PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(4): 91-97
https://doi.org/10.14719/pst.4623

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Yield and quality of beetroot to soil test crop response (STCR) - integrated plant nutrient system (IPNS) based fertilizer prescription in Ultisols of Western Ghats of Tamil Nadu, India

R. Arulmani[1], K.M. Sellamuthu[1*], S. Maragatham[1], A. Senthil[2], S.P. Thamaraiselvi[3], R. Anandham[4], P. Malathi[1] & G. Sridevi[1]

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu - 641003, India

[2]Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu - 641003, India

[3]Department of Floriculture and Landscape Architecture, Tamil Nadu Agricultural University, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu - 641003, India

[4]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu - 641003, India

*Email: kmsellamuthu@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY

Received: 11 August 2024
Accepted: 02 September 2024

Available online
Version 1.0 : 20 September 2024
Version 2.0 : 01 October 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Arulmani R, Sellamuthu KM, Maragatham S, Senthil A, Thamaraiselvi SP, Anandham R, Malathi P, Sridevi G. Yield and quality of beetroot to soil test crop response (STCR) - integrated plant nutrient system (IPNS) based fertilizer prescription in Ultisols of Western Ghats of Tamil Nadu, India. Plant Science Today. 2024; 11(4): 91-97. https://doi.org/10.14719/pst.4623

Abstract

Beetroot is one of the most important root vegetable crops and is consumed globally due to its rich nutrient content. The current research was conducted on a farmer's holding, using beetroot (Improved crystal hybrid) in Nilgiri district, Western Ghats of Tamil Nadu to study the effect of different N, P_2O_5, K_2O and integrated plant nutrient system (IPNS) dosages in yield attributes and quality parameters. Two field trials were conducted in farmer's land at Kadanad Village (11^0 48' N Latitude, 76^0 72' E Longitudes) during the winter of 2024 and in Emerald Village (11^0 31' N Latitude, 76^0 63' E Longitudes) during the summer of 2024. The experiment was designed using a RBD with ten treatments and three replications. The treatments were absolute control, blanket, blanket + FYM, STCR-NPK based fertiliser dose for an yield target of 35, 40 and 45 t ha^{-1}, soil test crop response - integrated plant nutrient system (STCR-IPNS) based fertiliser dose for an yield target of 35, 40 and 45 t ha^{-1} and farmer's practice. The treatment of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T_3) recorded the highest plant height (51.59 cm), more number of leaves per plant (24.05), leaf width (18.14 cm), higher total chlorophyll (47.28), root yield (44.21 t ha^{-1}) and quality parameters as total sugar (8.95%), reducing sugar (2.08%), non-reducing sugar (6.87%), total soluble solids (12.80 ^{0}B) and ascorbic acid (3.62 mg 100 g^{-1}). The treatment receiving inorganic NPK fertilizers along with FYM @12.5 t ha^{-1} (T3) recorded the highest beetroot of yield of 44.21 t ha^{-1} than the soil test based inorganic fertilizer application treatment (T6). Fertilizer prescription based on STCR-IPNS model found to be better choice to enhance yield and quality of beetroot.

Keywords

Beetroot yield; beetroot quality; STCR-IPNS; STCR-NPK alone

Introduction

Beetroot (*Beta vulgaris* L.), belongs to the Chenopodiaceae family cultivated mainly to provide food for both humans and livestock. The taproot part of the plant is called the beetroot, has nutrients and antioxidants required for human being. Beetroot consumed mainly as vegetables and typically eaten as salads. Beetroot possesses a chemical component called betalain, which is vital for heart health. Betanin, a most studied Betalain which is a glucoside, used as a food coloring agent. It also serves as a medicinal herb to treat a variety of ailments and as a natural color in the textile industry. This plant has various applications, including as a diuretic, carminative, antibacterial, antifungal, anti-inflammatory, antioxidant and antidepressant. Beetroot, which has an alkaline pH of 7.5-8.0, is abundant in vitamins C, B1, B2, niacin, B6 and B12 and its leaves provide a substantial amount of vitamin A. The roots contain proteins (1.7 g), carbohydrates (8.8 g), calcium (18 mg), phosphorus (55 mg) and water content of 87.7%.

Beetroot is cultivated annually across 0.079 lakh ha nationwide, with Telangana contributing 425 ha and an annual yield of 11,132 million tonnes (1). States *viz.,* Haryana, Himachal Pradesh, West Bengal, Uttar Pradesh and Maharashtra are the primary beetroot-producing states in India. To enhance soil fertility and boost crop production potential, the integrated plant nutrition system combines synthetic fertilizers with organic waste materials. The combined application of organic and inorganic fertilizers boosts agricultural output and is advantageous over mineral fertilisers.

One of the most expensive agricultural inputs is fertilizer, using the proper amount of fertilizer is essential to both environmental preservation and farm profitability. Moreover, poor crop nutrition exacerbates the problem of declining soil fertility. The objective of the present research is optimizing the production of beetroot without compromising the quality of beetroot.

Materials and Methods

Field experiments were conducted in farmer field at Kadanad Village (Winder-2024) Emerald Village (Summer-2024) of Nilgiri district, situated in the Western Ghats zone of Tamil Nadu. The soil at the experimental site is classified under the Ultisols order and is part of the Typic Haplohumult subgroup. Soil samples (0-15 cm depth) were collected before planting, air-dried in the shade, passed through a 2 mm sieve, and analyzed for physical and chemical properties. Soil pH and electrical conductivity (EC) in a (1:2) soil-to-water suspension were measured using a digital pH and EC meter (2). The soil samples were analyzed for organic carbon by the methods of chromic acid wet digestion (3), potassium permanganate nitrogen (4), bray phosphorus (5), ammonium acetate potassium (6), neutral normal ammonium acetate CEC (7) and DTPA extractant micronutrient (8).

The soil was red, non-calcareous, deep, well drained, clay loam in texture, acidic (pH 4.45), non-saline (EC 0.36 dS m^{-1}) and medium in CEC (18 cmol (p^{+}) kg^{-1}). The initial soil fertility status showed that soil organic carbon (SOC), available nitrogen (N), available phosphorus (P), and available potassium (K) were 30.27 g kg^{-1}, 424 kg ha^{-1}, 191 kg ha^{-1} and 522 kg ha^{-1}, respectively. Available micronutrients (DTPA extractable) *viz.,* Fe (43.06 mg kg^{-1}), Mn (11.23 mg kg^{-1}), Zn (2.16 mg kg^{-1}) and Cu (2.74 mg kg^{-1}) were in optimum ranges.

First, a fertility gradient experiment was conducted with a green leafy vegetable, Chakravarthy Keerai (*Chenopodium album* var. Ooty 1). Second, a trial crop experiment was planned with beetroot (hybrid: Improved Crystal). After confirming the gradient establishment, the main experiment began with beetroot as the test crop. Third, a validation experiment was conducted in a farmer's field within the same soil series, using beetroot (hybrid: Improved Crystal) to verify the STCR-IPNS model.

Field experiment was conducted with ten total treatment combinations, as presented in Table 2. The quantities of nitrogen, phosphorus and potassium required for the targeted beetroot yield were determined using fertilizer adjustment equations.

Table 1. Fertilizer prescription equation

Soil Test Crop Response (STCR)-Inorganic	STCR-IPNS
FN =0.69 T - 0.37 SN	FN =0.69 T - 0.37 SN - 0.62 ON
FP_2O_5 = 0.61 T – 0.54 SP	FP_2O_5 = 0.61 T – 0.54 SP - 0.86 OP
FK_2O = 0.82 T - 0.42 SK	FK_2O = 0.82 T - 0.42 SK - 0.63 OK

T, Yield target (q ha^{-1}); FN, Fertilizer N (kg ha^{-1}); FP_2O_5, Fertilizer P (kg ha^{-1}); FK_2O, Fertilizer K (kg ha^{-1}); SN, Soil available nitrogen (kg ha^{-1}); SP, Soil available phosphorus (kg ha^{-1}); SK, Soil available potassium (kg ha^{-1}); FYM, Farmyard manure (t ha^{-1}); ON, Organic nitrogen (kg ha^{-1}); OP, Organic phosphorus (kg ha^{-1}) and OK, Organic potassium (kg ha^{-1}).

Table 2. Treatment details for inorganic and integrated plant nutrient management-based fertilizer prescription in beetroot.

Treatments	FYM (t ha^{-1})	Fertiliser doses (kg ha^{-1})		
		N	P_2O_5	K_2O
T1-STCR-IPNS-35.0 t ha^{-1}	12.5	91	114	50
T2-STCR-IPNS-40.0 t ha^{-1}	12.5	140	174	77
T3-STCR-IPNS-45.0 t ha^{-1}	12.5	180	233	116
T4-STCR-NPK alone-35.0 t ha^{-1}	-	123	141	89
T5-STCR-NPK alone-40.0 t ha^{-1}	-	172	201	128
T6-STCR-NPK alone-45.0 t ha^{-1}	-	180	240	150
T7-Blanket (100% RDF alone)	-	120	160	100
T8-Blanket + FYM @ 12.5 t ha^{-1}	12.5	120	160	100
T9-Farmer's practice	-	80	85	76
T10-Absolute control	-	0	0	0

According to the treatment protocol, prior to sowing, the entire dose of phosphorus and potassium, along with half of the nitrogen dose, was applied as a basal treatment. The remaining half of the nitrogen dose was applied 30 days post-sowing. Before sowing, farmyard manure was added to the plots in accordance with the treatment guidelines. Nitrogen, phosphorus and potassium were supplied using urea, single super phosphate and muriate of potash, respectively. The beetroot seeds were sown with a spacing of 20 x 10 cm and thinning was carried out 20 days after sowing to maintain the spacing. Growth and yield traits were assessed at 30, 60 and 90 days after sowing (DAS).

The data on plant height (cm), no of leaves per plant, leaf width (cm), total chlorophyll, root yield (t ha^{-1}), total sugar (%), reducing sugar (%), non-reducing sugar (%), total soluble solid (^{0}B) and ascorbic acid (mg 100 g^{-1}) were recorded. Leaf chlorophyll content was measured using a SPAD-502 meter (Minolta Co. Ltd., Osaka, Japan). Total sugars and reducing sugars were measured using the method outlined by (9). Non-reducing sugars were calculated by subtracting reducing sugars from total sugars and expressed as a percentage.

Non-reducing sugars (%) = Total sugars (%) - Reducing sugars (%) (Eqn. 1)

The total soluble solids (TSS) were assessed using a hand-held refractometer with a range of 0-32 Brix. The refractometer was calibrated with distilled water after each reading, and the value was reported in Brix. Ascorbic acid was measured using the method described in (10).

Results and Discussion

Yield attributes

Plant height

Plant height was measured at 30 days after sowing (DAS), 60 DAS, and 90 DAS and the results showed significant differences among the treatments. At 30, 60 and 90 DAS, the highest plant height was observed in application of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) with 22.39 cm, 27.58 cm and 51.59 cm, respectively, which were statistically superior to all other treatments. Absolute control recorded the lowest plant height during 30, 60 and 90 DAS.

The beneficial impact of treatment (T3) on plant height may be attributed to the steady availability of nitrogen (N), an essential element of amino acids, nucleotides, nucleic acids, various coenzymes, cytokinins and alkaloids, which led to enhanced cell elongation, cell expansion and cell proliferation. The application of major nutrients and organic manure may have boosted photosynthetic activity, chlorophyll production, nitrogen metabolism, and auxin levels in the plants, resulting in a notable increase in plant height. The results are consistent with the findings of (11, 12). The plant height increased as the number of days after sowing (DAS) progressed. Organic manures contribute directly to plant growth by providing essential macro and micronutrients (13). The use of chemical fertilizers and organic manures significantly boosted plant height (14). The increase in plant height resulting from the use of organic manures combined with NPK could be attributed to the positive effect of organic manures' nitrification inhibition properties in the soil (15).

Number of leaves per plant

The number of leaves per plant recorded at various stages is shown in Table 3. At 30 DAS, 60 DAS and 90 DAS the highest number of leaves per plant was recorded in the application 180 N+233 P_2O_5+116 K_2O Kg ha^{-1}, along with FYM @12.5 t ha^{-1} (T3) with 10.80, 17.79 and 24.05, respectively, which were statistically different from the remaining treatments. The minimal number of leaves per plant was recorded in treatment of absolute control (T10).

The highest number of leaves per plant at all growth stages was observed in the T3 treatment, attributed to the prompt availability of all necessary nutrients, leading to an increased leaf count per plant. The likely reasons for the increased number of leaves may be attributed to the beneficial effects of macro nutrients on vegetative growth, which ultimately boost photosynthetic activity. These results are consistent with the findings of (16-19).

Leaf width

Variation among the treatments was recorded in leaf width due to treatments. Results on leaf width indicated that at 30, 60 and 90 days after sowing, the widest leaf width was observed in application of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) with 7.43 cm, 12.67 cm and 18.14 cm, respectively, which showed a statistically significant difference compared to the other treatments. The narrowest leaf width was recorded in treatment of absolute control (T10).

The maximum leaf width was observed in the T3 treatment, probably because the addition of FYM along with NPK significantly enhanced the leaf width of the beetroot. This could be attributed to the sustained nutrient availability from the use of both organic and inorganic forms. These results are consistent with the findings of (20), who reported that using organic materials in cauliflower ensures continuous nutrient supply to the plants, leading to enhanced growth and development.

Total chlorophyll

The total chlorophyll at various stages is shown in Table 3. The highest total chlorophyll was recorded in the 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3), with values of 25.43 (30 DAS), 34.08 (60 DAS) and

Table 3. Effect of different inorganic and integrated plant nutrient management on yield attributes of beetroot (two season mean data).

Treatment	Plant height (cm)			Number of leaves per plant			Leaf width (cm)			Total chlorophyll			Beetroot Yield (t ha^{-1})
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	
T1	16.28	28.53	45.51	9.08	15.04	21.96	4.74	10.59	15.83	21.89	28.73	40.08	35.40
T2	18.59	32.19	49.08	9.65	16.47	22.79	5.71	11.75	17.03	23.90	30.99	44.49	40.35
T3	22.39	38.38	51.59	10.80	17.79	24.05	7.43	12.67	18.14	25.43	34.08	47.28	44.21
T4	15.75	27.58	44.29	8.20	14.68	21.41	4.25	10.34	15.52	21.39	28.18	38.00	29.19
T5	17.77	30.70	46.39	8.21	16.22	22.89	5.53	11.66	16.61	23.43	30.79	43.44	38.90
T6	20.57	35.33	49.08	8.42	17.24	22.58	6.80	12.10	17.36	24.36	31.89	45.15	42.24
T7	15.63	27.01	43.72	8.06	13.91	20.16	4.38	9.79	15.03	20.69	27.88	36.63	28.34
T8	17.09	29.24	46.10	8.86	15.31	22.44	5.59	11.23	16.19	22.71	29.94	40.43	36.06
T9	14.74	25.17	44.18	7.85	14.09	20.06	4.09	9.47	14.78	20.52	27.54	35.34	25.96
T10	14.31	25.33	42.29	7.71	13.50	19.47	3.99	8.93	13.92	19.97	27.15	34.60	25.19
SEd	**0.41**	**0.70**	**1.18**	**0.22**	**0.25**	**0.47**	**0.12**	**0.23**	**0.33**	**0.50**	**0.47**	**0.83**	**0.93**
CD (0.05)	**0.87**	**1.47**	**2.49**	**0.47**	**0.53**	**0.99**	**0.26**	**0.49**	**0.70**	**1.06**	**1.00**	**1.76**	**1.96**

47.28 (90 DAS). The data showed significant differences when compared to all other treatments. The lowest total chlorophyll was recorded in treatment of absolute control (T10).

The T3 treatment, comprising 180 N, 233 P_2O_5, 116 K_2O kg ha^{-1} along with FYM at 12.5 t ha^{-1}, resulted in highest values chlorophyll at each stage. This may be due to the slow and steady release of available macronutrients, especially nitrogen. Nitrogen is a key component of chlorophyll, proteins, and amino acids and its synthesis is enhanced by an increased supply of nitrogen in the soil (21). Improved nutrient availability and a balanced C/N ratio likely contributed to the higher chlorophyll index observed in all the organic sources applied (22).

Beetroot yield

The results indicated that the highest beetroot yield (44.21 t ha^{-1}) was recorded in the application of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) and was significantly superior to all other treatments. The lowest beetroot yield was observed in the absolute control treatment (T10) (25.19 t ha^{-1}). The treatment received 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) recorded the highest beetroot yield of 44.21 t ha^{-1}, which is 4.44%, 22.60% and 55.99% higher than the STCR-NPK alone (T6), blanket with FYM @12.5 t ha^{-1} (T8) and blanket fertiliser alone (T7), respectively (Fig. 1).

The highest beetroot yield was observed in the T3 treatment, attributed to the maximum root length and diameter. The application of an optimal amount of NPK and organic manures supports the bio-physical processes in crop plants, facilitating the conversion of proteins and carbohydrates into root growth. Organic manures directly influence plant growth by providing all essential macro and micronutrients in available forms during mineralization and by enhancing the physical and physiological properties of the soil. Similar results have been reported by (23). Organic fractions might have enhanced the efficiency of chemical fertilizers, boosted nitrogen-fixing bacterial activity, and increased the humification rate, which improves the availability of both native and added nutrients, thereby boosting yield and yield-related characteristics (24). Similar findings regarding root yield have been reported by (25-27).

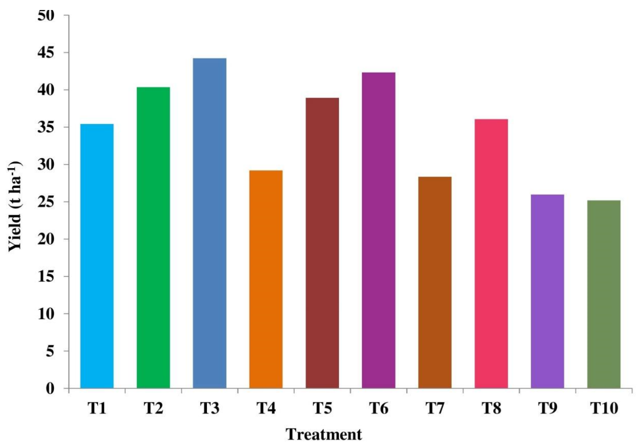

Fig. 1. Effect of different fertiliser dosages and STCR-IPNS on beetroot yield (t ha^{-1}).

Quality parameter

Total sugar

The total sugar content of beetroot roots was significantly influenced by the various treatments, as shown in Table 4. The highest total sugar content (8.95%) was recorded in the application of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3), which was significantly superior to all other treatments. The lowest total sugar content (6.69%) was recorded in the absolute control, which was comparable to T9 (7.82%). The treatment with STCR-IPNS based fertiliser dose of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) recorded 18.45% higher total sugar than STCR-NPK alone (T6), while it was 12.42% higher than the Blanket dosealong with FYM @12.5 t ha^{-1} (T8).

The data showed that the highest total sugar content was observed in the T3 treatment, which received 180 N, 233 P_2O_5 and 116 K_2O kg ha^{-1}, along with FYM at 12.5 t ha^{-1}. This increase in total sugar accumulation in the beetroot could be attributed to the improved nutrient availability and enhanced synthesis of total sugars when the plants received a combination of chemical fertilizers and organic manure. The current results closely align with the findings of (28).

Reducing sugar

The highest reducing sugar content (2.08%) was observed in treatment 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) (STCR-IPNS), which was statistically different from all other treatments. The lowest reducing sugar content (1.42%) was recorded in the absolute control treatment. Reducing sugar content of beetroot in STCR-IPNS based fertilizer dose of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) found to record 20.56% higher reducing sugar in STCR-NPK (T6). STCR-IPNS based fertilizers dose along with FYM @12.5 t ha^{-1} (T3)

Table 4. Effect of different inorganic and integrated plant nutrient management on quality parameter of beetroot (two season mean data).

Treat ment	Total sugar (%)	Reducing sugar (%)	Non-reducing sugar (%)	Total soluble solids	Ascorbic acid (mg 100 g^{-1})
T1	8.05	1.83	6.22	11.08	3.14
T2	8.52	1.96	6.56	11.65	3.36
T3	8.95	2.08	6.87	12.80	3.62
T4	7.20	1.57	5.63	10.20	2.60
T5	7.21	1.59	5.62	10.21	2.69
T6	7.40	1.64	5.76	10.42	2.91
T7	7.03	1.52	5.51	10.06	2.55
T8	7.85	1.77	6.08	10.86	3.08
T9	6.82	1.47	5.35	9.85	2.46
T10	6.69	1.42	5.27	9.71	2.41
SEd	**0.18**	**0.04**	**0.10**	**0.16**	**0.05**
CD	**0.38**	**0.09**	**0.21**	**0.35**	**0.11**

recorded 13.65% higher reducing sugar than the blanket fertilizer dose along with FYM @12.5 t ha^{-1} (T8).

The result showed that maximum reducing sugar content was recorded in the treatment received 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3). It was the combination of chemical fertilizer with FYM that led to a slightly higher accumulation of reducing sugars in beetroot. Slow and steady release of nutrients in critical growth stages resulted in higher reducing sugar. The higher availability of nitrogen required for tuber growth and development may have led to an increase in reducing sugars, which subsequently enhanced sugar accumulation after starch synthesis. With the combined use of inorganic and organic inputs, the sugar content has been found to increase. It clearly indicates greater nutritional availability for the plant (29).

Non reducing sugar

The highest non-reducing sugar content (6.87%) was recorded in treatment 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3), which was a statistically superior to all other treatment. The lowest non-reducing sugar content (5.27%) was observed in the absolute control treatment. Non-reducing sugar content of beetroot in STCR-IPNS based fertilizer dose of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) was found to record 17.73% higher non-reducing sugar than STCR-NPK (T6). STCR-IPNS based fertilizers dose along with FYM @12.5 t ha^{-1} (T3) recorded 12.00 % higher non-reducing sugar than the blanket fertilizer dose along with FYM @12.5 t ha^{-1} (T8). The results show maximum non-reducing sugar in T3 treatment, which was due to improved nitrogen availability and uptake facilitated by the use of organic manures, leading to a balanced C/N ratio and heightened plant metabolic activity. Similar findings were made by (30, 31).

Ascorbic acid

The highest amount of ascorbic acid content (3.62 mg 100 g^{-1}) was found in treatment of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3). This was followed by treatment with 4.23 mg 100 g^{-1}, using 140 N + 174 P_2O_5 + 77 K_2O kg ha^{-1} @ 12.5 t ha^{-1} and T1 with 4.06 mg 100 g^{-1}, using 91 N + 114 P_2O_5 + 50 K_2O kg ha^{-1} @ 12.5 t ha^{-1}, both of which were statistically superior to all other treatments. The lowest ascorbic acid content was recorded in absolute control (T10) (2.47 mg 100 g^{-1}), representing the absolute control treatment. The treatment with STCR-IPNS based fertiliser dose of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) recorded 24.39% higher ascorbic acid than STCR-NPK alone (T6), while it was 17.86% higher than the blanket dose along with FYM @12.5 t ha^{-1} (T8).

The data indicated that the highest ascorbic acid content was observed in the T3 treatment, which received 180 kg N, 233 kg P_2O_5 and 116 kg K_2O per hectare along with 12.5 t ha^{-1} of FYM. Naturally, application of inorganic fertilizers combined with FYM, improved macronutrient availability, leading to increased carbohydrate production and consequently, higher ascorbic acid content. Along with N and P fertilizers, the inclusion of manures might have increased the ascorbic acid content in beetroot, potentially boosting root biomass production through enhanced nutrient absorption by the crop. Similar findings related to the increase in ascorbic acid content in roots were also reported by (32-34).

Total soluble solids (°Brix)

The maximum TSS content (12.80 Brix) was observed in application of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3), which was significantly higher than all other treatments. The minimum TSS content (9.89 Brix) was noted in the absolute control (T10) treatment. The treatment with STCR-IPNS based fertiliser dose of 180 N+233 P_2O_5+116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3) recorded 22.84% higher TSS than STCR-NPK alone (T6), while it was 17.86% higher than the blanket dose along with FYM @12.5 t ha^{-1} (T8).

Highest TSS content was recorded in T3 treatment. This could be attributed to the accumulation of more reserve substances in beetroot. Similar results have been reported by (35, 25). The enhanced production of carbohydrates led to a higher amount of total soluble solids, which in turn improved the physiological and biochemical functions of the plant system. The present results may align with those of (36).

A correlation plot (Fig. 2) was analyzed to explore the relationships between variables and principal component groups. All beetroot quality parameters exhibited positive correlations with the PC groups, indicating possible connections between the variables and beetroot quality parameters observed across different treatments.

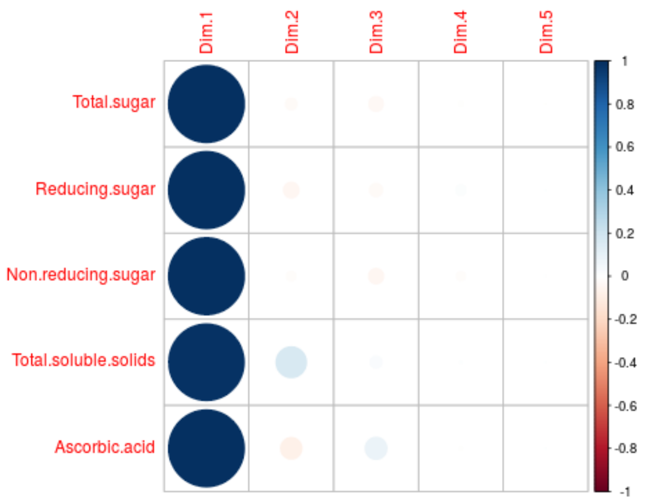

Fig. 2. Correlation plot between variables and principal components.

Conclusion

The results from the two field experiments conducted in Nilgiri District of Tamil Nadu, India during summer and winter 2023-24 indicated that the highest yield of beetroot was obtained in treatment with STCR-IPNS based fertilizer prescription, which received 180 N, 233 P_2O_5 and 116 K_2O Kg ha^{-1} along with FYM @12.5 t ha^{-1} (T3). Beet root yield was 4.41% higher in STCR-IPNS (T3) when compared to the treatment that received only inorganic fertilizer (STCR-

NPK alone) (T6). Also, STCR-IPNS (T3) treatment registered higher plant height, number of leaves per plant, leaf width, total chlorophyll, yield, total sugar, reducing sugar, non-reducing sugar, ascorbic acid and TSS compared to the remaining all other treatments. According to the experimental results, the application of STCR-IPNS based fertilizer prescription led to a significant increase in beetroot yield and quality.

Acknowledgements

The authors wish to thank Tamil Nadu Agricultural University for providing necessary support and facilities to perform this work.

Authors' contributions

RA conducted the experiment and drafted the manuscript; KM designed the experiment and edited the manuscript; SM, PM and AS interpreted the results of the study and SPT, RA and GS helped with the statistical analysis and edited the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

References

1. HAPIS-Horticulture Area and Production information System. Horticulture Area and Production Information system, Ministry of Agriculture, Government of India. 2017-2018. http://aps.dac.gov.in.
2. Jackson M. Soil chemical analysis, pentice hall of India Pvt. Ltd., New Delhi, India. 1973; 498:38:336.
3. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science. 1934; 37(1):29-38. https://doi.org/10.1097/00010694-193401000-00003.
4. Subbiah BV, Asija GL. A rapid procedure for determination of available nitrogen in soil. Current Science, 1956; 25: 259-260.
5. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil science. 1945; 59(1):39-46.. https://doi.org/10.1097/00010694-194501000-00006
6. Hanway JJ, Hiedal H. Soil analysis methods as used in the iowa state college soil testing laboratory. Iowa agriculture. American Society of Agronomy, 1952; 57:1025-27. .
7. Schollenberger CJ, Dreibelbis FR. Analytical methods in base exchange investigations on soils. Soil Science. 1930; 30(3):161-74. https://doi.org/10.1097/00010694-193009000-00001..
8. Lindsay WL, Norvell W. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil science society of America journal. 1978; 42(3):421-8. https://doi.org/10.2136/sssaj1978.03615995004200030009x .
9. A.O.A.C. Official methods of analysis. 15 th Edn. Association of official Analytical chemist, Washington, D.C.1956.
10. A.O.A.C. Official methods of analysis. 15 th Edn. Association of official Analytical chemist, Washington, D.C.1990.
11. Kirad KS, Swati B, Singh DB. Integrated nutrient management on growth, yield and quality of carrot. Karnataka Journal of Agricultural Sciences, 2010; 23(3):542-543.
12. Growth, yield and nutrient uptake by turnip (*Brassica Rapa* L.) cv. Pusa Sweti and their economics. Journal of Soils and Crops, 2012; 22(1):1-9.
13. Uddain J, Chowdhury S, Rahman MJ. Efficacy of different organic manures on growth and productivity of radish (*Raphanus sativus* L.). International Journal of Agriculture, Enviornment and Biotechnology. 2010; 3(2):189-93..
14. Tovihoudji GP, Djogbenou CP, Akponikpe PB, Kpadonou E, Agbangba CE, Dagbenonbakin DG. Response of Jute Mallow (*Corchorus olitorius* L.) to organic manure and inorganic fertilizer on a ferruginous soil in North-eastern Benin. Journal of Applied Biosciences. 2015; 92:8610-9. https://doi.org/10.4314/jab.v92i1.5.
15. Kumar S, Sutanu M, Kumar S, Singh HD. Efficacy of organic manures on growth and yield of radish (*Raphanus sativus* L.) cv. Japanese White. International Journal of Plant Sciences, 2014; 9 (1): 57-60.
16. Mounika V, Lakshminarayana D, Srinivas J, Sathish G, Gouthami P. Influence of Integrated Nutrient Management in Beet Root (*Beta vulgaris* L.) Cv. Crimson Globe for Growth and Yield under Alkaline conditions. Biological Forum - An International Journal, 2022; 14(1):464-469.
17. Jagadeesh CH. Effect of organic manures on growth, yield and quality of beet root, M.Sc. (Horti). Mojerla, Mahabub Nagar: College of Horticulture; 2015
18. Jabeen A, Narayan S, Hussain K, Ahamed KF, Ahmed MS. Effect of organic manures and biofertilizers on quality of spinach beet (*Beta vulgaris* var. bengalensis). Int. J. Curr. Microbiol. Appl. Sci. 2018;7(9):1312-17. https://doi.org/10.20546/ijcmas.2018.709.156 .
19. Mehwish K, Muhammad SJ, Kashif W, Khan MS. Response of carrot (*Daucus carota* L.) growth and yields to organic manure and inorganic fertilizers. American-Eurasian J. Agric. & Environ. Sci. 2016; 16(6):1211-8.
20. Hasan MR, Solaiman AH. Efficacy of organic and organic fertilizer on the growth of *Brassica oleracea* L. (Cabbage). International Journal of Agriculture and Crop Sciences. 2012; 4 (3):128-38.
21. Verma JP, Rathore SV, Kushwaha CS. Effect of level and method of application of nitrogen through urea on the performance of okra (*Abelmoschus esculentus* (L.) Moench). Progressive Horticulture, 1974; 5(4): 77-80.
22. Gairola S, Umar S, Suryapani S. Nitrate accumulation, growth and leaf quality of spinach beet (*Beta vulgaris* Linn.) as affected by NPK fertilization with special reference to potassium. Indian Journal of Science and Technology. 2009; 2(2):35-39. https://doi.org/10.17485/ijst/2009/v2i2.2.
23. Kushwah L. Effect of organic manures, inorganic fertilizers and their combinations on growth, yield and quality of radish *(Raphanus sativus* L.*),* M.Sc (Horti.). Gwalior RVSKVV.2016.
24. Shreeniwas CH, Murlidhar S, Rao MS. Yield and quality of ridge gourd fruits as influenced by different levels of inorganic fertilizers and vermin-compost. Annals of Agricultural Research, 2000; 21; 262-66.
25. Mahorkar VK, Bodkhe VA, Ingle VG, Jadhao BJ, Gomase DG. Effect of various organic manures on growth and yield of radish. Asian Journal of Horticulture, 2007; 2(1):155-57.
26. Rao KR, Mushan LC, Mulani AC, Khatavkar RS, et al. Effect of vermicompost on the growth and yield of onion (*Allium cepa*). Karnataka Journal of Agricultural Science, 2009; 23(2): 361-63.
27. Narayan S, Kanth RH, Narayan R, Khan FA, et al. Effect of planting dates and integrated nutrient management on productivity and profitability of potato (*Solanum tuberosum*) in Kashmir valley. Indian Journal of Agronomy. 2014; 59(1):145-50.

https://doi.org/10.59797/ija.v59i1.4527.

28. Jayathilake PKS, Reddy IP, Srihari D, Reddy KR, Neeraja G. Integrated nutrient management in onion (*Allium cepa* L.). *Tropical Agricultural Research*. 2033; 15:1-9.
29. Congera A, Anjanappa M, Indiresh K, Basavaraja P, Munirajappa R. Influence of organic manures, inorganic fertilizers and bio-fertilizers on yield and quality attributes of potato (*Solanum tuberosum* L.) J Agri Horti Res, 2021; 5(1): 57-62. https://doi.org/10.21203/rs.3.rs-150214/v1
30. Jagadeesh M, Madhavi M, Siva P, Padmaja VV. Effect of Organic Manures on Growth and Yield attributes of Beet Root cv. Crimson Globe. International Journal of Current Microbiology & Applied Sciences, 2018; 7(11): 3538-53. https://doi.org/10.20546/ijcmas.2018.711.403
31. Baria VK, Goswami PB, Nadoda NA. Effect of integrated nitrogen management on the quality attributes of beetroot (*Beta vulgaris* L.) var. crimson globe. The Pharma Innovation Journal, 2023; 12(11): 1830-32.
32. Ismail AMA, Ghait RAA. Effect of balanced fertilization of NPK on yield and quality of sugar beet. Egyptian Journal of Agricultural Research. 2004; 82(2): 717-29. https://doi.org/10.21608/ejar.2004.258178
33. Fatideh MM, Asil MH. Onion yield, quality and storability as affected with different soil moisture and nitrogen regimes. South West. J. Hortic. Biol. Environ. 2012; 3:145-65.
34. Chatterjee R, Jana JC, Paul PK. Vermicompost substitution influences shelf life and fruit quality of tomato (*Lycopersicon esculentum* Mill.). National Institute of Food Technology Entrepreneurship and Management (NIFTEM), Sonipat, Haryana, India.2008. https://doi.org/10.7726/ajast.2013.1006.
35. Pandey A, Sharma MD, Shah SC. Quality parameters of carrot as affected by varieties and nutrient sources. Azarian Journal of Agriculture, 2017; 4(6): 200-05.
36. Singh DP, Kumar S, Sutanu M, Vijay PK. Studies on integrated nutrient management on growth, yield and quality of carrot (*Daucus carota* L.). International Journal of Agriculture Sciences, 2017. 51(8): 2187-88.