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Studies on high density planting and nutrient requirement of banana in different states of India

Debnath Sanjit[1], Bauri F.K.[1], Swain S.[2], Patel A.N. [3], Patel A.R. [3], Shaikh N.B. [4], Bhalerao V.P. [4], Baruah K. [5], Manju P.R. [6], Suma A.[6], Menon R.[6], Gutam S.[7] and Patil P.[7*]

ICAR-All India Coordinated Research Project on Fruits; [1]BidhanChandra Krishi Viswavidyalaya, Mohanpur, West Bengal
[2]Orissa University of Agriculture and Technology, Bhubaneswar, Odisha;
[3]Navsari Agriculture University, Gandevi, Gujarat
[4]Mahatma Phule Krishi Vidyapeeth, Jalagon, Maharashtra;
[5]Assam Agricultural University, Jorhat, Assam
[6]Kerala Agriculture University, Kannara, Kerala; [7]Indian Institute of Horticultural Research, Hessarghatta, Bengaluru
*Corresponding author Email : pcfruits.iihr@icar.gov.in

ABSTRACT

An experiment was conducted under the ICAR-All India Coordinated Research Project on Fruits to study the high density planting (HDP) and nutrient requirement of banana at six research centres across the country, including Bhubaneswar (Orissa), Gandevi (Gujarat), Jalgaon (Maharashtra), Jorhat (Assam), Kannara (Kerala) and Mohanpur (West Bengal) to enable higher productivity of banana and profit to farmers. Objective of this study was to explore the possibility of increasing productivity through intervention of only per unit plant population (through planting system) and level of nutrition, but without any interference to the regional choices of variety (e.g. choice variety Nendran for Kerala or Martaman for West Bengal), production system (mono/poly- clone, single/multi-year plantation, and POP of respective states), for which national productivity ranges are much skewed also. Results indicated that intervention of only plant density could increase productivity of banana within the existing system of production and choice of variety of different region or states. The experiment was laid out in RBD with four planting densities (S_1P_2, S_1P_3, $S_2P_2$and S_2P_3, where S_1=2m x3m, S_2=1.8m x3.6m, P_2=2 suckers/hill, P_3=3 suckers/hill), three nutrition levels (F_1, $F_2$and F_3, which is 100%, 75% and 50% of RDF) and one with region-specific conventional planting density and nutrition (100% of RDF) practices as control.The results of this experiment showed that HDP (S_1P_3, 5000 plants / ha) in banana, accommodating three suckers per hill at 2m x 3m spacing increased productivity over the conventional system at the Bhubaneswar, Gandevi, Jorhat, Kannara and Mohanpur centres. The increase in productivity due to HDP (5,000/ha) over control was 28.9% (RDF 25%) to 50.6% (RDF 100%) at Bhubaneswar, 15.2% (RDF 25%) to 21.9% (RDF 100%) at Gandevi, 4.0% (RDF 25%) to 7.4% (RDF 100%) at Jorhat, 33.5%(RDF 25%) to 43.5% (RDF 100%) at Kannara and 46.5%(RDF 25%) to 79.0% (RDF 100%) at Mohanpur. The nutrient requirement under HDP was 100% RDF at Kannara, 75% RDF at Bhubaneswar and Mohanpur and 50% RDF at Gandevi and Jorhat centres, which indicates a saving in cost of fertilizer input by 25% -50%. It is therefore, recommended for HDP (5000 plants/ha) in banana, accommodating three suckers per hill at 2m x 3m (6.6 ft x 3.8 ft) spacing with 50% RDF in the agro-climatic regions of Gandevi and Jorhat, with 75% RDF in the agro-climatic regions of Bhubaneswar and Mohanpur and with 100% RDF in the agro-climatic region of Kannara in order to ensure higher productivity and profit to farmers.

Keywords: Banana, productivity, input saving, nutrition strategy and planting

INTRODUCTION

Sustainable increase in productivity is the key objective of commercial fruit cultivation to meet the per-head demand of fruits for human nutrition. High density planting (HDP), mediated by canopy management, was found to be very useful for increasing the productivity of fruit crops. However, the commonly used canopy management tools for perennial fruit trees (training, pruning and dwarfing rootstocks) were not feasible for canopy management and HDP of herbaceous perennial plants such as banana (Debnath *et al.*, 2015). Productivity in bananas is governed by the 'source' and 'sink' components of the plant system and its usefulness necessitates distinguishing between physiological and agronomic approaches (Turner, 1998). HDP in banana was found to have direct effect on growth and yield parameters, *viz*., pseudostem height, girth, leaf number, leaf area index, absorption of solar light, bunch weight and productivity (Nalina *et al*., 2000; Thippesha *et al*., 2005; Debnath *et al*., 2017). This, therefore, indicated the need forregion-specific fine-tuning of agronomic practices including spacing, plant density, nutrition and so on, for successful HDP in banana. For HDP of cv. Martaman (AAB) in the Gangetic alluvium region of West Bengal, the identified optimum leaf area index (LAI) was 5.50, corresponding to a plant population of 5000/ha, accommodating 3 plants/pit at 2m × 3m spacing (Debnath *et al*., 2015). These technological inputs on HDP in banana through research works are essentially needed for intervention and betterment of the much-skewed distribution of banana productivity across the different states in India. The average national productivity of banana in India is 34.86 t/ha, of which only five states recorded a productivity of more than 45 t/ha - Madhya Pradesh (69.52 t/ha), Gujarat (65.62 t/ha), Andhra Pradesh (56.24 t/ha), Maharashtra (52.04 t/ha) and Uttar Pradesh (45.72 t/ha). In fact, banana is grown in rest of the states with much lower productivity (3.40 to 44.94 t/ha) (Anon, 2018). With this back ground, an experiment was conducted to study the HDPand nutrient requirement of banana across the different states in the country for increasing productivity and profitability of the farmers.

MATERIALS AND METHODS

The Indian Council of Agricultural Research (ICAR), through its All India Coordinated Research Project (AICRP) on Fruits, conducted an experiment between 2009 to 2015 to study the HDP and nutrient requirement of banana at six research centres across the country, including Bhubaneswar (Orissa), Gandevi (Gujarat), Jalgaon (Maharashtra), Jorhat (Assam), Kannara (Kerala) and Mohanpur (West Bengal) to ensure higher productivity of banana and profit for farmers (Table1). The experiment was laid out in Randomized Block Design (RBD), replicated four times with 15 plants per replication and 13 treatment combinations, including four planting densities (S_1P_2, S_1P_3, S_2P_2 and S_2P_3, where S_1=2mx3m, S_2=1.8m x3.6m, P_2=2 suckers/hill, P_3=3 suckers/hill), three nutrition levels (F1, F2 and F3=100%, 75% and 50% of RDF) and with one

Table 1. Soil type, agro-climatic region and location of experimental sites under ICAR-AICRP on Fruits

Centre	Soil type, agro-climatic region and location
Bhubaneswar OUAT, Odisha	Soil: Saline, lateritic, alluvial, red and mixed red and black; East and South East Coastal Plain; 20^{0}15'N latitude and 85^{0}52' E longitude
Gandevi NAU, Gujarat	Soil: Clay loam; Agro-climatic region-I (south Gujarat) and heavy rainfall area; 21^{0}N latitude, 73^{0}E longitude, 7.6 m above mean sea level
Jalgaon MPKV, Maharashtra	Soil: Black; Deccan plateau, hot semi-arid eco region; 21^{0}Nlatitude, 74.33^{0}Elongitude
Jorhat AAU, Assam	Soil: Sandy loam; upper Brahmaputra valley zone; 26.75^{0}Nlatitude, 94.22^{0}Elongitude
Kannara KAU, Kerala	Soil: Clay loam; 10°32'6.5" N latitude, 76°20'9.8" E longitude, 58m above mean sea level
Mohanpur BCKV, West Bengal	Soil: Clay-loam; the Gangetic Alluvium region of West Bengal; 23.5^{0}North latitude, 89^0 Elongitude, 9.75 m above mean sea level

region-specific conventional planting density and nutrition (100%RDF) practice as control. For a particular region/state, existing package of practices (POP) was fixed and followed both for conventional density and treatment densities. Compared the impact of density and nutrition level (variable factor) only, while the POP (including irrigation method and amount) was a constant for the same region/state. Details were given above on the variable factors only, viz., plant population (S_1P_2, S_1P_3, S_2P_2& S_2P_3) and nutrition levels (F1, F2 & F3). Uniform, healthy sword suckers were disinfected and planted in $1m^3$ pits as per spacing treatments. Region-specific recommended varieties and POP (nutrition, irrigation, protection, and so on) were followed for the respective research centres (Table 2). Initial soil nutrient status was estimated from the soil samples randomly collected

Table 2. Variety, planting materials, conventional spacing, plant population, recommended fertilizer dose (RDF) and irrigation method followed at different centres

Centre	Variety & planting material	Conventional spacing & plant population/ha	Recommended dose of fertilizer (RDF/plant/crop cycle)	Irrigation method followed
Bhubaneswar	Grand Nain (AAA), Sucker	1.8 m x 1.8 m, 3086	10 Kg FYM + 200g N + 50g P_2O_5 + 200g K_2O	Drip
Gandevi	Grand Nain, Sucker	1.8 m x 1.8 m, 3086	10 Kg FYM + 300g N + 90g P_2O_5 + 200g K_2O	Drip
Jalgaon	Grand Nain, Sucker	0.9x1.5x2.1m, 4444 (paired row system)	10 Kg FYM + 200g N + 40g P_2O_5 + 200g K_2O	Drip
Jorhat	Jahaji (AAA), Sucker	1.5m x1.5m, 4444	12 Kg FYM + 110g N + 33 g P_2O_5 + 330 g K_2O	Rainfed
Kannara	Nendran (AAB), Sucker	2 m x 2 m, 2500	10 Kg FYM + 190g N + 115 g P_2O_5 + 300 g K_2O	Basin
Mohanpur	Martaman (AAB), Sucker	2 m x 2 m, 2500	10 Kg FYM + 200g N + 40g P_2O_5 + 200g K_2O	Check basin

Table 3. Initial soil nutrient status of experimental plots at different centres

Centre	Organic carbon (%)	Total nitrogen (%)	Available Soil Nitrogen (N) content (kg/ha)	Available Soil Phosphorus (P_2O_5) content (kg/ha)	Available Soil Potassium (K_2O) content (kg/ha)
Bhubaneswar	0.61	0.67	200.0	67.6	134.4
Gandevi	0.66	-	230.0	52.8	230.0
Jorhat	0.60	0.64	192.2	40.1	119.1
Kannara	0.70	0.70	260.0	55.0	155.0
Mohanpur	0.78	0.70	285.0	58.0	165.0

from experimental field during final land preparation (Table 3). Observations on growth characters (*viz*., pseudostem height (m), girth (cm), leaf number, leaf area index, days taken for shooting) and leaf nitrogen, phosphorus and potassium content (N, P & K in %) were recorded at shooting or flowering stage of the plant. The crop duration (days), finger number per bunch, finger weight (g), bunch weight (kg), yield (t/ha), TSS (^{0}B), acidity (%), shelf-life (days) of fruits, yield increase over control (%), B: C ratio and soil nutrient status (available N, $P_2O_5$and K_2O in kg/ha) were recorded after harvest. Quality of fruit was analyzed as per A.O.A.C. (1984) methods. The available nitrogen was determined by using the alkaline potassium permanganate method (Subbiah

and Asija, 1956). The available soil phosphorus was estimated by Olson method (Jackson, 1967). Available soil potassium was determined by using Flame photometric method, whereas Walkley and Black's rapid titration method was used to determine the organic carbon content of the soil (Jackson, 1967). The micro-kjeldahl method as described by Black (1965) was used to estimate the leaf N content. The Leaf P content was estimated by using the Vanado-molybdate yellow colour method and the leaf K content was determined by using Flame photometry (Chapman and Pratt, 1961). The amount of nutrients applied per hectare was estimated on the basis of plant population per hectare under HDP and conventional systems and the recommended fertilizer dose (RDF) at the respective centres, considering that per ton FYM contributed 0.5 kg N, 0.2kg P_2O_5 and 0.5 kg K_2O. The amount of nutrients removed through fruit harvest from HDP (those that produced higher yield and highest B:C ratio) and conventional systems was calculated based on fruit yield and nutrient removal (6.7 kg N, 1.7 kg $P_2O_5$and 6.7 kg K_2O) per ton banana produce (Ganeshamurthy *et al*., 2011). Pooled data for three crop cycles' was analyzed for statistical inference by following the statistical method for RBD, as described by Gomez and Gomez (1983).

RESULTS AND DISCUSSION

The Major objective of this study was to investigate productivity increase, if any, due to variations in per unit plant population and nutrition level. Yield increase for each region/state was estimated separately, in respect of its variety and POP only, by comparing the yield under HDP & conventional density of that particular variety. It was reflected from the observations that HDP could increase productivity in different region/state with the same variety & POP of respective region, only including intervention of HDP system.

It was observed that the plant growth characters showed significant variations (C.D. at 5%) due to density of planting and a level of nutrition at all centres (Tables 4, 5 and 6). Maximum height of the pseudostem was recorded with a planting density of 5000/ha with 100% RDF (S1P3F1) at all centres

Table 4. Variations in pseudostem height (H in m) and girth (G in cm) at shooting stage of plant due to different planting densities and nutrition levels

Treat-ment	No. of Plants/ha.	Bhubaneswar		Gandevi		Jorhat		Kannara		Mohanpur	
		H	G	H	G	H	G	H	G	H	G
S1P2F1	3333 plant/ ha	2.32	55.12	1.85	61.18	1.22	61.27	3.23	42.25	2.90	64.38
S1P2F2		2.30	54.53	1.78	59.38	1.21	58.30	3.12	40.92	2.87	62.80
S1P2F3		2.28	53.82	1.73	58.05	1.18	59.40	3.06	41.35	2.83	62.53
S1P3F1	5000 plant/ ha	2.41	53.91	1.98	59.88	1.81	53.30	3.38	41.15	3.02	62.42
S1P3F2		2.39	51.62	1.89	59.01	1.76	55.67	3.29	40.66	2.99	61.10
S1P3F3		2.37	50.23	1.86	55.47	1.40	63.50	3.24	39.15	2.97	60.46
S2P2F1	3086 plant/ ha	2.31	56.83	1.79	60.21	1.58	57.20	3.23	43.10	2.87	65.43
S2P2F2		2.27	55.74	1.75	56.77	1.12	63.10	3.14	41.70	2.86	64.83
S2P2F3		2.25	54.95	1.69	56.33	1.10	56.10	3.11	42.25	2.82	63.19
S2P3F1	4630 plant/ ha	2.38	54.94	2.00	58.25	1.28	57.53	3.37	41.65	2.99	62.47
S2P3F2		2.33	53.91	1.93	55.99	1.39	56.10	3.29	41.15	2.92	61.73
S2P3F3		2.31	52.87	1.86	55.98	1.36	65.10	3.25	40.00	2.90	61.33
Control		2.20	57.01	1.87	62.78	1.13	74.10	3.05	46.85	2.78	66.18
SEm (±)		0.02	0.33	0.04	1.05	0.004	0.65	1.23	0.41	0.04	0.79
C.D. at 5%		0.07	1.54	0.12	2.96	0.008	0.42	0.03	1.139	0.08	1.62

Table 5. Variations in leaf number per plant and leaf area index (LAI) at shooting stage of plant due to different planting densities and nutrition levels.

Treat-ment	No. of Plants/ ha.	Bhubaneswar		Gandevi		Jorhat		Kannara		Mohanpur	
		Leaf/ Plant	LAI	Leaf/ Plant	LAI	Leaf/ Plant	LAI	Leaf/ Plant	LAI	Leaf/ Plant	LAI
S1P2F1	3333	10.59	3.58	20.89	1.02	24.65	2.60	11.00	5.48	12.70	3.25
S1P2F2	plant/	10.44	3.47	20.33	0.99	26.16	2.65	10.40	5.17	12.40	3.17
S1P2F3	ha	10.32	3.36	20.04	0.97	24.33	2.44	10.20	5.29	11.90	3.05
S1P3F1	5000	10.21	4.35	19.79	1.00	26.64	2.83	10.80	8.16	11.60	4.45
S1P3F2	plant/	9.82	4.22	19.47	0.98	25.62	2.58	10.40	8.11	11.30	4.35
S1P3F3	ha	9.64	4.15	19.02	0.94	25.32	2.72	10.00	7.98	11.00	4.22
S2P2F1	3086	11.02	3.26	20.78	1.00	23.76	2.45	11.67	3.53	13.10	3.11
S2P2F2	plant/	10.64	3.14	20.35	0.97	24.03	2.16	11.27	3.65	12.80	3.03
S2P2F3	ha	10.62	3.09	19.56	0.90	23.74	2.49	10.70	3.47	12.10	2.87
S2P3F1	4630	10.32	4.14	19.65	0.99	26.33	2.53	10.80	5.30	11.70	4.16
S2P3F2	plant/	10.27	4.05	19.50	0.95	26.05	2.65	10.40	5.33	11.40	4.05
S2P3F3	ha	9.84	3.92	19.30	0.93	26.15	2.71	10.50	5.14	11.00	3.91
Control		11.24	2.70	21.53	1.04	21.45	6.48	13.50	1.72	13.60	2.61
SEm (±)		0.17	0.17	0.42	0.02	0.53	0.22	0.31	0.56	0.27	0.50
C.D. at 5%		0.52	0.52	1.17	0.07	1.10	0.46	0.92	1.20	0.55	1.01

Table 6. Variations in days taken for shooting (DS in days) and crop duration (CD in days) due to different planting densities and nutrition levels.

Treat-ment	No. of Plants/ha.	Bhubaneswar		Gandevi		Jorhat		Kannara		Mohanpur	
		DS	CD	DS	CD	DS	CD	DS	CD	DS	CD
S1P2F1	3333	217.4	309.3	288.5	398.1	254.7	341.7	247.5	336.1	297.1	389.1
S1P2F2	plant/	214.3	304.2	294.8	390.3	253.3	342.9	248.2	338.7	293.3	383.3
S1P2F3	ha	212.5	299.3	298.9	402.8	252.0	341.2	258.5	343.7	292.6	379.6
S1P3F1	5000	240.4	338.4	312.2	413.0	279.7	335.4	259.6	348.1	309.7	407.7
S1P3F2	plant/	236.7	332.7	302.7	421.5	281.7	352.7	259.5	347.5	303.4	399.4
S1P3F3	ha	219.3	312.7	311.4	420.8	284.7	350.1	265.8	354.1	298.6	391.6
S2P2F1	3086	218.6	308.4	291.2	393.7	245.0	332.1	239.6	329.5	295.3	385.3
S2P2F2	plant/	216.8	303.4	285.3	383.2	242.0	326.0	240.7	330.2	293.5	380.5
S2P2F3	ha	215.5	299.3	293.8	407.8	240.7	322.9	247.6	336.1	296.1	380.1
S2P3F1	4630	236.6	331.5	313.7	411.5	270.7	351.0	251.5	339.5	306.4	401.4
S2P3F2	plant/	237.4	329.8	313.3	415.7	272.3	351.6	257.3	345.3	304.2	396.2
S2P3F3	ha	219.8	307.9	324.0	414.5	269.7	347.2	259.8	348.5	299.9	387.9
Control		210.3	296.0	291.5	378.1	230.7	328.0	219.3	309.3	275.4	374.5
SEm (±)		3.63	5.23	6.73	6.90	0.86	0.57	1.26	1.80	8.57	8.57
C.D. at 5%		10.60	15.50	19.65	19.40	1.77	1.25	4.55	5.28	17.50	17.50

except at Gandevi, whereas maximum girth of pseudostem was recorded with conventional planting density and nutrition at all centres. Leaf number per plant at the shooting stage was recorded to be maximum in conventional planting at all centres except Jorhat, however, the leaf area index was recorded to be maximum in highest density of planting with 100% RDF (S1P2F1) at the Bhubaneswar, Kannara and Mohanpur centres. It was seen that more time (days) was required from planting to harvesting under the higher density of planting (5000 plant/ha), when compared to a lower plant population of 3086, 3333 and 4630 /ha. Such variations in plant growth characters *viz*., increase in pseudostem height, leaf area index, durations for shooting and harvesting, but reduction in pseudostem girth and leaf number per plant at shooting, as a result of high-density planting in banana were also established by the findings of Rodriguez *et al.* (2007), Thippesha *et al.* (2007), Pujari *et al*. (2011) and Debnath *et al*. (2015).

Fruit yield and quality parameters were found to vary significantly due to different densities of planting and nutrition levels, across the centres (Tables 7,8 and 9). Finger number per bunch was recorded as being higher under lower density of planting, including control, at all centres except Jalgaon. Similarly, the weight of an individual bunch was also higher under lower density of planting. But the total fruit yield per unit area, that is, the productivity of banana showed steady increase due to increase in the density of planting. Maximum content of total soluble solids and shelf life of fruit were recorded under conventional plant density and nutrition at the Bhubaneswar, Jorhat and Mohanpur centres, whereas non-significant effect was recorded on the total soluble solids content of the fruit at Gandevi and Kannara centres. A plant population of 5000/ha with 100% RDF resulted in maximum fruit acidity at all centres. These results corroborated with the findings of Nalina *et al*. (2000), Thippesha *et al*. (2007), Pujari *et al*. (2011) and Debnath *et al*. (2015).

The per cent increase in productivity over control due to different planting densities and nutrition levels varied from 8.3 to 50.6 at Bhubaneswar, 8.8 to 21.9 at Gandevi, 2.4 to 7.4 at Jorhat, 4.5 to 43.5 at Kannara and 5.7 to 79.0 at Mohanpur centre (Table 10). Maximum productivity and B: C ratio

Table 7. Variations in finger number (FN) and finger weight (FW in gram) due to different planting densities and nutrition levels

Treat-ment	No.of Plants/ha.	Bhubaneswar		Gandevi		Jalgaon	Jorhat		Kannara		Mohanpur	
		FN	FW	FN	FW	FN	FN	FW	FN	FW	FN	FW
S1P2F1	3333 plant/ ha	128.4	119.3	129.9	142.8	154.0	151.3	145.9	52.4	166.5	108.7	122.2
S1P2F2		123.6	118.4	123.0	141.6	148.0	145.1	144.1	51.0	165.2	102.4	121.1
S1P2F3		112.7	116.5	116.5	133.8	125.0	150.8	140.6	50.8	157.4	96.4	119.8
S1P3F1	5000 plant/ ha	124.4	114.2	113.5	128.6	131.0	173.8	123.8	52.0	148.3	104.0	119.3
S1P3F2		122.0	112.7	105.1	128.1	124.0	177.8	127.1	50.7	148.1	100.9	118.0
S1P3F3		108.9	111.3	99.7	122.3	110.0	196.6	104.3	50.3	142.5	87.5	116.6
S2P2F1	3086 plant/ ha	127.3	125.2	131.0	146.7	154.0	159.4	154.5	52.0	163.4	107.5	124.8
S2P2F2		124.5	123.1	126.9	140.8	142.0	175.4	150.6	51.2	159.1	103.5	123.2
S2P2F3		118.4	119.8	121.5	134.3	127.0	155.4	155.2	50.5	151.5	97.8	120.5
S2P3F1	4630 plant/ ha	122.3	118.7	110.9	131.9	136.0	166.1	119.8	51.3	149.8	104.0	121.2
S2P3F2		120.7	116.4	108.0	124.7	125.0	158.9	112.3	50.7	144.3	101.0	119.9
S2P3F3		108.3	115.3	105.4	118.4	110.0	188.1	102.9	50.5	139.9	88.8	117.5
Control		130.2	129.4	133.7	147.5	147.0	269.5	161.8	56.9	168.7	110.7	125.3
SEm (±)		2.97	2.91	4.01	3.55	1.95	0.31	1.68	0.19	1.95	4.31	1.05
C.D. at 5%		9.01	8.92	11.3	9.98	5.69	0.67	NS	0.53	3.66	8.81	2.15

Table 8. Variations in bunch weight (BW in kg) and yield (Y in t/ha) of fruit due to different planting densities and nutrition levels

Treat-ment	No.of Plants/ha.	Bhubaneswar		Gandevi		Jalgaon		Jorhat		Kannara		Mohanpur	
		BW	Y	BW	Y	BW	Y	BW	Y	BW	Y	BW	Y
S1P2F1	3333	14.4	48.1	17.2	57.3	20.4	67.9	14.1	47.1	8.7	29.1	12.1	40.1
S1P2F2	plant/	13.6	45.4	16.3	54.2	19.3	64.3	14.0	46.7	8.4	28.1	11.3	37.5
S1P2F3	ha	13.4	44.6	15.1	50.4	14.9	49.6	13.1	43.8	8.0	26.7	10.5	34.3
S1P3F1	5000	12.0	59.8	15.3	76.5	18.8	93.8	15.5	77.6	7.7	38.5	11.2	55.7
S1P3F2	plant/	11.6	57.8	14.9	74.7	17.1	85.3	15.8	78.7	7.5	37.5	10.9	54.4
S1P3F3	ha	10.2	51.2	14.5	72.3	13.9	69.3	16.1	80.2	7.2	35.8	9.2	45.6
S2P2F1	3086	15.1	46.8	16.7	51.5	20.8	64.2	12.6	38.9	8.5	26.2	12.3	37.8
S2P2F2	plant/	14.3	44.2	16.1	49.6	19.6	60.4	11.4	35.1	8.1	25.2	11.6	35.5
S2P2F3	ha	13.9	43.0	13.9	42.9	15.3	47.3	13.1	40.4	7.6	23.6	10.7	32.9
S2P3F1	4630	12.0	55.7	17.3	80.3	19.6	90.6	16.5	76.4	7.7	35.6	11.3	52.0
S2P3F2	plant/	11.6	53.8	14.7	68.3	17.3	80.3	16.5	77.0	7.3	33.9	11.0	50.1
S2P3F3	ha	10.7	49.7	14.1	65.4	14.3	66.1	16.6	77.0	7.1	32.7	9.5	43.3
Control		15.9	49.0	20.3	62.8	21.2	94.2	17.2	74.7	10.7	26.9	12.4	31.1
SEm (±)		0.52	0.60	0.71	2.45	0.90	3.31	0.08	0.06	0.05	0.56	0.55	0.64
C.D. at 5%		1.54	1.80	2.09	6.90	2.65	9.65	0.18	0.12	0.15	0.98	1.13	1.30

Table 9. Variations in total soluble solids (TSS in ^{0}Brix), acidity (A in %), and shelf-life (SL in days) of fruits due to different planting densities and nutrition levels

Treat-ment	No.of Plants/ha.	Bhubaneswar			Gandevi			Jorhat			Kannara	Mohanpur		
		TSS	A	SL	TSS	A	SL	TSS	A	SL	TSS	TSS	A	SL
S1P2F1	3333	22.9	0.30	6.90	20.1	0.37	9.14	18.8	0.15	7.50	30.4	24.6	0.48	10.1
S1P2F2	plant/	22.3	0.29	6.70	19.7	0.35	9.26	17.9	0.19	8.33	30.2	23.8	0.46	9.70
S1P2F3	ha	22.1	0.27	6.20	19.7	0.30	8.80	19.2	0.16	8.06	30.0	23.2	0.42	9.50
S1P3F1	5000	22.7	0.37	6.80	19.9	0.39	8.94	20.2	0.31	8.80	30.4	24.4	0.59	9.80
S1P3F2	plant/	21.6	0.36	6.40	19.6	0.35	9.49	19.6	0.21	9.27	30.2	23.7	0.58	9.50
S1P3F3	ha	20.9	0.34	6.00	19.8	0.32	9.85	19.5	0.26	9.08	29.9	23.1	0.56	9.10
S2P2F1	3086	23.1	0.33	7.00	20.0	0.35	8.93	16.7	0.16	7.73	30.0	24.8	0.55	10.2
S2P2F2	plant/	23.0	0.33	6.80	19.6	0.33	9.03	13.7	0.21	8.60	29.8	24.5	0.55	9.80
S2P2F3	ha	22.4	0.30	6.60	19.6	0.30	9.05	18.6	0.17	7.69	30.0	24.1	0.48	9.60
S2P3F1	4630	22.6	0.36	6.80	20.1	0.37	9.33	19.6	0.35	7.18	30.1	24.5	0.55	9.90
S2P3F2	plant/	21.7	0.35	6.50	19.4	0.36	8.95	19.2	0.22	8.75	29.8	23.9	0.54	9.80
S2P3F3	ha	21.1	0.32	6.10	19.6	0.31	9.00	21.0	0.23	8.81	29.6	23.3	0.51	9.50
Control		23.2	0.31	7.30	20.1	0.31	8.97	24.0	0.14	11.3	29.5	25.1	0.49	10.4
SEm (±)		0.21	0.01	0.18	0.23	0.01	0.20	0.25	0.01	0.19	0.2	0.33	0.05	0.28
C.D. at 5%		0.64	0.04	0.54	NS	0.02	0.56	0.53	0.01	0.39	NS	0.67	0.10	0.58

Table 10. Variations in yield increase over control (YI in %) and B:C ratio due to different planting densities and nutrition levels

Treat-ment	No.of Plants/ha.	Bhubaneswar		Gandevi		Jalgaon		Jorhat		Kannara		Mohanpur	
		YI	BCR	YI	BCR	YI	BCR	YI	BCR	YI	BCR	YI	BCR
S1P2F1	3333	21.1	2.47	-	3.90	-27.9	2.32	-	2.78	8.3	2.13	29.0	2.41
S1P2F2	plant/	14.4	2.54	-	4.12	-31.7	2.25	-	3.06	4.5	2.02	20.7	2.56
S1P2F3	ha	12.4	2.49	-	4.31	-47.3	1.77	-	3.15	-0.7	2.05	10.5	2.45
S1P3F1	5000	50.6	2.41	21.9	4.24	-0.4	2.76	4.0	3.73	43.5	2.60	79.0	2.42
S1P3F2	plant/	45.6	2.67	19.0	4.77	-9.4	2.58	5.4	3.93	39.8	2.55	75.9	2.65
S1P3F3	ha	28.9	2.32	15.2	5.40	-26.4	2.16	7.4	4.94	33.5	2.47	46.5	2.34
S2P2F1	3086	17.8	2.44	-	3.57	-31.8	2.25	-	2.22	-2.4	2.13	21.4	2.45
S2P2F2	plant/	11.4	2.57	-	3.84	-35.9	2.16	-	2.15	-6.3	2.02	14.1	2.54
S2P2F3	ha	8.3	2.43	-	3.65	-49.8	1.73	-	2.94	-12.1	2.02	5.7	2.44
S2P3F1	4630	40.4	2.34	27.9	4.76	-3.8	2.75	2.4	4.00	32.5	2.52	67.2	2.31
S2P3F2	plant/	35.4	2.47	8.8	4.51	-14.8	2.50	2.7	4.32	26.1	2.45	61.2	2.45
S2P3F3	ha	25.2	2.29	4.2	5.00	-29.8	2.15	3.1	4.40	21.7	2.41	39.3	2.28
Control		-	2.25	-	4.57	-	2.91	-	3.99	-	1.74	-	2.49
SEm (±)		-	-	-	-	-	-	-	-	-	-	-	-
C.D. at 5%		-	-	-	-	-	-	-	-	-	-	-	-

were estimated due to highest planting density of 5000 plants/ha at all centres, except Jalgaon. It varied from 28.9% to 50.6% at Bhubaneswar, 15.2% to 21.9% at Gandevi, 4.0% to 7.4% at Jorhat, 33.5% to 43.5% at Kannara and 46.5% to 79.0% at Mohanpur, over the conventional system (control). However, the estimated B: C ratios varied with the levels of nutrition (50%, 75% and 100% of RDF) within the same planting density of 5000/ ha. For Kannara centre, maximum B: C ratio was 2.65 with 5000 plant/ha and 100% RDF, whereas, for Mohanpur and Bhubaneswar centres, it was 2.65 and 2.67, respectively with 5000 plants/ha and 75% RDF. In case of Jorhat and Gandevi centres, the B:C ratio was 4.94 and 5.40, respectively with 5000 plants/ha and 50% RDF. Hence, there were savings in fertilizer input by 25% at the Mohanpur and Bhubaneswar centres and by 50% at the Jorhat and Gandevi centres. It was noted that although the bunch weight of an individual plant under high density planting decreased, the total number of plants and bunches per unit area was much higher and hence the productivity much higher (Debnath *et al*., 2015). Increase in the photosynthetic canopy surface and light interception under high density planting are reported to be the major contributing factors for higher productivity in banana (Thippesha *et al.*, 2007, Debnath *et al*., 2015).

Significant variations were recorded in the soil nitrogen, phosphorus and potassium content (kg/ha) after harvesting of banana and in the leaf N, P and K content at the shooting stage of the fruit at all centres (Tables 11, 12, 13and 14). As compared with soil nutrient status after harvest inthe conventional system (control), no significant depletion was observed due to the combination of high density planting and nutrition treatment (that resulted in higher yield and maximum B:C ratio) in the available soil nitrogen content (except at the Gandevi, Jalgaon and Jorhat centres), the available soil phosphorus content (except at the Gandevi and Jalgaon centres) and the available soil potassium content (except at the Jalgaon and Jorhat centres). At the Bhubaneswar centre, maximum leaf N and P content was recorded in control, whereas it was lowest in the 5000 plants/ha with 50% RDF treatment. But leaf K content was recorded as being maximum under the 3086 plants/ha with 100% RDF treatment and lowest in the 4630 plants/ha with 50% RDF treatment. However, leaf N, P and

Table 11. Variations in available soil nitrogen (N) content (kg/ha) after harvest due to different planting densities and nutrition levels

Treatment	No.of Pl./ha	Bhubaneswar	Gandevi	Jalgaon	Jorhat	Kannara	Mohanpur
S1P2F1	3333	196.0	259.3	225.0	276.5	280.0	281.3
S1P2F2	plant/	194.0	249.7	222.0	301.5	274.3	279.2
S1P2F3	ha	187.0	244.7	208.0	234.6	289.0	272.4
S1P3F1	5000	191.0	265.0	211.0	194.8	312.2	278.1
S1P3F2	plant/	185.0	256.1	209.0	205.7	356.6	274.2
S1P3F3	ha	177.0	249.7	203.0	200.2	328.8	270.5
S2P2F1	3086	198.0	260.2	220.0	211.6	285.6	282.3
S2P2F2	plant/	196.0	250.5	212.0	227.0	274.2	280.3
S2P2F3	ha	189.0	247.3	209.0	216.6	269.3	274.8
S2P3F1	4630	195.0	264.1	214.0	193.2	286.1	279.3
S2P3F2	plant/	188.0	248.8	211.0	204.5	295.0	276.1
S2P3F3	ha	182.0	244.3	205.0	183.6	268.1	271.1
Control		198.0	263.2	214.0	206.1	266.2	282.3
SEm (±)		7.62	-	0.61	2.05	3.56	5.20
C.D. at 5%		15.54	-	1.79	4.24	8.20	10.62

Table 12. Variations in available soil phosphorus (P_2O_5) content (kg/ha) after harvest due to different planting densities and nutrition levels

Treatment	No.of Pl./ha	Bhubaneswar	Gandevi	Jalgaon	Jorhat	Kannara	Mohanpur
S1P2F1	3333	64.0	61.0	19.8	14.2	136.4	55.5
S1P2F2	plant/	62.0	57.8	19.3	19.2	139.9	53.4
S1P2F3	ha	59.0	56.1	18.4	14.6	115.2	50.1
S1P3F1	5000	60.0	61.8	19.1	17.9	129.8	51.2
S1P3F2	plant/	58.0	57.1	18.9	9.8	139.9	48.3
S1P3F3	ha	55.0	54.8	17.9	17.7	128.5	43.6
S2P2F1	3086	67.0	61.9	19.3	10.9	115.3	56.4
S2P2F2	plant/	64.0	57.1	18.9	10.9	126.4	54.1
S2P2F3	ha	61.0	53.9	18.3	11.5	120.8	51.3
S2P3F1	4630	65.0	61.4	19.2	12.2	142.6	53.5
S2P3F2	plant/	61.0	57.1	19.2	14.6	139.6	51.4
S2P3F3	ha	57.0	54.4	18.2	18.8	129.2	45.7
Control		69.0	60.7	19.2	13.3	70.2	57.6
SEm (±)		5.20	-	0.11	0.07	3.69	4.76
C.D. at 5%		14.04	-	0.31	0.15	7.25	9.97

Table 13. Variations in available soil potassium (K_2O) content (kg/ha) after harvest due to different planting densities and nutrition levels

Treatment	No.of Pl./ha	Bhubaneswar	Gandevi	Jalgaon	Jorhat	Kannara	Mohanpur
S1P2F1	3333	129.0	333.9	631.0	74.4	397.6	160.2
S1P2F2	plant/	125.0	323.7	628.0	67.2	532.0	156.7
S1P2F3	ha	120.0	316.3	614.0	77.3	425.6	150.4
S1P3F1	5000	124.0	327.5	622.0	69.4	436.8	154.5
S1P3F2	plant/	118.0	319.0	619.0	50.4	565.6	151.2
S1P3F3	ha	112.0	310.8	602.0	81.8	515.2	143.2
S2P2F1	3086	130.0	334.7	630.0	87.3	459.2	161.4
S2P2F2	plant/	127.0	324.8	627.0	74.9	481.6	158.1
S2P2F3	ha	120.0	317.3	616.0	86.7	470.4	151.1
S2P3F1	4630	126.0	324.7	625.0	65.0	526.4	157.3
S2P3F2	plant/	123.0	317.2	624.0	85.2	487.2	154.3
S2P3F3	ha	118.0	310.6	607.0	79.4	414.4	149.4
Control		130.0	330.7	622.0	71.7	330.4	162.5
SEm (±)		5.84	-	2.76	3.74	2.65	6.28
C.D. at 5%		14.60	-	8.04	7.73	7.40	13.12

Table 14. Variations in leaf N, P and K content (%) at the shooting stage due to different planting densities and nutrition levels

Treat-ment	No.of Plants/ha.	Bhubaneswar			Jorhat			Kannara			Mohanpur		
		N	P	K	N	P	K	N	P	K	N	P	K
S1P2F1	3333	2.76	0.33	3.59	2.83	0.29	4.23	2.41	0.04	0.49	2.82	0.28	3.71
S1P2F2	plant/	2.72	0.32	3.57	3.21	0.35	5.31	1.95	0.13	0.84	2.78	0.26	3.69
S1P2F3	ha	2.62	0.27	3.50	2.93	0.19	4.84	2.31	0.14	0.83	2.68	0.23	3.60
S1P3F1	5000	2.74	0.33	3.60	3.04	0.20	4.88	2.28	0.11	0.85	2.80	0.26	3.70
S1P3F2	plant/	2.67	0.29	3.58	3.04	0.14	5.44	1.67	0.13	0.78	2.73	0.24	3.62
S1P3F3	ha	2.58	0.23	3.48	4.06	0.18	5.84	2.10	0.09	0.74	2.64	0.18	3.52
S2P2F1	3086	2.77	0.32	3.68	2.43	0.25	4.34	1.72	0.14	0.79	2.83	0.27	3.71
S2P2F2	plant/	2.70	0.30	3.62	2.71	0.36	3.13	2.48	0.11	0.83	2.76	0.25	3.65
S2P2F3	ha	2.64	0.27	3.58	2.75	0.32	4.71	2.41	0.05	0.59	2.70	0.22	3.61
S2P3F1	4630	2.77	0.32	3.55	2.85	0.33	4.80	2.49	0.08	0.71	2.81	0.27	3.68
S2P3F2	plant/	2.71	0.30	3.51	2.32	0.34	4.21	2.42	0.05	0.57	2.74	0.25	3.64
S2P3F3	ha	2.63	0.24	3.41	3.41	0.23	5.34	2.58	0.04	0.66	2.66	0.19	3.54
Control		2.79	0.34	3.65	3.45	0.30	3.11	2.81	0.04	0.50	2.85	0.20	3.72
SEm (±)		0.01	0.01	0.01	0.02	0.03	0.02	0.01	0.01	0.32	0.01	0.01	0.67
C.D. at 5%		0.01	0.02	0.02	0.03	0.06	0.04	0.01	0.01	0.02	0.01	0.02	0.02

K content showed no specific trend at the Jorhat and Kannara centres. At the Mohanpur centre, minimum leaf N, P and K content was recorded under the highest planting density (5000 plants/ha) with the lowest nutrition level (50% RDF). The nutrients applied to and nutrients removed through fruit harvest from HDP (producing higher yield and highest B:C ratio) and conventional systems were calculated and are presented in Table 15. Under the HDP system, the region-specific, per-plant RDF was increased in proportion to the increase in plant population per unit area, therefore, any remarkable

Table 15. Nutrient applied to and nutrient removed through fruit harvest from HDP (producing higher yield and highest B:C ratio) and conventional system (control)

Centre	HDP producing higher yield and highest B:C ratio						Conventional system producing lower yield and lower B:C ratio					
	Nutrient applied (kg/ha)*			Nutrient removed through fruit harvest (kg/ha)**			Nutrient applied (kg/ha)*			Nutrient removed through fruit harvest (kg/ha)**		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Bhubaneswar	1375	550	1500	387	98	550	848	339	926	266	67	266
Gandevi	1875	750	1500	484	123	750	1157	463	926	421	107	421
Jorhat	1000	525	2250	537	136	400	889	467	1999	500	127	500
Kannara	1325	875	2000	258	65	530	662	437	1000	180	46	180
Mohanpur	1375	500	1500	364	92	550	687	250	750	208	53	208

*Estimated on the basis of RDF and planting density in HDP and conventional systems.

**Calculated as per Ganeshamurthy *et al*. (7) and fruit yield from HDP and conventional systems.

depletion in soil and plant nutrient status may not have shown at many centres. It was observed by Debnath *et al*. (6) that the root zone of plants under the high density planting system had more density of effective feeder roots compared to the root zone of plants under the conventional (low density) planting system and it indicated better uptake of applied manures and fertilizers. In present study, the site-specific application of nutrients (RDF) to the high-density feeder root zones of banana plants under HDP might have caused better utilization of applied nutrients, resulting in 25%-50% savings of RDF.

CONCLUSION

The results of this experiment showed that high density planting (HDP:5000plants/ha) of banana, accommodating three suckers per hill at 2m x3m spacing,increased productivity over the conventional planting system at the Bhubaneswar, Gandevi, Jorhat, Kannara and Mohanpur centres. Under the HDP system, the nutrient requirement was 100% RDF at the Kannara centre, 75% RDF at the Bhubaneswar and Mohanpur centres and 50% RDF at the Gandevi and Jorhat centres. This indicated a savings in cost of fertilizer input by 25% at the Bhubaneswar and Mohanpur centres and by 50% at the Gandevi and Jorhat centres. It was therefore, recommended that HDP (5000 plants/ha) in banana be adopted, accommodating three suckers per hill at 2m x3m (6.6 ft x 3.8 ft) spacing with 50% RDF in the agro-climatic region of Gandevi and Jorhat, with 75% RDF in the agro-climatic region of Bhubaneswar and Mohanpur and with 100% RDF in the agro-climatic region of Kannara for higher productivity and return on investment to farmers.

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