical fertilizers.

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Table 1. Combination of nitrogen, phosphorus, potassium and FYM used in the experiment

T_1- $N_0P_2K_2$	T_{13}- $N_2P_3K_2$
T_2- $N_1P_1K_1$	T_{14}- $N_2P_3K_3$
T_3- $N_1P_1K_2$	T_{15}- $N_1P_3K_2$
T_4- $N_1P_2K_1$	T_{16}- $N_3P_2K_1$
T_5- $N_1P_2K_2$	T_{17}- $N_3P_2K_2$
T_6- $N_2P_0K_2$	T_{18}- $N_3P_2K_3$
T_7- $N_2P_1K_1$	T_{19}- $N_2P_1K_3$
T_8- $N_2P_1K_2$	T_{20}- $N_3P_3K_2$
T_9- $N_2P_2K_0$	T_{21}- $N_3P_3K_3$
T_{10}- $N_2P_2K_1$	T_{22}- $N_0P_0K_0$ + FYM @ 5 t ha^{-1}
T_{11}- $N_2P_2K_2$	T_{23}- $N_0P_0K_0$ + FYM @ 10 t ha^{-1}
T_{12}- $N_2P_2K_3$	T_{24}- $N_0P_0K_0$ (absolute control)

(where, N_0, N_1, N_3, N_4 corresponds to 0, 30, 50, 70 kg N/ha; N_0, N_1, N_3, N_4 corresponds to 0, 60, 80, 100 kg P_2O_5/ha; N_0, N_1, N_3, N_4 corresponds to 0, 60, 80, 100 kg K_2O /ha)

Table 2 Effect of graded doses of fertilizer on Rice

Strip-I $N_0P_0K_0$		Strip-II $N_{80}P_{40}K_{40}$			Strip-III $N_{160}P_{80}K_{80}$		
Yield (q ha^{-1})		Yield (q ha^{-1})		% increase	Yield (q ha^{-1})		% increase
Grain	29.6	Grain	45.2	52	Grain	42.9	44
Straw	33.8	Straw	51.7	53	Straw	53.4	57

Table 3. Range and average yield of fruit and biomass of Bottle Gourd (cv. *Kaveri*), soil test values and NPK uptake in different fertility gradient stripes.

Parameter	Strip-I		Strip -II		Strip-III	
	Range	Mean ±SEm	Range	Mean ±SEm	Range	Mean ±SEm
Fruit yield (q ha^{-1})	52.9-92.9	77.5±1.38	73.6-106.3	87.3±1.35	95.1-116.3	103.5±0.61
Vine yield (q ha^{-1})	32.8-55.8	44.7±1.11	41.0-60.2	49.9±1.0	53.7-68.4	58.9±0.51
Av. N (kg ha^{-1})	106.7-128.6	117.3±0.48	123.8-143.8	135.9±0.42	137.9-152.3	145.6±0.36
Av. P_2O_5 (kg ha^{-1})	27.6-38.8	34.2±0.62	31.9-49.1	41.8±0.93	45.3-75.9	64.5±1.23
Av. K_2O (kg ha^{-1})	66.1-126.7	87.1±1.75	42.6-102.8	66.8±1.72	65.2-195.6	99.3±1.13
N uptake (kg ha^{-1})	12.2-43.8	26.6±1.61	20.2-47.6	30.8±1.81	27.1-61.0	42.1±1.61
P uptake (kg ha^{-1})	5.0-26.9	13.8±1.93	10.5-34.8	19.4±1.85	16.2-45.0	30.3±1.79
K uptake (kg ha^{-1})	9.6-42.4	24.5±1.63	15.1-53.5	32.6±1.96	25.1-68.4	44.3±1.60

Table 4. Basic data required for fertilizer adjustment equations of bottle gourd in *Inceptisols.*

Basic data	N	P_2O_5	K_2O
Nutrient requirement (kg q^{-1})	0.3	0.2	0.3
Soil efficiency (Cs, %)	15	21	21
Fertilizer efficiency (Cf, %)	28	15	22
Organic matter efficiency (Co, %)	7.6	9.8	7.8

Table 5. Targeted yield equations for bottle gourd

Fertilizer dose	Without FYM	With FYM (IPNS)
Nitrogen (kg ha^{-1})	FN= 1.26T – 0.54 SN	FN= 1.26T – 0.54 SN – 0.26 O N
P_2O_5 (kg ha^{-1})	FP_2O_5= 1.6T- 1.34 S P_2O_5	FP_2O_5= 1.6T- 1.34 S P_2O_5 – 0.62 O P_2O_5
K_2O (kg ha^{-1})	FK_2O= 1.6T- 0.94 S K_2O	FK_2O= 1.6T- 0.94 S K_2O – 0.34 O K_2O

(FN, FP_2O_5 and FK_2O= Nitrogen phosphatic and potassic fertilizers required (kg ha^{-1}); T= Yield target (in quintals); SN, S P_2O_5 and S K_2O = Soil testing values of N, P_2O_5 and K_2O (in kg); ON, OP_2O_5 and OK_2O = Nutrients N, P_2O_5 and K_2O supplied through organic source (in kg))

Table 6. Ready reckoner chart of fertilizer doses for different yield targets of bottle gourd under varying fertility status

Initial soil status (kg ha^{-1})			Yield Target (q ha^{-1})											
			80			100			120			140		
N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
100	20	70	47	101	62	72	133	94	97	165	126	122	197	158
110	25	80	41	94	53	66	126	85	92	158	117	117	190	149
120	30	90	36	88	43	61	120	75	86	152	107	112	184	139
130	35	100	31	81	34	56	113	66	81	145	98	106	177	130
140	40	110	25	74	20	50	106	57	76	138	89	101	186	121
150	45	120	20	68	15	12.5	100	20	70	132	79	95	163	111
160	50	130	14	61	20	40	93	20	65	125	70	90	157	102
170	55	140	9	54	20	34	86	28	59	118	60	85	150	92
180	60	150	4	48	20	29	80	19	54	112	51	79	144	79
190	65	160	12.5	41	20	23	73	10	49	105	42	74	137	74

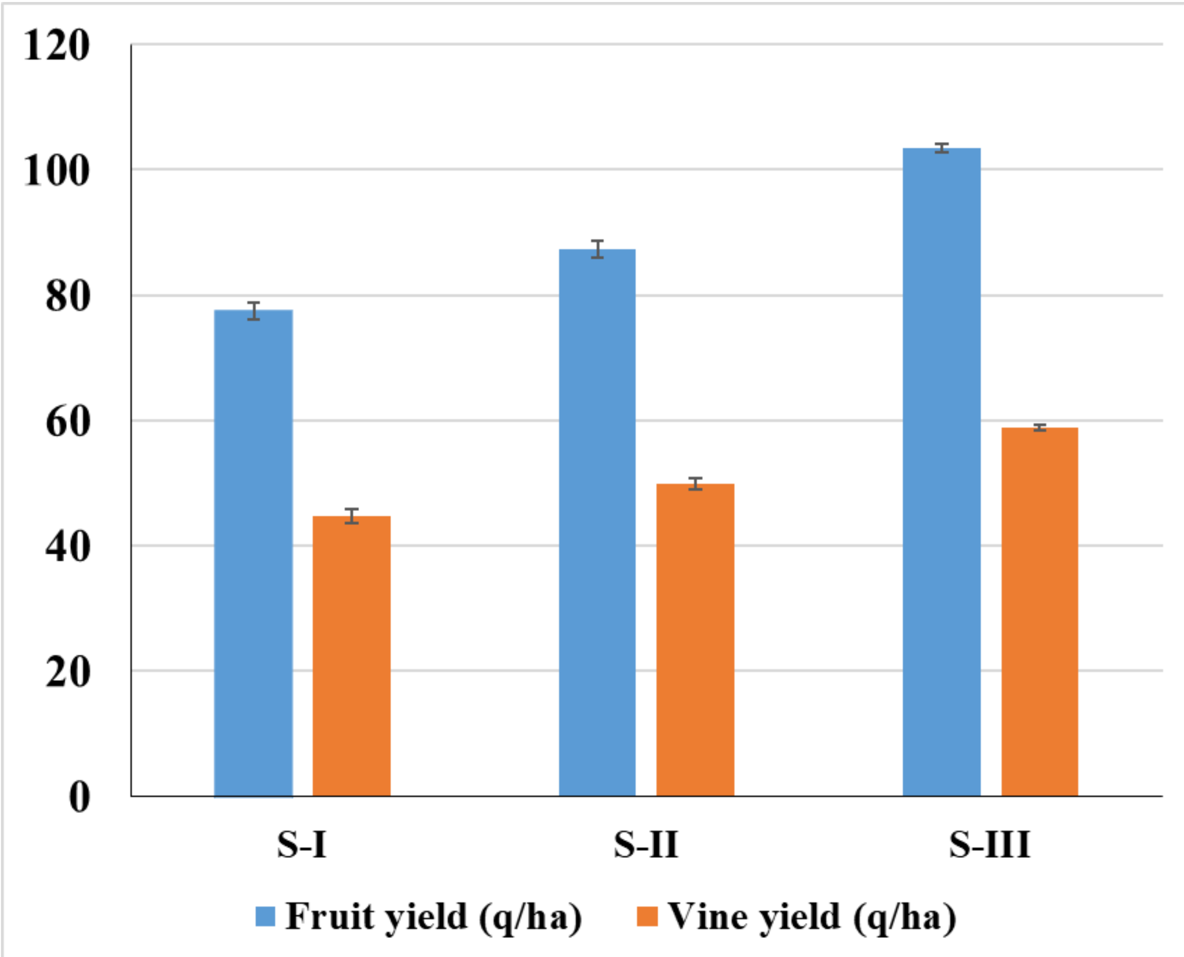

Fig.1. Average fruit and vine yield of bottle gourd crop in different fertility gradient strips