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Banana production and productivity enhancement through spatial, water and nutrient management

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ABSTRACT

Bananas and plantains globally the fourth important food crop, recorded wide variation in production and productivity in most of the banana growing regions. This is attributed mainly to the variety, type of planting material used, season and method of planting besides management techniques such as water and nutrients. Among all the commercial varieties of banana, owing to comparatively higher yield potential and better marketability both in domestic and export markets the Cavendish group of bananas such as Grand Naine, Williams, Robusta are preferred over other cultivars of banana. Planting sword suckers is beneficial and more ideal conventional planting material than the water suckers, butts and bits of rhizomes. However, the in-vitro banana plants of Dwarf Cavendish and Robusta are superior to conventional suckers due to their vigorous growth, early flowering (19 days) and reduced crop duration by 29 and 22 days, respectively. With reference to plant spacing and planting density which is determined by varieties grown, soil fertility status, prevailing climatic conditions etc. and maintenance of lower density of 625-1000 plants ha^{-1} recorded low productivity at <30t ha^{-1}, while, high density of 5000 plants ha^{-1} recorded 120t ha^{-1}. However, time taken for maturity was distinctly longer in higher densities, with 120 and 160 days Bunch grade and fruit quality are, however determined by pre-harvest bunch management practices. Influence of method of irrigation, fertilizer application and the role of nutrient elements, organic farming, INM and use of bunch sleeves on yield and fruit quality in different commercial cultivars under various conditions is discussed.

Key words: Bananas, planting density, drip and fertigation, nutrition, bunch sleeves

INTRODUCTION

Bananas and plantains are popular globally not only for their nutritional value but also for their economic importance, especially, to small and marginal farmers in developing countries. These are grown in over 130 countries across the world in an area of 10.1 million ha producing 121.85 million tonnes (FAO, 2009). World banana production is concentrated in Africa, Asia, the Caribbean and Latin America because of the climatic conditions. Among the various continents, Asia has the lion's share of 60% of the global banana production and India, China, Philippines and Indonesia are the major producers in the South, South-East Asian regions. India contributes 48% of the total production in Asia from 37% of total area (Table 1).

Globally, India stands first both in area and production, but has a very meager share of < 0.05 % of the international banana trade. Bananas with year round availability provide a permanent source of income not only to the farmers and rural populations, but also to the traders and retailers, thus, playing an important role in poverty alleviation. The fruit is composed of mainly water and carbohydrates and provides energy (104 K calories per 100g). In addition to being a rich source of carbohydrates, with edible fibre, vitamins,

Table 1. Major banana producing countries in the world.

Country	Area (000 ha)		Production (Million tons)		Productivity (t/ha)	
	2001	2009	2001	2009	2001	2009
India	466	748	14.20	26.99	30.50	35.87
Brazil	513	491	5.74	6.58	11.18	13.41
Philippines	400	415	5.06	7.48	12.65	13.56
Indonesia	285	315	3.60	5.45	8.14	15.49
China	259	269	5.40	8.04	20.84	23.20
Ecuador	298	227	8.03	6.13	26.94	27.07
Cameroon	312	082	2.25	0.79	7.21	9.72
Mexico	074	078	1.97	2.36	26.62	29.99
Columbia	444	062	4.20	1.58	9.45	25.15
Costa-Rica	054	042	2.32	2.22	42.96	52.54
Others	5207	7473	41.79	56.02	-	-
Total	8310	10100	94.56	121.85	-	-

Source : FAO STAT (2001, 2009) NhB (2009) potassium, phosphorus, calcium and with minimum fat bananas are the safest and cheapest fruit ensuring nutritional security to people of all age groups and economic status.

India produces about 30 million tonnes of bananas from an area of 0.83 million ha (NHB, 2011). Among horticultural crops, contribution of banana to Agricultural Gross Domestic Product (AGDP) is the highest (Singh, 2007). Interestingly, in India there has been appreciable increase in area production and productivity of banana during 1962-2011 (Fig. 1) and 1991-2011 (Table 2) owing to technological interventions.

In many banana growing states of India, there has been a steady increase in area, production and productivity (Table 3) which is partly due to increased area under cultivation and largely due to adoption of high yielding varieties like Grand Naine, Robusta and other Cavendish clones, virus free quality planting material and improved production technologies etc.

There is a need to focus on standardization of improved production technologies suitable for different systems of cultivation to realize potential yields in many commercial cultivars for targeted banana production. Selection of high-yielding varieties, planting of healthy, disease-free planting material, choosing the right planting density, need-based and timely application of inputs, viz., irrigation water and nutrients, maintenance of weed-free conditions, etc., are important to bridge the gap between actual yield and potential yield per unit area.

Commercial varieties of banana

India is home to a wide range of *Musa* cultivars belonging to various groups, from delicate diploids of AA

Growth of the banana industry in India

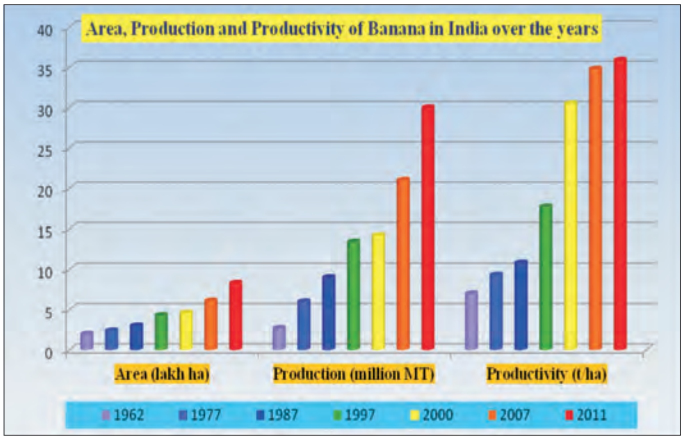

Fig 1. Area, production and productivity of Banana in India over the years

Table 2. Year-wise area, production and productivity of bananas and plantains in India

Year	Area (000'ha)	% of Total fruit area	Production (000'mt)	% of Total fruit production	Productivity (mt/ha)
1991-92	383.9	13.4	7790.0	27.2	20.3
2001-02	466.2	11.6	14209.9	33.0	30.5
2002-03	475.3	12.5	13304.4	29.4	28.0
2003-04	498.6	10.7	13856.6	30.4	27.8
2004-05	589.6	11.9	16744.5	34.0	28.4
2005-06	569.5	10.7	18887.8	34.1	33.2
2006-07	604.0	10.9	20998.0	35.3	34.8
2007-08	658.0	11.2	23823.0	36.3	36.2
2008-09	709.0	11.6	26217.0	38.3	37.0
2009-10	770.3	12.2	26469.5	37.0	34.4
2010-11	830.0	13.0	29780.0	39.8	35.9

Table 3. State-wise area, production and productivity of banana in India

State	2008-09			2009-10			2010-11		
	Area (000' ha)	Production (000' mt)	Productivity (mt/ ha)	Area (000' ha)	Production (000' mt)	Productivity (mt/ Ha)	Area (000' ha)	Production (000' mt)	Productivity (mt/ ha)
Tamil Nadu	124.4	6667.0	53.6	113.7	4980.0	43.8	125.4	8253.0	52.5
Maharashtra	80.0	4960.0	62.0	85.0	5200.0	61.2	82.0	4303.0	65.8
Gujarat	60.9	3571.6	58.7	61.9	3779.8	61.0	64.7	3978.0	61.5
A P	80.1	2804.0	35.0	80.6	2819.6	35.0	79.3	2774.8	35.0
Karnataka	75.4	1918.8	25.4	104.4	2132.3	20.4	111.8	2281.6	20.4
M P	28.8	1498.0	51.9	33.0	1459.8	44.2	38.1	1719.6	45.2
Bihar	31.3	1373.6	43.9	31.5	1435.3	45.6	31.9	1517.1	47.6
U P	-	-	-	30.4	1138.6	37.4	32.4	1346.1	41.5
West Bengal	39.8	954.1	23.9	41.0	982.2	23.9	42.0	1010.1	24.0
Assam	47.9	852.6	17.8	53.4	805.2	15.0	47.6	723.6	15.2
Others	140.2	1617.4	11.5	135.5	1735.8	12.8	175.3	1873.1	10.7
Total	708.8	26217.2	37.0	770.3	26469.5	34.3	830.5	29779.9	35.9

(NHB, 2011)

and AB to the hardy, seeded *balbisiana* clones. Owing to high yield and export potential, Cavendish group of bananas (such as Grand Naine and Robusta) are the major commercial cultivars of banana, while Poovan is ideal for subsistence farming. Rasthali, Ney Poovan, Karpuravalli, Monthan, Thellachakkarakeli, Nendran and Virupakshi command regional preferences.

Scenario of production technologies in banana Season of planting

In India, planting season varies from area to area and in most parts, very cold or hot seasons are unsuitable (Naik, 1949 and Jacob, 1952). Planting during winter leads to initial exposure to unfavorable conditions of hot summer and heavy winds during critical stages of growth. In general, planting banana before commencement of the monsoon stands to help the plants build up rapid growth and establishment before onset of the cold weather (Sham Singh *et al*, 1963). But, in view of the divergent climatic and soil conditions prevalent in our country, bananas are grown all through the year. In Israel, which experiences severe cold winter, planting is generally done during March, i.e., spring planting is the rule. In the sub-tropics, planting is done during the dry season with pre-irrigation to facilitate better establishment (Holder and Gumbs, 1981). In the sub-tropics of South Africa, summer planting helps to avoid winter flowering. In North-Western Australia, where the summer is very hot, planting during winter (June-July) is practiced. In Puerto Rico, planting during December facilitates harvesting during February – April, which fetches a very high price. Under Nigerian conditions, planting during January to May is often prone to cyclone damage; August to December planting is found ideal. In Bangladesh, September-October and February-March are the two main seasons for successful banana cultivation (Haque, 1984).

Planting material

Sword suckers are the best but poor suckering is undesirable. Butts and bits are equally good as suckers but delay flowering (Bhan and Majumdar, 1956). Young or old suckers, and rhizomes express no significant variation in flowering and fruit yield. Sword Suckers have more vigorous growth and heavier bunches in 11 months compared to water suckers that take 15 months (Srivastava, 1963). Germination of the 'Robusta' suckers stored under shade for 7, 14 or 21 days before planting was 100%, 63% and 36%, respectively (Marykutty *et al*, 1979). Grouping of uniform suckers ensures uniform growth in a block and helps all plants to

Popular banana cultivars grown in different regions of India

State	Cultivars
Andhra Pradesh	Grande Naine, Robusta, Thellachakkarakeli (Cavendish), Bontha (Bluggoe), Amrithapani, Karpurachakkarakeli (Mysore).
Assam	Robusta, Honda, Chini Champa (Mysore), Malbhog, Manohar, Kachkel, Bhimkol, Athiakol, Jatikol, Digjowa (Silk)
Bihar	Alpon, Chinia, Chini Champa (Mysore), Malbhog (Silk), Muthia, Kothia, Gauria (Bluggoe), Kanthali (Pisang Awak).
Gujarat	Grande Naine, Basrai, Gandevi, Mahalakshmi, Harichal, Lacatan, Shrimanti.
Karnataka	Elakki Bale (Ney Poovan),Grande Naine, Mysore, Robusta, Rasa Bale (Silk), Hoo Bale, Karibale (Bluggoe), Jwaribale (Pome), Boodi Bale.
Kerala	Nendran, Njali Poovan (Ney Poovan), Palayankodan (Mysore), Poovan (Silk), Monthan, Red Banana,
Madhya Pradesh	Grande Naine, Basrai, Shrimanti, Robusta, Mahalakshmi,
Maharashtra	Grande Naine, Shrimanti, Basrai, Robusta, Mahalakshmi, Safedvelchi, Rajeli (Plantain)
Tamil Nadu	Grande Naine, Robusta, Poovan (Mysore), Monthan (Bluggoe), Karpuravalli (Pisang Awak), Rasthali (Silk), Nendran, Ney Poovan, Sevvazhai (Red Banana), Pachanadan (Pome), Virupakshi/Sirumalai (Hill Banana), Matti, Namarai, Peyan, Sanna Chenkadali, Elavazhai (Leaf purpose).
Uttar Pradesh	Grand Naine
West Bengal	Amrit Sagar, Mortamon (Silk), Champa (Mysore), Giant Governor, Grand Naine, Lacatan, Kanthali (Pisang Awak)

Commercial cultivars of banana


Poovan


Rasthali


Karpuravalli


Robusta


Monthan


Hill banana


Nendran


Spotless Grand Naine

Ney Poovan

Udhayam

Red Banana

Virupakshi

derive equal benefit from sunlight. Freshly lifted suckers have higher establishment, reduced crop cycle, larger bunches and higher yields than suckers stored for 10 days (Patel and Chundawat, 1988). Use of tissue culture planting material was found superior with vigorous, uniform plant growth, precocity of flowering and harvest as well as higher yield in Dwarf Cavendish and Robusta (Daniells, 1988 and Reddy and Kumar, 1996), Nendran (Pradeep *et al*, 1992) and Cavendish bananas (Robinson and Anderson, 1990) as compared to the conventional suckers.

Planting depth and method of planting

In general, bananas are planted adopting any of the two main methods of planting, namely, holes and furrows (Simmonds, 1966). Depth of planting varies with type of soil and planting material (Robinson, 1995). Since growth of suckers usually takes place from the middle and upper parts of the corm, there is a tendency for successive shoots to be borne close to the soil surface and even above the soil surface (Simmonds, 1966). In plants established from suckers, root system is adventitious, and unfavourable conditions increase sensitivity of the plant to water stress. Reducing the extent of root system tends to result in plants less securely anchored. Such plants are prone to toppling under the weight of an early maturing bunch, especially, in windy or wet seasons. The entire mat may get uprooted, leaving the area unproductive for the life of the plantation. The larger pit sizes of 2 feet cube gave the heavier bunches and hands than the pit sizes of 1 or 1.5 feet cubes and the sucker production increased with pit size (Ahmed and Mannan, 1970). Robinson (1995) reported that shallow planting depth could cause a plant to dry out and thereby induce a superficial root system in both mother plant and the suckers. Bakhiet *et al* (2003) observed differences in the time to corm germination when type of planting material differed. Days from planting to shooting, and from planting to harvest of the mother plant crop, significantly decreased with increasing planting depth; but, the time from shooting to harvest did not statistically differ.

Planting depth of 60cm resulted in significantly shorter interval between harvests. Planting in deep holes seem to hasten flowering, whereas maturation is controlled by temperature during bunch development, as observed by Robinson (1981); whereas, Fraser and Eckstein (1998) reported a tendency for longer cycle with deep planting, using tissue culture derived banana plantlets. Here, bunch weight increased with planting depth, the largest bunch been observed at 60cm. Number of hands per bunch and bunch weight in plants planted in 60cm holes was significantly higher; number of fingers per hand, however, did not vary with planting depth (Bakhiet and Elbadri, 2005). Planting of suckers in larger holes is required in under-prepared or less uniform soil-tilth conditions. Bunch mass and the number of fingers were higher in 'Nanicao' plants planted at 30cm depth, than in those planted at a lesser depth of 10cm (Manica, 1976; Obiefuna, 1983). For tissue-cultured plants, the recommended planting depth is 10cm deeper than their level in the polybags. The smaller size of *in-vitro* plantlets and pared suckers make it possible to establish a banana plantation using shallower planting holes. Reducing the size of planting hole may accelerate establishment of plants, given that the root-bearing zone is located at the level of a mineral rich topsoil layer. Deep planting increased bunch weight and reduced time to flowering, over successive ratoon crops.

Spacing / planting density

Optimum density that is defined as the density at which gross margin per hectare per annum is maximized over the entire plantation life varies with locality, cultivar, soil type and fertility, and management level. Choice of spacing depends upon cultivar and, further, varies from region to region depending upon cultural practices of the area In recent years, there has been considerable emphasis on high-density planting wherein yield of an individual plant cannot be increased beyond a certain limit. Total yield and net returns can be increased per unit area by adopting closer spacing as this also reduces weed growth and provides protection against wind damage.

Plant population under various planting systems

S.No.	Method of planting	Spacing (m)	Population density (No./ha)
1.	***CONVENTIONAL PLANTING***		
	D i) warf Cavendish	1.5x1.5	4440
	ii) Robusta and Nendran	1.8x1.8	3080
	iii) Rasthali, Poovan, Karpuravalli, Monthan	2.1x2.1	2260
2.	***HIGH-DENSITY PLANTING***		
	a) *Paired-row planting system*		
	i) Dwarf Cavendish	1.2x1.2x2.0	5200
	ii) Robusta, Grand Naine, Poovan, Rasthali and Ney Poovan	1.5x1.5x2.0	3800
	b) 3 *suckers/hill* (1 foot apart	1.8x3.6	4500
	in the pit) Robusta Nendran)	1.8x3.0	5550

In India, planting of banana cv. Amritsagar at 6 X 6 ft spacing yielded 63.8 % more fruits than those at 8 X 8 ft however; the wider spacing recorded the heaviest fruits and bunches (Ahmed and Mannan, 1970). Under West Bengal conditions in cv. 'Jahajee', highest profit was obtained from double dose of fertilizer at closer spacing of 2mx2m (Sarma and Roy, 1972). Under the same conditions in cv. 'Giant Governor', decrease in plant density from 2500 pl/ha to 1125pl/ha, induced early flowering and fruit maturity. Weight of bunch and other yield parameters increased with decrease in plant density (Chattopadhyay *et al*, 1980). In Hill Banana, under *Coorg* conditions yields were 32, 39 and 50 t/ha for 2.4mx2.4m, 2.4mx1.8m and 1.8mx1.8m spacing respectively (Mustaffa, 1983). In 'Robusta' (AAA), 'Nendran' (AAB) and 'Monthan' (ABB) bananas, root number increased with increasing density. Number of roots was greatest at flowering and, ABB had higher number and longer roots than AAA/AAB (Mohan and Madhava Rao, 1984). In Basrai banana, the highest yield was 67.82 t/ha at 1.5mx1.2m spacing than plants spaced at 1.5mx1.5m or 1.5mx1.8m (Singh and Kashyap, 1992). At Vellayani, Kerala, a spacing of 1.75mx1.75m was adjudged the best for Nendran (Anil *et al*, 1995). In Basrai banana in Anand, Gujarat, highest yield (93.27 t/ha) was obtained at a spacing of 1.2mx1.2m. The combination of narrow spacing (1.2mx1.2m) and 15th June planting, recorded highest yield of 107.7 t/ha. Planting two suckers per hill at 2mx2m spacing (5000 pl./ha) with higher doses of nutrients, i.e., 360:250:500g NPK recorded highest bunch weight and economic yield than three suckers per hill with conventional planting and lower dosage of nutrients in Robusta grown under sandy-clay loam soils of Chikmagalur in Karnataka (Thippesha *et al.*, 2007). Observations on incidence of leaf spot indicated that 3 suckers/hill recorded least incidence (Selvarajan *et al*, 2001). However, maximum nematode population was recorded in planting three suckers per hill and was least in the paired row system (Anon., 2001). Final decision on the most suitable optimum planting density will rely not only on marketable yield but also on profit margin and convenience of the planting system adopted.

For hot, dry areas receiving higher heat units/heat stress, high density of > 3000 plants/ha is recommended whereas, for mild subtropics with cold winter, comparatively low density with < 2000 plants/ha is advisable. In plantations with short life-spans of 1 or 2 cycles, much higher optimum density is recommended, whereas for longer life-span plantations (five or more ratoons), lesser density would be ideal.

The yield increased with increasing density from 1120 to 3360 and for fresh consumption, a density < 2500/ha is recommended In South Africa, light transmission through the canopy was found to be 14% under 2222pl/ha and 30% under 1000 plants/ha and a LAI of 6.3 was attained at 2222 plants/ha (Robinson and Nel, 1985). In 'Williams' banana, yield in higher densities (1666 plants/ha) were distinctly higher (51.0 to 56.4 t/ha/year) than in the lower density (1250 pl/ha), i.e., 39.1 to 48.9 t/ha/year in Burgershall and Levubu stations of S. Africa (Robinson *et al*, 1985).

In Brazil, among densities ranging from 625 to 2500 plants/ha, the best results were recorded in 2500 plants/ha (37t/ha) (Lichtemberg *et al*, 1986). Closer spacing of 1.5m between plants made it difficult to select the next sucker (Daniels *et al*, 1987). At Amiad and Ginosar, Israel, a rectangular 3 x 2.8m layout was used and 2, 3 or 4 plants planted per hole (2381, 3571 and 4091/ha). Average bunch weight decreased from 35-36kg to 27.5kg, and total yield increased from 80-82t to 112t/ha. Time between flowering and harvest was distinctly longer the higher densities (with extremes of 120 and 160 days) because of a lag of about 4 leaves under high density (Israeli and Nameri, 1988).

At *San Carlos*, Brazil, first and second harvests were best at high densities (hexagonal planting, 1,720 plants/ha) or double-rows (1704 plants/ha) compared to the traditional density (1,111 plants/ha). The hexagonal, monoculture system was most productive in the third cycle. In Colombia, under HDP of accommodating 3332 to 5000 plants/ha, flowering was delayed by 3 to 5 months, but was compensated by higher yields. Yield from high-density plot in double rows (2,587 plants ha^{1}) was 1035 boxes/ ha against 680 boxes from a triangular plan (1,600 plants/ha). In South Africa, 'Williams' banana were grown under densities of 1000, 1250, 1666 and 2222 plants/ha for 5 successive cycles. The yield was significantly higher in 2222/ha in all the cycles. However, spread of the harvest increased with density, indicating a strong competition. Density of 1666/ha was finally recommended for reasons of cost (inputs), income, less spread of harvest and ease of operation (Robinson and Nel, 1989).

Under South African conditions, based on plant vigour, optimum density per hectare for 'Williams' was between 2005 and 2339; for 'Valery', 'Grand Naine Central America' and 'Grand Naine Israel', it was between 2339 and 2618; and for the smaller 'Dwarf Cavendish' plants, it was 2618 plants/ha. The *in- vitro* plants of 'Grande Naine' planted at 5.0m x 2.5m spacing with three plants per hole

(2,400 plants/ha), twelve months later a new planting was inserted between the existing plants. The first crop took 14 months and the second 12 months to mature. Annual yields of 73.1 t/ha and 77.7 t/ha, with more than 90% of fruits qualifying as 'Extra' (Cabrera *et al*, 1998).

Water management

Worldwide, water is the most limiting non-biological factor in banana production, and copious irrigation is required at all stages of growth. It is estimated that a good crop of banana requires 25mm/week for satisfactory growth. The total water requirement of banana plants is about 900-1200mm for an entire life cycle and this can be met through both natural precipitation (rainfall) and supplementary irrigation. In the tropical conditions, water requirement is 900-1800mm per crop (Stover and Simmonds, 1987). Maintaining optimum moisture at all stages of growth is very critical, and providing good drainage facility to drain out excess water from the root zone is equally important to promote growth and enhance productivity. In general, irrigation of banana plantations every 3-4 days during the hot period and at 7-8 days interval during cool weather is recommended. In the banana growing regions, effective RF and supplementary irrigation / irrigation need varies widely. In Honduras, parts of Ecuador, Colombia and Windward Islands, the total precipitation range is 1500-3500mm distributed over 8 months, a condition that warrants drainage during monsoon; whereas, there is a need for supplementary irrigation during dry summer months (Jaramillo, 1984). However, in Costa Rica and Panama, there is a well-distributed rainfall of 2500-4500mm and, thus, no supplementary irrigation is required. In contrast, in Israel, the entire water need is met through supplementary irrigation (1050-1500 mm/annum). In Semi-tropics, irrigation of banana plantations during dry months increased yield by 15-20 % (Daniels, 1984).

Drip irrigation

It is one of the best methods of irrigation in areas experiencing water scarcity. Here, water is allowed to reach the root zone of the crop in small quantities. Drip irrigation has the advantage of coverage of large areas with less water, requiring very less labour but providing more uniform irrigation and is also fertigation and salinity friendly. In India, drip irrigation is superior to the conventional basin-irrigation in terms of ensuring more vigorous growth, higher yields, minimal weed growth and high water use efficiency (Hegde and Srinivas, 1989). In addition to economy of water use, drip irrigation activates uptake of nutrients. For banana, replenishment of evaporation losses up to 80 % was found to be optimal for realizing higher yields.

Drip irrigation and fertigation techniques

Drip irrigation and fertigation has the most significant role for achieving not only higher productivity and water use efficiency, but also to attain sustainability with economic use and productivity.

Fertigation could help in long run for efficient and uniform application of water and fertilizer, with minimum manpower, to improve productivity and quality of the produce. At Coimbatore, under the garden land system, highest bunch weight (26 kg) was recorded under conventional planting with 50% N and K fertigation and 3 suckers/hill with 100 % (110:330 g/plant) N and K fertigation. Planting 2 suckers per hill at a spacing of 1.8mx1.8m (6000 plants/ha) with 50% RDF fertigation was found to be highly economical. It gave a maximum total yield (135.78 t/ha) with high cost–benefit ratio of 3.75. At Thrissur with Nendran (AAB), planting 2 suckers/pit (3086 plants/ha) with 75% fertilizer recorded significantly higher bunch weight and total yield (31.90t/ha) than the control (20.90t/ha). At Jalgaon, Grand Naine (AAA) grown under conventional planting recorded earliest flowering (287.7days). Maximum bunch weight (14.95kg) was recorded in 3suckers/hill with 75% N and K fertigation. Total yield of 82.8 t/ha was recorded in 2 plants/hill with 75% N and K fertigation. For export quality fruits (over 20cm length and 12cm girth), 3 suckers/hill under Paired Row system with 75% N and K fertigation was found superior (Anon., 2008).

Robusta banana grown under sandy-loam conditions of Coimbatore, irrigation @ 25 litre/day and fertigation with 100% RDF of 200:300g N& K recorded the most vigorous plant growth, earliest flowering and harvest, highest bunch weight (44.53 kg) and yield (111.33 t/ha) under the normal planting system. HDP population of 5000 pl/ha + 40 litres of water/day + 75% RDF fertigation (450:675g N & K plant-1) recorded yield increase of 209.7% over conventional planting (Mahalakshmi *et al*, 2000).

Fertigation gives flexibility in application of fertilizers to meet specific crop requirements at various stages of growth. Application of N in the form of urea, and K in the form of Muriate of Potash (MOP) through the system, could be advantageous. MOP may be dissolved in water and kept overnight to facilitate complete dissolution, while urea can be dissolved instantly. These fertilizers allowed into the system on either daily or weekly basis and may be stopped 10-15 days prior to harvest of bunches. Apart from straight fertilizers, specific formulations of water-soluble fertilizers needed for the banana crop (based on crop growth stage) can also be used in fertigation. Commercially available fertigation-grade water soluble fertilizers are found highly effective in banana even in places where quality of irrigation water is not fully suitable for the drip system.

Banana under drip irrigation performed better in growth and flowered earlier in comparison to that under surface irrigation Application of urea through the irrigation system was more efficient and significantly more yields were obtained with fertigation than with hand-broadcasting on soil surface (Arscott, 1970). In Israel, banana cultivation with very frequent irrigation was seen to be very successful (Lahav and Kalmar, 1981). In Hawaii, drip irrigation doubled the yield as compared to a well-maintained sprinkler system (Young *et al*, 1985).

Under drip irrigation, banana plants flowered 15 days earlier and recorded higher yields with higher finger, hand and bunch weight as compared to basin-irrigation (Hedge and Srinivas, 1991). Daily or weekly fertigation significantly increased the yield compared to monthly fertigation, but no advantage was seen with daily over weekly fertigation on loamy soils. Banana is a heavy feeder both in respect of nutrients and water. Fertigation proved successful in commercial banana cultivars like Robusta (Mahalakshmi *et al*, 2000), Nendran (Pandey *et al*, 2001) and Ney Poovan with fertilizer and water economy and fertigation can save 20 to 30 % on fertilizer while improving yield and quality compared to conventional fertilizer application (Srinivas, 1996). Thadchayini and Thiruchelvan (2005) obtained highest yield (41,000kg ha^{-1}) in the drip system, 31 % higher than in surface irrigation.

Water requirement in banana at different growth stages

Sl. No.	Crop-growth stage	Duration (weeks)	Quantity of water (litre /plant)
1	After planting / Ratoon	1-4	4-8
2	Juvenile phase	5-9	8-10
3	Critical growth stage	10-19	12
4	Flower bud differentiation stage	20-32	16-20
5	Shooting stage	33-37	20 and above*
6	Bunch development stage	38-50	20 and above*

Nutrient management in banana Leaf nutrient concentration

Banana leaf samples are normally taken just before or following floral emergence and when all the female hands are visible (Martin-Prevel, 1977). However, age of the tissue to be sampled depends on nutrients being diagnosed for (Fox *et al*, 1989). In most banana producing countries, lamina of the third leaf is sampled for tissue analysis. However, samples of central vein of the third leaf and petiole of the seventh leaf are also used. Lamina of the third leaf is sampled by removing a strip of tissue 10cm wide on both sides of the central vein, and discarding everything but the tissue that extends from the central vein to the centre of the lamina. Arunachalam *et al* (1976) reported that maintenance of optimum levels of nitrogen in lamina-3 and midrib-3 in banana varieties varies with crop age. This aspect should be taken into account in leaf analysis-based nutrient recommendation programme for banana. Maximum nitrogen, phosphorus and potassium content in leaf were recorded in a treatment receiving 100 % recommended dose of fertilizer along with organic booster-slurry to increase nutrient concentration in banana leaf (Ziauddin, 2009).

Hewitt (1955) reported that 2.6% N in the leaf is adequate for banana, while Murray (1962) showed that

Critical levels of leaf NPK in different cultivars

Cultivar	Location	Leaf nutrient concentration (%)			Reference/s
		N	P	K	
Robusta	The Caribbean / West Indies	2.90	0.29 - 0.48	3.80	Twyford and Coulter (1964) and Twyford (1967)
Dwarf Cavendish	India	3.18 - 3.43	0.46 - 0.54	3.36- 3.76	Arunachalam (1972)
Robusta	India	3.29	0.44	3.11	Ramaswamy and Muthukrishnan (1974)
		1.70 - 2.30	0.17 - 0.24	4.00 - 4.50	Vadivel (1976)
		0.90 - 2.26	0.11 - 0.32	3.60 - 5.60	Ashok kumar (1977)
		2.30 - 2.44	0.22 - 0.25	3.97 - 4.19	Krishnan and Shanmugavelu (1980)
		3.51	0.15	3.43	Kotur and Mustaffa (1984)
Jahaji	India	1.98	0.26	3.07	Hazarika and Mohan (1990)
Basrai	India	2.80	0.52	3.80	Ray *et al* (1993)
Robusta	India	2.98	0.32	2.53	Mahalakshmi (2000)
		3.01	0.36	2.28	Kavino (2001)
		2.09	0.10	4.48	Nalina (2002)

<1.5% nitrogen is designated as deficient for banana. Bhangoo *et al* (1962) obtained highest yield in Giant Cavendish banana grown in Honduras with 2.8 %nitrogen. Ramaswamy and Muthukrishnana (1974) reported a level of 3.3 % N to be optimum in Robusta banana. Results obtained by Jambulingam *et al* (1975) suggested that leaf K should be above 4.3%for optimum production. Later work by Arunachalam *et al* (1976) showed that adequate levels of nutrient in banana leaf ranged from 3.18-3.43, 0.46-0.54, 3.36-3.76, 2.3-2.4 and 0.25-0.28 % for N, P, K, Ca and Mg, respectively. Ram and Prasad (1988) observed an increasing trend in content of nitrogen up to flowering in banana. According to Ray *et al*(1988), leaf content of 2.8:0.52:3.8% NPK at shooting was a good indicator for satisfactory productivity in Robusta banana.

Critical levels of nutrients in banana cvs. Robusta and Ney Poovan

Nutrient conc.	Robusta	Ney Poovan
N (%)	1.67-3.43	2.23-3.35
P (%)	0.12-0.21	0.12-0.23
K (%)	2.28-4.14	2.68-4.78
Ca (%)	0.48-1.70	0.40-1.28
Mg (%)	0.33-0.58	0.14-0.65
S (%)	0.03-0.18	0.06-0.13
Fe (ppm)	53-196	58-189
Mn (ppm)	112-417	142-516
Zn (ppm)	8-38	14-37
Cu (ppm)	10-32	11-33
Yield limit	30 kg/plant	12 kg/plant

Weerasinghe *et al* (2004) showed the need to maintain nitrogen content of the third youngest leaf (lamina-3) at 3.5 % at five months of age (early vegetative stage), and at 3.0 % during the rest of the growth cycle, to obtain high yields in 'Kolikuttu' banana. Elements absorbed in excessive quantities can reduce plant yield directly through toxicity, or indirectly by reducing the concentration of other nutrients below critical range.

Fertigation and NPK uptake

Banana requires high levels of nutrients for ideal growth and production. It is estimated that a crop of fifty two tonnes in one hectare removes 320:32:925kg $N:P_2O_5:K_2O$ every year (Lahav and Turner, 1983). Uptake of nutrients was higher in sucker grown banana plants compared to tissue culture plants due to greater accumulation of dry matter by the former. Uptake of nutrients in banana increased in fertigation treatments compared to conventional methods of fertilizer application. A treatment of 25 % N through urea+50 % N as ammonium sulphate +25 % N as calcium ammonium nitrate exhibited higher nutrient uptake (Bhalerao *et al*, 2010).

Fertigation schedule

Based on trials conducted at the National Research Centre for Banana, Tiruchirapalli, in commercial cultivars of banana, a weekly fertigation schedule has been developed.

Weekly fertigation schedule for banana (g/plant/week)

Weeks after planting (total no. of weeks)	Urea	Total (g/plant)	MOP	Total (g/plant)
9 to 18 week (10 weeks)	15	150	8.0	80
19 to 30 week (12 weeks)	10	120	10	120
31 to 40 week (10 weeks)	7.0	70	12	120
41 to 46 week (5 weeks)	Nil	Nil	10	50
Total	——	340	——	375

Fertigation and crop growth parameters

Application of N, P and K through fertigation influenced vegetative growth, number of hands and fingers, bunch weight and fruit yield in banana (Hedge and Srinivas, 1991). Significantly higher plant height and girth was observed with application of nitrogen and potassium, each at the rate of 200g per plant (Srinivas, 1996). Banana plants effectively utilized the accurately placed fertilizer in solution form in the active root zone area, resulting in vigorous growth, early flowering and early bunch development. Similarly, leaf area index (which is a measure of source-size) was significantly higher with drip irrigation over the furrow-irrigated control. Bhalerao *et al* (2010) studied the effect of different sources of nitrogen on growth and yield in banana cv. Grand Naine under drip irrigation. Combined application of 25 %N through ammonium sulphate + 25 % N through calcium ammonium nitrate was beneficial in terms of attaining maximum plant vigour, early flowering and lower crop duration.

Fertigation and yield-attributing characters

Post-shoot application of K (44^{th} to 47^{th} week after planting) favoured growth and development of bunches with better fruit-filling, resulting in increased finger weight, length and mid-circumference (Yadav *et al*, 1988). In cv. Robusta, fertigation treatment (200:30:300g NPK/plant) registered the maximum bunch weight, with corresponding highest number of hands and fingers (Mahalakshmi *et al*, 2000). Application of 240g N/plant in four split doses at 2, 4, 6 and 8 MAP recorded significantly higher pseudostem height and girth, number of leaves/plant, number of fingers/bunch, yield, total sugar and sugar acid ratio in cv. 'Jahajee' (Naresh Babu *et al*, 2004).

Drip, fertigation and yield

Banana crop under drip irrigation resulted in increased yield, higher number of hands with more length and girth of fruits. Weekly fertigation with proportionate quantities of 200:30:300g NPK/plant/year starting with 9^{th} week after planting, effectively increased yield of banana cv. Robusta (Mahalakshmi *et al*, 2000). Similarly, increase in level of nitrogen and potassium fertigation improved growth and fruit yield was significantly higher with more finger weight with 1:2 nitrogen and potassium fertilizers, compared to 1:1 ratio Fertigation with 75 % RDF through surface drip-irrigation increased fruit yield in both the main and ratoon crops of banana by 9.12 and 12.85 %, respectively (Dinesh Kumar and Pandey, 2008).

Drip irrigation and quality parameters

Drip irrigation significantly increased total sugars / reducing sugars and total soluble solids in banana fruits (Somogyi, 1952; Natesh Beena *et al*, 1993). In tissue-culture raised banana cv. Dwarf Cavendish, application of 300g nitrogen in 5 splits significantly increased the TSS (23.8^0 brix), reducing sugars (6.38%), total sugars (17.48%) and sugar acid ratio (Tirkey *et al*, 2003). Dinesh kumar and Pandey (2008) recorded statistically significant values of TSS, total sugars and reducing sugars with application of 75 % RDF and the increased total sugars in banana might be due to higher uptake of nitrogen and potassium by the plant.

In general, it is observed that banana requires larger quantity of potassium, moderate quantity of nitrogen and relatively lower dose of phosphorus for growth and yield. Requirement of nitrogen and potassium for banana in higher amounts was reported as early as 1921 by Fawcett, and was later confirmed by Norris and Ayyar (1942). Nalina (2002) justified that application of 150 % of recommended dose of NPK (165:5.5:495g $plant^{-1}$) in four splits, viz., 2, 4, 6 and 8 months after planting, was essential to increase growth and development, yield and quality of tissue-culture banana. Daniells and Armour (2010) observed that banana utilized about 50 % of the applied fertilizers, while the remaining nutrients were held in the soil.

Nutrients in growth and development

Banana, an exhaustive user of water and nutrients due to its large rhizosphere, rapid growth and high yielding nature, demands large quantities of nutrients from organic and inorganic sources (Lahav, 1973). Major nutrients like nitrogen (N), phosphorus (P) and potassium (K) play an important role in the vegetative and reproductive phases of crop growth, depending on the cultivar. For optimum growth and fruit yield, banana requires maintaining optimum levels of nutrients, often supplied only in part by the soil (Swennen, 1990).

Nitrogen on growth and leaf production

Many experiments confirm a positive influence of nitrogen on plant growth, flowering and productivity in banana cultivars (Arunachalam *et al*, 1976; Mustaffa, 1983). Ramaswamy and Muthukrishnan (1973) suggested that increased nitrogen application gave the highest number of functional leaves. Increase in level of nitrogen significantly increased height and girth in banana (Chattopadhayay *et al*, 1980). Application of 120g nitrogen (half dose of nitrogen as foliar spray and the other half as soil application) recorded maximum pseudostem height and girth in cv. Giant Cavendish (Ghosh *et al*, 1989), while, application of 200g nitrogen (100%) through soil recorded taller plants (Anon., 1996). Application of 200g nitrogen (100%) recorded higher number of leaves per plant in cv. Robusta (Anon, 1996) and had a positive influence on leaf production, length and breadth (Ghosh *et al*, 1989). Soorianathasundaram *et al* (2000) found that in cv. Nendran, pseudostem height was higher when plants received 75 % of nitrogen as urea, than at 50 %; whereas, pseudostem girth was maximum in plants when the entire N was supplied as urea. Application of 200g N as ammonium sulphate, or as CAN 50g or as urea, and 100g as ammonium sulphate recorded favorable growth (Anon, 2004). Application of 300g nitrogen in both the first and second crop recorded maximum pseudostem height and circumference at shooting stage and significantly reduced phyllochron in cv. Robusta (Pandey *et al*, 2005).

Effect on flowering

Bhan and Muzumdar (1956) found that shooting was earlier by about 31 days with lowest level of nitrogen (100g N/plant). Similar results were reported by Ramaswamy and Muthukrishnan (1974). Flowering was delayed considerably with no nitrogen application (Kohli *et al*, 1984). The required net assimilation was presumably reached early in the plants receiving higher dose of nitrogen, thus hastening the process of initiation and emergence of inflorescence (Chattopadhayay *et al*, 1980; Israeli and Lahav, 1986; Ghosh *et al*, 1989; Singh *et al*, 1990; Praburam and Sathiyamoorthy, 1993; Parida *et al*, 1994; Hansan *et al*, 2001).

Effect on fruit maturity

Croucher and Mitchell (1940) reported that fruit maturity was earliest at lower level of nitrogen. Similar findings were reported by Champion (1970) and Butler (1960). Arunachalam *et al* (1976) reported that nitrogen shortened maturation period by 14 days and time from planting to shooting by 10 days, thus, reducing the entire crop cycle by one month in Cavendish banana. Praburam and Sathiyamoorthy (1993) found that application of 200g nitrogen per plant recorded the earliest flowering in 283.2 as well as least total crop duration (404 days) in cv. Rasthali. Plants receiving 100 % N as urea were the earliest to shoot (265 days), while, reduction in supply of inorganic N delayed shooting markedly in cv. Nendran (Soorianathasundaram *et al,* 2000).

Effect on yield and fruit characters

As early as in 1940, Croucher and Mitchell reported that in banana cv. Gros Michel, increased yields could be obtained by application of nitrogen. Similar findings were recorded by Brown and Eastwood (1940), Gopalan Nayar (1953), Teaotia and Dubey (1971) in cv. Harichal. In Robusta application of 180g nitrogen per plant produced higher yield (44.23t/ha) in comparison to 90g and 270g of nitrogen (Randhawa *et al,* 1972). Application of nitrogen increased the number of hands, number of fruits and weight of fruit in cvs. Dwarf Cavendish, Giant Cavendish, Robusta and Lacatan (Arunachalam *et al,* 1976), Giant Governor (Venketasan *et al,* 1985) and in Karpura Chakrakeli (Ghosh *et al,* 1989). In banana cv. Robusta, application of 150 to 260g N plant^{-1} registered vigorous plant growth, early flowering, highest bunch weight and yield (Randhawa *et al* 1973; Kotur and Mustaffa, 1984; Kohli *et al,* 1984; Mustaffa, 1988). According to Geetha Nair *et al* (1990), in Nendran, application of 400g N in four splits increased fruit length up to 26.6cm. Soorianathasundaram *et al* (2000) reported that in cv. Nendran, application of 100% nitrogen as urea recorded heaviest bunches (10.80kg); whereas, under Jalgaon conditions, application of 200g nitrogen per plant as calcium ammonium nitrate (CAN) and ammonium sulphate in combination with urea at 75% dose, resulted in increased bunch weight (11.3 kg) in cv. Ney Poovan (Anon, 2004).

Effect on fruit quality

Soil application of N increased sugar content and fruit acidity; but, when partially replaced by foliar application, fruits recorded higher TSS and ascorbic acid content, and less titrable acidity (Ghosh *et al*, 1989). Meena and Somasundaram (2004) reported that in var. Poovan, 150 % recommended N and K in 3 or 4 splits registered maximum TSS (19.6%), lower acidity (0.25%) or sugar-acid ratio (51.2%) compared to the control (15.9%, 0.30% and 37.7%, respectively).

Effect on status of soil and leaf N concentration

With the initial application of higher dose of nitrogen fertilizer, the N was not adequately reduced to ammonium due to an inefficient nitrate reductase system. After the second dose of fertilizer, nitrogen content of the leaf tissue increased with increase in level of nitrogen applied (Twyford and Coulter, 1964). Excess nitrate accumulation results in poor plant metabolite production and often limits yield (Parr, 1967). Randhawa *et al* (1972) found maximum leaf nitrogen (3.03 %) in 270g nitrogen application per plant in cv. Robusta. Seven months after planting, leaf nitrogen rose to a maximum of 3.29% at 170g N /plant (Ramaswamy and Muthukrishnan, 1974). Valsamma and Mathew (1980) suggested that nutrient status of the third leaf at shooting ranged from 1.33 to 2.08 % nitrogen. Kohli *et al* (1984) recorded the highest leaf nitrogen content of 2.94 % at the shooting stage with application of 350g nitrogen per plant

Dosage of nitrogen

In banana, regardless of the cultivars, soil or climate, amount of total nitrogen uptake by the plant is closely related to total dry matter production (Lahav, 1995).

He also found that excess nitrogen in banana promoted pseudostem elongation, resulting in lodging and consequently loss of yield. An over-supply of nitrogen increases the time needed for fruit-filling and affects fruit quality. Research carried out by Follett (2001) indicated that excess of nitrogen increased nutrient loss into environment through leaching, denitrification and volatilization and these losses have a potential to pollute the environment. Daniells and Armour (2010) reported that lower rate of 300kg ha^{-1} each of N and K fertilizer resulted in higher yields and saved Rs.32500 ha^{-1} as against each 500kg of N & K ha^{-1}. They also found that lowering the application of nitrogen reduced the rate of soil acidification and in turn reduced the decline in cation exchange capacity and lime requirement in Queensland, Australia. Efficiency of various sources of nitrogen in cv. Ney Poovan was assessed by Keshavan *et al*(2011) who found that combined application of 25 % N as CAN + 25 % N as urea + 50 % N as ammonium sulphate resulted in better vegetative growth, physiological attributes and soil leaf nutrient status culminating in increased yield in terms of bunch weight (12.1kg), number of hands (11.8), number of fingers (59.3) and finger weight (173.3g) over control.

Significance of phosphorus fertilization

Phosphorus is essential for better development of rhizome and a strong root system. It also plays a vital role in overall development of the plant and flower set. The plant can store P longer and can utilize it for fruit production and development. Phosphorus is a mobile nutrient, moving from older leaves to younger leaves, and in turn, to the bunch. Uptake of this macronutrient is reported to peak between two to five months after planting, *i.e.*, at the vegetative phase (80%) and, thereafter, the uptake is reduced. Requirement of phosphorus in banana is much less than nitrogen and potassium (Norris and Ayyar, 1942; Martin-Prevel, 1964; Turner, 1969; Jauhari *et al*, 1974; Vadivel, 1976). Requirement of P under Indian conditions varied from 35 to 225g plant^{-1} (Shanmugam and Velayutham, 1972).

Phosphorus has a promotive effect on the young root system and stimulates growth. In excess, however, it has depressing effects on number, weight and size of fingers (Croucher and Mitchell, 1940; Katyal and Chadha, 1961). Response to application of phosphorus has been reported to be poor with no significant effect on day to maturity, number of hands or fingers bunch^{-1} (Bhan and Majumdar, 1956; Osborne and Hewitt, 1963; Pillai *et al*, 1977). Jagirdar and Ansari (1966) observed that in cv. Basrai, the stem girth increased when P was applied along with K at 48 and 96 lb acre^{-1}, respectively. According to Ramaswamy (1974), number of hands bunch^{-1}, bunch weight, fruit size and volume increased for up to 60g of P_2O_5 plant^{-1}. Knight (1988) found that tissue culture bananas responded positively to increase in phosphorus levels. Banana had a slow response to phosphorus (Lin and Fox, 1987) and, later, it was confirmed that banana plants obtained adequate phosphate from soils through mycorrhizal association (Fox *et al*, 1989). Kurien *et al* (2000) reported that movement and mobilization of phosphorus occurred mainly in the male inflorescence, rhizome, fruit and fruit peduncle of the banana plant system. Growth and yield of banana suffered due to low P from the regular fertilizer dose, while, finger number was not strongly influenced by P level, although single fruit weight showed a strong positive relationship to increased P supply. It was observed that 50% reduction in P application resulted in 23 % reduction in single fruit weight (Hongwei *et al*, 2003 and 2004). Harthi and Yahyai (2009) concluded that application of 100g P plant^{-1} yr^{-1} produced highest yield in cv. Williams. Barakat *et al* (2011) found that regular P source could be substituted by rock phosphate along with N and K nutrients for better growth and yield.

Influence of potassium on banana

Banana, being a potassium loving crop, has a very high demand for this nutrient. In India, the applied dose of K varies from 800 to 1600 kg ha^{-1} (Kumar *et al*, 2008). Potassium now occupies an important place not only with regard to its content in plant tissues, but also for its role in physiological and biochemical functions. It is commonly known as "quality mineral nutrient" and is the most important element in banana nutrition. Its concentration in the plant system is much higher than all other nutrients, or even, all the mineral nutrients combined. Results of many experiments have showed that adequate supply of K fertilizers not only increases growth and yield in banana, but also improves quality of the fruit, physiology of the plant and offers resistance against biotic and abiotic stresses. Potassium application at early stages recorded maximum plant growth parameters closely associated with yield. (Bhargava *et al* 1993). Lahav (1972) also recorded highest growth with 290g K plant^{-1} in cv. Williams. Robusta registered maximum pseudostem height, girth, number of leaves and leaf area with application of 300-400g K plant^{-1} (Mustaffa, 1987; 1988 and 2000). Likewise, Hasan and Chattopadhyay (2000) observed enhanced growth and yield-attributing parameters with application of 300-600g K plant^{-1}. Khoreiby and Salem (1991) and Ray *et al* (1993) also observed vigorous plants, maximum leaf area and extended leaf longevity in Dwarf Cavendish and Basrai cultivars when fed with 300 or 500g of K plant^{-1}.

Influence of NPK on banana

Increase or decrease in one nutrient element may substantially enhance or deplete availability of other elements. Considerably greater response to nutrients was observed when these were applied together rather than separately in banana at Uttar Pradesh (Ram and Prasad, 1989). Fertilizer range of 100-180: 15-100: 186-400 g of NPK plant^{-1} improved growth and yield in cv. Robusta as observed by many workers (Kohli *et al*, 1976; Randhawa and Iyer, 1978; Nanjan *et al*, 1980; Pillai and Khader, 1980) in India, whereas, Dwarf Cavendish showed increased growth and yield when supplied with 72-200:90-96:150-480 g of NPK plant^{-1} (Teaotia *et al*, 1972; Chattopadhyay and Bose, 1986; Shelke and Nahate, 1996). Koen *et al* (1976) reported increased yield in Dwarf Cavendish with application of 450:36.8:210g NPK plant^{-1} in Levuba. Application of

300:300g of N&K plant^{-1} in banana cv. Harichal registered higher yield (Pandit *et al*, 1992 and Pathak *et al*, 1992). Guerrero and Gadbau (1996) observed that increased growth and yield in cv. Williams was due to application of recommended dose of 550:750g N&K plant^{-1}. Ray *et al*(1993) recorded higher yield by application of 200:100:300gNPK plant^{-1} in cv. Basrai and in Grand Naine banana application of 165:62.5:495g NPK plant^{-1} showed increased yield (Nalina, 2002). In contrast, Suma *et al* (2007) and Pujari *et al* (2010) observed highest number of hands (8.35) and fingers bunch^{-1} (121.67) with 200:40:200g NPK plant^{-1} in cv. Grand Naine. Harthi and Yahyai (2009) observed that application of higher dose of fertilizer (900:150:750g plant^{-1} year^{-1}) resulted in low bunch weight and reduction in fruit weight in Cavendish cv. Williams. Similar results were reported by Butler (1960) and Pujari *et al* (2010).

Foliar fertilization in banana

Banana is a highly exhaustive crop and requires large quantities of mineral nutrients for rapid growth and development, readily responding to applied nutrients. It is reported that a mature banana plant removes 221:52:981g N, P_2O_5 and K_2O per plant, respectively. In general, a large quantity of nutrients applied to soil is lost through run-off, leaching and fixation in the soil. In low fertility soil with cation exchange capacity (CEC) of 5-10m.eq./100g with 1400-2000mm rainfall/year, as much as 165:22:376:89:36 kg of N, P, K, Ca and Mg were lost (which represent 60-85% of applied fertilizers). Besides soil application, supplementary foliar spray of N as urea was found effective in increasing bunch weight by improving finger size besides improving fruit quality. Ramasamy (1976) reported that foliar application of P along with soil application of 110g and 330g each of N and K_2O increased bunch weight and reduced crop duration by 13 days, with a cost:benefit ratio of 1:2.7 against 1:2.3 in conventional soil application. Banana is known to respond well to foliar nutrition, especially to major, secondary and micronutrients. However, it is best to use this mode to correct nutrient needs difficult to attain through soil application.

Foliar spray of major nutrients is a contingent measure to boost yields whenever the crop suffers from nutrient deficiency. Foliar application of 1.0 % urea and 2.0 % muriate of potash as mixture increased bunch weight and fruit quality (Vijayaraghavan and Ayyamperumal, 2000). Foliar application of 2,4-D @25ppm either alone or in combination with fertilizer application (110:30:330 g NPK plant^{-1}) resulted in favourable growth in Red banana (Selvarajan and Doraipandian, 2000). Kumar and Jeyakumar (2001) reported that foliar application of $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $CuSO_4$ (0.2%) + H_3BO_3 (0.1%) during 3rd, 5th and 7th month after planting, in addition to the recommended dose of NPK @ 110:35:330g pl^{-1} year^{-1}, improved bunch weight, besides enhancing fruit quality. Foliar spray of sulphate of potash (1.5%) along with recommended dose of fertilizer had a positive impact on bunch weight and fruit quality, as reported by Ramesh Kumar and Kumar (2007).

Bio-fertilizers on growth / yield in banana

Use of biofertilizers is found to be essential not only to reduce the quantum of inorganic nutrients or organic manures to be applied, but also to increase the beneficial soil flora and fauna, thereby increasing fertility of the soil. Jeeva *et al* (1988) reported that *Azospirillum* inoculation + 100% N application enhanced height and girth of the pseudostem, leaf production, leaf area and increased bunch weight by 8.2% compared to non-inoculated control plants which received 100% N alone.

In-vitro derived banana plants inoculated with VAM and/or with phosphate solubilizing bacteria (*Phosphobacteria)* was significantly taller and produced greater dry matter compared to the untreated plants (Alonso reyes *et al*, 1995). Studies on *Azatobacter chrococcum* as a nitrogen fixer and bio-stimulant for banana revealed that bacterial inoculation (20 l/h) stimulated plant height, number of leaves and shoots, and pseudostem diameter. Bacterial inoculation also favoured fruit development and could compensate for 20% of N fertilizer without changing yields, corresponding to 30g N/ plantlet.

Fertilizer schedule for important commercial banana cultivars

Variety	3rd month			5th month			7th month		
	Urea	Super	MOP	Urea	Super	MOP	Urea	Super	MOP
Poovan, Ney Poovan Rasthali, Karpuravalli Dwarf	100	300	150	200	-	250	150	-	200
Cavendish, Robusta, Grand Naine Nendran, Monthan	100	300	200	200	-	300	150	-	250

Organic manures on soil physical properties

Application of organic manures and amendments to soil increases crop yield by enhancing the latter's physical properties besides improving availability of nutrients, to the plant and organic carbon and cation exchange capacity of the soil. Soil physical characteristics such as texture, compaction and drainage influence banana growth and development, and limit the effective soil depth and aeration in the rhizosphere. Owing to their effect on water retention capacity, permeability and water-air-balance, presence of coarse fragments (above 15% by volume) is considered as a limiting factor for root growth in banana. Majumdar *et al* (2002) reported that application of 50 % RDF along with 10t ha^{-1} vermicompost improved soil porosity and reduced bulk-density of the soil. Mustaffa *et al* (2004) observed that application of organic manures (2.5kg compost + 1kg vermicompost + 1kg *neem* cake + 2.5kg poultry manure plant^{-1} at 3rd, 5th and 7th month after planting) improved soil physical-properties. The effect of organic farming practices in banana on soil quality improvement was due to increased cation exchange capacity, lesser bulk-density and, in turn, increased porosity (Mei *et al*, 2007). Singh *et al*(2009) found application of organic manures (FYM @ 330qha^{-1} + pongamia oil cake @ 8.30qha^{-1} + neem oil cake @ 8.30qh^{-1} + Sterameal @ 8.30qh^{-1} + rock phosphate @ 8.30qha^{-1} + wood ash @ 8.30qha^{-1}) increased the physical properties and water holding capacity of the soil. Phirke and Mahorkar (2010) concluded that fortification of soil with organic manures like nitrogen fixers, phosphate solubilizing microbes, Vesicular Arbuscular Mycorrhizae (VAM) and bio-fertilizers not only increased soil porosity, but also infiltration of water in banana fields.

Organic manures on growth

Continuous use of inorganic fertilizers leads to undesirable changes in the soil and environment, ultimately endangering the very sustainability of farming (Sharma, 1988). Inclusion of organic manures in the nutrient schedule of banana not only supplies micronutrients, but also improves physical, chemical and biological properties of the soil. Banana responds positively to large amounts of mulch and organic matter. Heavy organic manuring is required to equalize chemical fertilization in banana (Lahav, 1973). Soil application of 0.5kg of *neem* cake along with 10g *Pseudomonas fluorescens* plant^{-1} at 3rd, 5th and 7th month after planting enhanced growth of banana. Mustaffa *et al* (2004) reported that application of organic manures significantly improved growth parameters in cvs. Rasthali and Karpuravalli. Soil application of powdered *neem* seed or *neem* cake at 100g plant^{-1} at planting and subsequently at 3 or 4 months' interval positively influenced growth in banana. Ratan *et al* (2008) concluded that application of organic manures such as vermicompost, FYM, poultry manure, neem cake and its combinations recorded equal leaf nutrient status compared to100 % inorganic fertilizers in cv. Grand Naine. Sundararaju and Kiruthika (2009) found that application of *Paecilomyces lilacinus* 10g plant^{-1} + *neem* cake 100g plant^{-1} improved growth characters like pseudostem height, girth, number of leaves, number of roots, root length and root weight in cv. Robusta. Athani *et al* (2009) opined that *in-situ* vermi-composting increased pseudostem height, girth, number of functional leaves, leaf area and leaf area index in cv. Rajapuri. Badgujar *et al* (2010) recorded higher pseudostem height, pseudostem girth, total number of leaves, days taken to shooting and less number of days for harvesting with application of 20 kg FYM + 1 kg *neem* cake + 200: 40:200g NPK plant^{-1}.

Organic manures on yield attributes

Application of 8.25t ha^{-1} cattle manure along with cattle-shed washings and slurry at every four months increased yield attributes in banana (Herath *et al*, 1977). Mustaffa *et al* (2004) studied the influence of different organic manures on cvs. Rasthali and Karpuravalli and concluded that application of 2.5kg compost + 1kg vermicompost + 1kg *neem* cake + 2.5kg poultry manure at 3rd, 5th and 7th month after planting recorded maximum values for yield parameters. Application of organic amendments such as farmyard manure, green leaves, wood ash, neem cake and other oil cakes produced bunches weighing 25-30kg as compared to 10-12kg under normal production systems in Chengalikodan (Menon *et al*, 2004). On the contrary, Navarro (2005) calculated that there was no difference in bunch weight between chemical fertilization or organic fertilization in banana under soil and climatic conditions of the Central-southern part of Tolima, Colombia. Pushpakumari *et al* (2008) revealed that application of coir pith compost increased bunch weight (18.9t ha^{-1}) compared to application of FYM (17.4t ha^{-1}), poultry manure (17.9t ha^{-1}) or vermicompost (17.0 t ha^{-1}) in banana. They also confirmed that different organic sources could be effectively used as a substitute for chemical fertilizers without any reduction in bunch yield in cv. Nendran. Bhalerao *et al* (2009) studied the influence of 100 % organic manures (FYM + green manure + *neem* cake 1.0kg + bio-fertilizer) on cv. Grand Naine and found lesser yield of banana over that with INM practices. Thomas (2009) elucidated that oil cakes from *neem*, *marotti*, castor, groundnut and mustard markedly influenced yield in banana owing to their higher nutrient content. Anusuya (2009) found that application of vermicompost alone gave equally good performance with reference to bunch weight, on par with 100 % recommended dose of fertilizers. In Egypt, Barakat *et al* (2011) found that application of bio-fertilizers along with compost, rock phosphate and feldspar recorded maximum bunch weight, with better fruit characteristics in cv. Williams.

Organic manures on fruit quality

In general, application of organic manures resulted in better quality fruits. *In-situ* green manuring with sunnhemp and mulching with banana residues improved fruit quality in terms of TSS, sugars, acidity and sugar:acid ratio (Sathyanarayana and Babu, 1992). Menon *et al* (2004) observed that application of organic amendments, viz., FYM, green leaves, wood ash, neem cake and groundnut cake improved the quality of fruits and organic manures produced uniform golden yellow bunches at maturity, and fetched 4 to 5 times higher price in cv. Chengalikodan. Mustaffa and Kumar (2008) found that combined application of compost, vermi-compost, *neem* cake and poultry manure recorded maximum TSS, acidity, total sugars and starch content in Rasthali and Karpuravalli cultivars. Moniem *et al* (2008) observed that application of 100 % RDF through FYM or banana compost registered values statistically on par as regard fruit quality parameters. In cv. Grand Naine, application of vermicompost (3kg plant^{-1}) and castor cake (3kg plant^{-1}) produced superior quality fruits with shelf life (Patel *et al*, 2010).

Integrated nutrient management (INM)

Proper manuring and fertilizer application is required in banana for obtaining high yields. Moreover, continuous use of chemical fertilizers affects soil health, thereby reducing organic matter content and beneficial soil microorganisms. Considering the present concerns on soil health and environmental security, there is a need to opt for integrated nutrient management involving sources of organic manures, organic cakes and bio-fertilizers, including mycorrhizae, besides chemical fertilizers. Hence, an integrated nutrient management (INM) system is needed to be introduced with the aim to achieve efficient use of chemical fertilizers in conjunction with organic manures. In INM, a combined application of organic and inorganic sources of nutrients, maintains plant nutrients in soil and improves nutrient-use efficiency, which is essential for sustainable crop production. Organic matter acts as a source and a sink for plant nutrients besides providing an energy substrate for soil micro organisms. Thus, it enhances activity of soil flora and fauna, as well as the intrinsic soil properties, soil nutrient capital, water-holding capacity. Soil structure, in turn, makes it less susceptible to leaching and erosion. Therefore, INM practices are essential to maintain / enhance soil quality and sustainability of an agro-ecosystem (Carter, 2002). Conjunctive use of FYM with recommended levels of inorganic fertilizers improves soil fertility giving increased yield of the crop.

Availability of FYM in adequate quantities to meet the requirement of the banana for integrated and conjunctive use with inorganic fertilizers is a major problem. However, there is scope for supplementing FYM with green manures, vermicompost, bio-fertilizers and commercial organic formulations (Bhalerao *et al*, 2009). Integrated nutrient management in banana is being practiced and experimented in various parts of our country. Bhalerao *et al* (2009) observed that combined application of 100 % recommended dose of NPK along with 10kg FYM plant^{-1} and *Azospirillum* and Phosphate solubilizing bacteria 25g plant^{-1} increased pseudostem height, girth took, minimum days to flower and crop duration, and yield attributes. Similar trend was reported by Mustaffa *et al* (2004); Bhalerao *et al* (2009), Hazarika and Ansari (2010); Badgujar *et al* (2010) and Barakat *et al* (2011) in banana. The remaining nutrients are to be supplied through external sources such as inorganic fertilizers and / or organic/biological sources. Consequently, several inorganic fertilizer combinations have been recommended for optimum yield in banana but, in the long run, these cannot sustain fertility status of the soil. In recent times, much attention has been given to integrated use of organic manures and inorganic fertilizers to meet the economic need of farmers for sustainability in terms of crop productivity and soil fertility (Hazarika and Ansari, 2010a).

INM on quality parameters

Combined application of nitrogen (300g), potassium (200g), *karangi* cake (1000g) and Planofix (150 ppm) significantly improved the quality parameters such as TSS, acidity, sugars, and sugar:acid ratio and ascorbic acid (Singh *et al*,2000). Naby and Sonbaty (2005) found that application of FYM with mineral NPK gave highest fruit chemical properties (TSS and total sugar) in banana. Balakrishnan *et al* (2006) reported that application of 75 %RDF + 25 %RDF through vermicompost increased pulp weight, peel weight, and lowered pulp:peel ratio in cv. Poovan. Application of 50 %banana compost + 50 % mineral fertilizers enhanced fruit quality in terms of increased total soluble solids, total sugars, lower starch and total acidity (Eman *et al*, 2008). Thangaselvabai *et al*(2009) recommended application of *Azospirillum* along with NPK in two splits for increasing fruit quality in cv. Rasthali. Application of vermicompost and castor cake each @ 3kg pl^{-1} produced superior quality fruits and enhanced shelf life in cv. Grand Naine (Patel *et al*, 2010).

Banana bunch sleeves for enhancing bunch grade

Worldwide, wind is considered as the single most serious threat faced by banana and plantain growers. Winds of even moderate speed damage fruits through scarring of the peel surface in several ways (by blowing dust and debris that hit the delicate outer skin and cause cellular damage and, subsequently, scarring of fruits). In addition, fruits are attacked by sucking pests, including different types of thrips such as red rust thrips, flower thrips and fruit scarring beetles right from bunch emergence until harvest of bunch. In majority of the cases, insects feeding on immature fruits is the main cause of peel damage, especially in regions with high populations of sucking pests. Due to pre-harvest damage caused by these sucking insect pests, farmers suffer significant losses. In general, most fruit scarring pests cause superficial peel damage which does not affect eating quality of the fruit. However, it negatively affects the fruit's external appearance and market value. Since quality standards are rather rigid in the export market, fruits having external blemishes caused by pests, are totally unacceptable to the discerning export market.

Significance of bagging banana bunches

Covering the bunch with dried banana leaves is practiced in many commercial banana growing countries as a measure to avoid any damage to the fruits and protect the fruit from insect attack, thereby ensuring better bunch quality. For centuries, old banana leaves have been wrapped around maturing bunches in New Guinea. In 1936, it was demonstrated that covering bunches with hessian bags protect to them against winter-chilling which improved the quality. Later, paper bags were used, although to a limited extent. In recent years, the practice of covering the bunch with polythene sleeves during development to protect fruits intended for the export market has gained momentum and has become an important cultivation practice especially in the banana exporting countries. Bagging is done to protect bunches from low temperature and is followed in countries like India (Gopalakrishna and Deo, 1960) and Australia (Berrill, 1956). Bunch covers are also effective against sunburns and blemishes caused by wind-blown dust and by birds (Samson, 1980). Chillet and Jannoyar (1996) reported that bagging raised the temperature around bunches and reduced the shooting-to-harvest interval under temperate conditions, as, bagging changed the microclimate around the bunch. Bunch covers are effective in increasing yields of bunches maturing during winter months. Some growers also experimented with double bunch covers (often, a clear cover placed inside a coloured cover) to provide greater warmth for the winter bunches. Research findings of Malaysian Agricultural Research & Development Institute (MARDI), suggest that skin injuries to Cavendish banana can be greatly reduced (up to 90%) by wrapping the fruit bunch.

Colour of bunch covers

Although several colours gave excellent results, the banana industry standardized blue bags for many years. More recently, blue, green, yellow and clear (with or without silver sides) have been used. The bunch covers consistently increased bunch weight by about 25 %. The bag comes as a tube which slides up the bunch and is tied loosely only at the top and left open at the bottom. This allows air movement and prevents possible overheating inside the bag. At the Centre for Tropical Horticulture, Alstonville, NSW, experiments showed that while yield increases of 25 to 30 % could be expected in some seasons, no significant yield increase occurred in some others. However, covered bunches always produced fruit that was much better in appearance, than the uncovered bunches. Fruits from covered bunches were more uniform in size and fullness from the front to the back and top to the bottom of the bunch, than in uncovered bunches. Banana bunches emerging in September and were covered with blue polythene sleeves, combined with use of paper inserts, to avoid sunburn. Results revealed that bunches covered with blue polythene yielded 22% more, and this increase rose to 28% if a newspaper was placed over the top hand. Covering also raised the percentage of top-grade fruits and the paper-protection enhanced quality by reducing sunburn (Rippon and Turner, 1970).

Types of bunch covers

Various types of covering—dry banana leaves, canvas, drill cloth, *sisal* sacks, or burlap or so-called 'Hessian' bags (made of jute), have been put over banana bunches intended for export, especially, to enhance fruit development in winter and to avoid blemishes. Type of bunch cover to be recommended depends upon climatic conditions prevalent in the region. Generally, thick, non-perforated polythene covers which favour heat build-up inside, are found best suited for cooler, sub-tropical banana growing regions; whereas, for tropical growing environments, comparatively thinner and perforated bunch covers (that allow better aeration inside the cover) are more suitable.

Banana bunch covers are usually designed with 100 gauge thick, white or blue polythene sleeves, normally of 80cm width; but, plantains (Nendran) owing to the lateral orientation of fruit, require a width of 100cm. The tubular/hollow sleeve should be slid up the bunch from the bottom. Bagging of the bunch is done with six to 10 % ventilation, with the bags at about 20-30 cm above the first hand, and leaving the bottom-end open so there is no accumulation of floral remnants or moisture which, otherwise, may cause fungal infection at a later stage. In general, the length of polythene sleeves varies from 1.0m to 1.5 depending on the length of the bunch. In the case of very long bunches in Udhayam banana, bunch-cover 2.0m long is required. Recently, polypropylene bunch covers that allow better aeration inside the cover have been found equally effective. Unlike the polythene sleeves, these do not require holes.

Bunch trimming

Effect on yield and fruit quality of polyethylene bunch covers (applied one week after abscission of the last female flower bract) and bunch-trimming (by removal of the distal one or two hands of the bunch) was investigated. Bunch covering increased fruit weight per bunch by 4 % and decreased the period from bunch emergence to harvest by 5 days. However, yield reduced by 5 %with trimming one hand per bunch, and by 13-15 % with trimming two hands. These yield declines occurred without accompanying improvement in fruit grade. Thus, bunch trimming was found unprofitable in North Queensland (Daniels *et al*, 1987).

Timing of covering the bunch

The timing of bunch-covering during development of bananas was examined to arrive at the optimum, for fruit quality. Covers open or sealed, were applied at various stages of bunch development. Sealed covers increased the severity of maturity-bronzing whenever applied. Maturity-bronzing was slightly less when open covers were applied when the last female bract lifted on the bunch (early), compared to a week or so later when the fingers had curled up. Bunch weight did not increase by application of open covers, but sealed covers increased bunch weight by up to 9%. This was due to the increased finger length along the entire bunch. Application of covers (both open and sealed) at earlier than conventional time increased finger length at the proximal end of the bunch, the effect being greater the earlier the covers were applied. Open covers reduced the time taken from bunch emergence to harvest by 5-11 days, compared to no covering. Very early and early covering gave the largest reduction, whereas, sealed bunch covers delayed harvest by up to 16 days, compared to no covering. There was a non-significant reduction of 2-4 days in fruit green-life, related to delay in bunch-filling caused by sealed covers. Sealed covers led to some fruit abnormalities, including severe spotting by *Deightoniella* sp., in slightly s-shaped fruits, and a dull fruit-appearance. Early application of open bunch covers is recommended to reduce maturity-bronzing as it also increases finger length, and bunch-filling time is reduced by about 1.5 weeks. It is cautioned that the cover should not be put on until bracts have lifted from the fruits (about 21 days after "shooting") so that the young fingers will be firm enough to resist friction from the cover.

Benefits of bunch covers

Wrapping produces bananas high in quality and free from insect bites, fungi or bacteria as well as physical injuries such as abrasions, blemishes and cuts. Bunch covers protect fruits against wind damage, fruit-scarring by the adjacent leaf/petiole, sunburn, damage due to dust, light hail, bird feeding and improve fruit quality and increase the yield. More importantly, significant reduction in insect pest damage to the fruit peel can be achieved by covering the bunch shortly after bunch emergence, preferably before emergence of the first hand. In addition to the benefits of producing blemishless fruits, there is significant reduction in post harvest anthracnose disease on the fruit from sleeved bunches. The net effect of bunch-cover use is better quality fruit and increased marketable yield. Overall, bunch covers help produce larger individual bananas with less skin damage, thereby fetching better market price and higher profits. In addition, polythene bunch covering advances fruit maturity by 7-10 days.

Effect of bunch cover on finger grade (mm), finger length (cm) and bunch weight (kg) of tissue culture banana cv. Williams

Treatment	Grade (mm)	Finger length (cm)	Bunch weight (kg)
Control	30.94 a	19.07 a	8.62 a
Dull blue	33.33 a	20.03 a	10.44 a
Shiny blue	33.44 a	20.37 a	9.16 a
LSD	NS	NS	NS

Performance of banana bunches/fruits with different bagging materials

Treatment	Harvesting maturity (± sd)	Bunch weight (kg)	Hand weight (kg)	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Brix value (% ± sd)
No bagging	104 ± 2.8	13.74	1.32	93.5	12.7	11.5	20.9 ± 1.0
Blue bag	103 ± 2.8	18.26	1.72	109.1	14.9	13.4	21.4 ± 0.7
Colorless bag	103 ± 2.5	18.14	1.70	117.2	14.6	13.9	21.1 ± 1.2
White bag	102 ± 2.6	16.86	1.58	110.9	14.3	14.6	20.7 ± 1.4
Polypro bag	103 ± 2.6	18.24	1.62	110.3	14.8	14.2	20.5 ± 0.9
Poly sac bag	102 ± 2.1	18.90	1.64	112.2	14.9	13.9	21.0 ± 0.9
CV%		8.28	11.31	10.3	7.30	10.1	
LSD ($p=0.05$)		1.90	0.24	14.8	1.4	1.8	

(Source: Weerasinghe and Ruwanpathirana, 2002)

Precautions to be exercised

In spite of the benefits, bunch covers can cause problems such as sun burn when polythene sleeves are used during very hot periods. However, these can be easily overcome by:

- Use of reflective covers
- Maintaining sufficient number of leaves on the plant is a must as these provide additional shade to the bunch covers/ bunch
- Polypropylene covers which are aerated & biodegradable

Though there has been many success stories achieved by the farmers from certain banana growing regions particularly in the states of Maharashtra, Gujarat and Tamil Nadu who have achieved very high yields of export quality bananas, attention is warranted for the adoption of technologies right from the selection of high-yielding varieties, planting of healthy planting material preferably the tissue cultured plants, drip and fertigation techniques, better mat and bunch management practices for equally enhancing the production and productivity of bananas in other parts of the country as well. Among the techniques for enhanced production, it is important to choose ideal plant spacing with high density planting and maintenance of ideal plant population depending on cultivar and management level play a vital role to bridge the gap between actual yield and the potential yield from a unit area. It is also essential to enhance the input use efficiency of major inputs of water and nutrients through adequate nutrient diagnostics and need based application at correct proportion and in time to avoid deficiency/excesses of nutrients. Proper bunch management practices also ensure harvest of good grade bunches with blemish less fruits thus in turn confirms comparatively premium price and profit to the banana growers as well as healthy and hygienic fruits to the consumers.

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