Training Manual on

Role of Balanced Fertilization for Horticultural Crops

Edited by
Dr. N. Kumar
Professor (Hort.)

Horticultural College and Research Institute
Tamil Nadu Agricultural University
Coimbatore - 3

Sponsored by

International Potash Institute
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TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE - 641 003, TAMIL NADU, INDIA

Dr. C. RAMASAMY
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FOREWORD

India is endowed with varying ecological situations and it is possible to grow almost all groups of Horticultural Crops. India produces 45.5 million tones of fruits annually from an area of 3.8 million ha, resulting in 88 g per capita availability daily as against a recommended consumption of 120 g per capita/day. Besides, it's productivity of 12.0 t/ha is also very low when compared to many countries. Now India has emerged as the second largest producer of vegetables with a total estimated production of 88.62 million tones from an area of 6.15 million ha with productivity level of 14.4 tones/ha. The productivity level of vegetables is still very low mainly because of some limitations, which require immediate attention and can be taken up as new challenges in 21^{st} century for increasing farm level income of the vegetable growers.

India, 'Land of Spices' is the world's largest producer, consumer and exporter of spices, grown in 3.2 million ha with a production of 3.76 million tones. Of which, exports accounted for Rs.20, 8671.02 lakhs were exported. To meet the internal consumption and international demand, an annual growth rate of 8-10% is envisaged. Plantation crops grown in an area of 7.32 million ha with a production of 16.0 million tones earn a foreign exchange of more than Rs.10, 000 crores through export of various products, besides contributing towards environment protection and sustaining large number of agro based industries.

Floriculture has emerged as a viable diversification option in the agri-business. Though the commercial cultivation of flowers in open field conditions is the mainstay of Indian horticulture, protected cultivation opens up newer avenues for quality production and export to earn valuable foreign exchange. A consistent increase of 10-15% jump in the flower trade has been visualized during the last few years, which is largely due to the adoption of modern technologies (Hi-tech horticulture).

There are several constraints in increasing the area under horticultural crops and their production. Yet to sustain the production and increase the productivity of these crops, judicious nutrition management is one of the options. I understand that **International Potash Institute, Switzerland** is committed to this cause by supporting research and extension activities in different parts of the world including India. Further, I am happy to note that it is organizing a one day training programme on ***"Role of Balanced Fertilization for Horticultural Crops"*** for the benefit of the Extension functionaries in the development departments of Agriculture / Horticulture in Tamil Nadu in collaboration with Tamil Nadu Agricultural University.

I am sure that this manual which is a compilation of extensive research work done on the nutrient management of horticultural crops by TNAU scientists and other National Institutes will be quite useful for the extension functionaries and the enthusiastic horticulturists. I congratulate **Dr.N.Kumar**, Prof. (Hort.,) at this occasion for his concerted efforts in compiling and bringing out this manual.

(C. RAMASAMY)

Coimbatore
November 21, 2007

INTERNATIONAL POTASH INSTITUTE

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MESSAGE

The International Potash Institute (IPI), based in Switzerland, is an International Research Organization supporting research and extension activities with respect to adequate and balanced nutrition of crops to sustain productivity and production in different parts of the world. IPI has a network of regional coordinators. To meet its goals of promoting balanced fertilization, the institute sponsors research projects, organizes seminars, symposia and workshops, conducts research and demonstration experiments and publishes scientific literature in different languages, worldwide.

Concern of a global food production to feed the growing population of the world requires increased efforts to develop new expedients for the future. Tamil Nadu accounts for nearly 6% of the area under fruits and 4% of the area under vegetables in India. In terms of production, the State's share is nearly 10% in fruits and 6% in vegetables. The state ranks second in the production of mango and third in the production of sapota.

In cooperation with TNAU, IPI conducted demonstration experiments in papaya crop in Coimbatore, Dindigul, Theni and Madurai districts of Tamil Nadu. These activities well proved the highest efficiency of fertilizer application practices recommended by TNAU scientists (paper by Dr. N. Kumar in this Manual).

This booklet summarizes results obtained in long-term experiments in most important horticultural crops in Tamil Nadu by prominent researchers from TNAU, providing best fertilizer management practices for farmers. We hope it will be a helpful tool for both state extension functionaries and farmers.

(Hillel Magen)

Vladimir Nosov
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Balanced Fertilization for Soil Fertility Management

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Increasing global population warrants higher demand for cereals as food by 2020. To match the expected cereal demand, cereal yields must be increased from current 2.9 t/ha to almost 4.9 t/ha, and rice yields by 60 to 70%. Another crisis is the decreasing rate in the availability of arable lands. The per capita land availability will decline from currently 0.14 ha to 0.10 ha in 2025, due to severe competition from urbanization, industrialization and civic needs etc.

According to a conservative estimate the food grain demand in India for the years 2010 and 2020 is projected to be 246 and 294Mt, respectively (Table 1), indicating the need to increase our food grain production in the years to come. This warrants increasing in our production and productivity of cereals which is highly dependent upon the judicious nutrient management practices.

Table 1. The current production and future demands of food grains in India

Food grain	Production(Mt) in 2001-02	Estimated demand (Mt)	
		2010	2020
Rice	93.1	103.6	122.1
Wheat	71.8	85.8	102.8
Total cereals	198.8	224.4	265.8
Pulses	13.2	21.4	27.8
Total foodgrains	212.0	245.8	293.6

Source : FAI (2003) and Kumar (1998)

Global fertilizer consumption status

Increases in cereal production in the past 40 years were well associated with corresponding increases in fertilizer consumption (Fig.1) in developing countries (FAO, 2000).

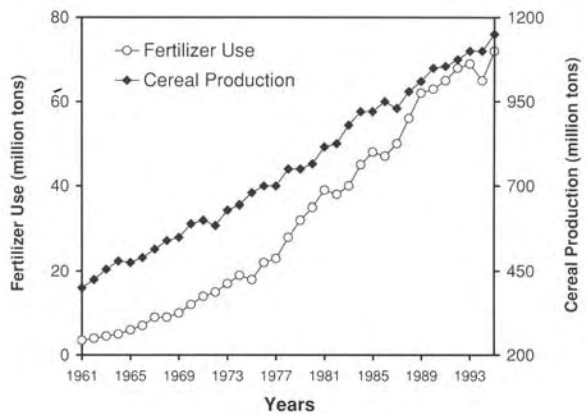

Fig. 1. Growth in fertilizer use and cereal production in developing countries (1961-1995)

Subsequently, use of nitrogen fertilizer recovered fairly well whereas use of phosphate and especially of potash fertilizers is still below the level achieved during the late eighties although crop output continued to increase further. This resulted in fertilizer usage becoming unbalanced in two respects:

- Nutrient ratio, especially of N to K.
- The ratio of fertilizer nutrient to nutrient removed by crops, i.e the input/output ratio.

Fertilizer Scenario in India

Even though India is the third largest fertilizer user, average rate of nutrient application is 90 kg/ha^{-1}(65% as N, 25% as P_2O_5, 10% as K_2O). The fertilizer consumption in the country ranges from 1.1-325 kg N ha$^{-1,}$ 0.8-153.8 kg P_2O_5 ha^{-1} and 0.2-129 kg K_2O ha$^{-1.}$ There are a lot of disparities in the fertilizers consumption pattern both between and within the eco-regions in India.

The current fertilizer use in Tamil Nadu is 112 kg ha^{-1} consisting of 60.1, 24.6, and 27.3 kg ha^{-1}N:P_2O_5:K_2O, respectively with the use ratio being 2.2:0.9:1.0. While most of the nitrogen is applied in the form of urea, the major phosphatic and potassic sources continue to be DAP (46% P_2O_5) and muriate of potash (60% K_2O), respectively. This ratio is certainly much better than the northern states mainly because southern region has high value crops where the crops are being fed better than the cereals, oilseeds and pulses dominated cropping systems in the northern region (Tiwari and Rao, 2005) (Table 2).

Table 2. State wise consumption of P_2O_5 and K_2O in relation to N (2001) in southern region

State in descending order of P	N applied kg ha^{-1}	kg P_2O_5 applied/ 100kg N	State in descending order of K	N applied Kg ha^{-1}	kg K_2O applied/ 100kg N
Karnataka	54.5	53.8	Kerala	26.2	83.2
Kerala	26.2	48.9	Tamil Nadu	76.2	45.1
Pondicherry	317.4	47.3	Pondicherry	317.4	39.7
Andra Pradesh	86.8	46.1	Karnataka	54.5	32.5
Tamil Nadu	76.2	40.7	Andra Pradesh	86.8	19.1
All India	58.7	38.8	All India	58.7	14.8

Source : Tiwari and Rao, 2005

Changing Soil Fertility Scenario in India

Indian agriculture is operating under the pressure of multi nutrient deficiencies. Nitrogen deficiency in soils is almost universal. Phosphorus deficiencies are not far behind those of N as in 95 per cent districts, the P fertility is either low or medium.

Many years ago, it was found that out of 361 districts, soils in 47 districts were of low K status, in 192 were medium and in 22 districts were high in K fertility. Since then K deficient areas have increased and crops in many areas are responding to K where they were not responding some years ago. Crops in general remove as much or more K than they remove N but average consumption of K_2O ha^{-1} is still 8.7 kg while that of N is 58.7 kg ha^{-1} at a highly unbalanced N:K_2O ratio of 7:1.

In the long-term fertilizer experiments, there are indications that when exchangeable K is not rapidly replenished, crops start drawing on the non-exchangeable K, resulting in soil mining and depletion of soil K reserves (Tiwari and Rao, 2005). The results of the LTFE of Tamil Nadu Agricultural University, Coimbatore reveal that the K removal by intensive cropping is disproportionately higher than the amount of K added through fertilizer (Murugappan, 2001) (Table 3).

With intensive cultivation of high yielding varieties, deficiencies of secondary and macronutrients caused declining productivity of crops in many soils. Among secondary nutrients, sulphur deficiency is an important problem in many states and soils in 130 districts are considered to be suffering from S deficiency to varying extent. Though it is believed that magnesium deficiency occurs in acid soils or where exchangeable Mg is below 1 meq $100g^{-1}$ or less than 10 per cent of soil CEC is occupied by Mg^{++} but the problem seems to be of greater magnitude than expected. Among micronutrients zinc, boron and iron deficiencies were found most common problem. Soil application of zinc, boron and sulphur was found more effective than their foliar application and *vice-versa* for iron and manganese.

Table 3. Nutrient budgeting in a long term fertilizer experiment in Tamil Nadu (from 23 crop cycles of Finger millet-Maize-Cowpea)

Treatment	Nutrient added per cycle (Kg/ha)			Nutrient removed per cycle (Kg/ha)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Control	-	-	-	76	22	95
100% N	250	-	-	99	28	122
100% NP	250	163	-	233	71	287
50% NPK	125	82	27	199	64	265
100% NPK	250	163	53	234	79	321
150% NPK	375	245	80	258	89	352
100% NPK + FYM	375	163	53	280	100	386

Balanced Fertilization and Agricultural Production

Balanced fertilization is the key to increased plant use efficiency of applied nutrients. A balanced fertilization programme does more than simply replace the amount of any nutrient removed by the crop. It ensures that fertilizers are applied in adequate amounts, and correct ratios for optimum plant growth, and it ensures, sustenance of soil and crop productivity. The long-term fertilizer experiments being conducted at different locations of the country have clearly demonstrated the need for balanced fertilization (Swarup *et al.* 1998).

Large number of long term field experiments at many locations indicated the effects of balanced nutrient supply on grain yield of wheat. Each added nutrient other than N greatly increased grain yield over the N application alone. Continuous use of N alone leads to severe depletion of other nutrients, with a corresponding decrease in the grain yield (Fig. 2). The substantial increase in grain yield by Zn application in addition to the NPK application indicate critical importance of these nutrients in crop production (Tandon, 1995).

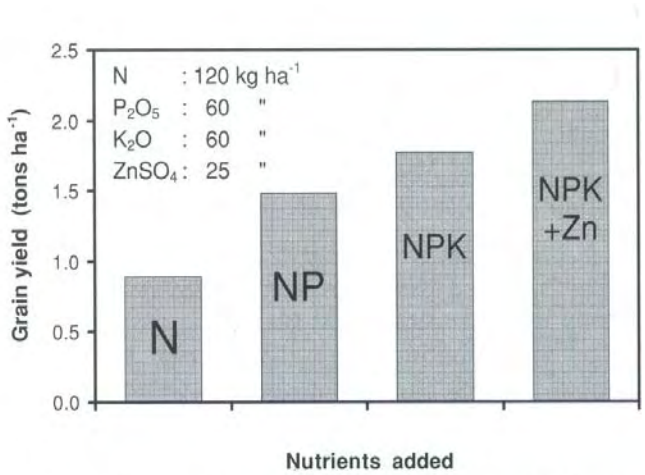

Fig. 2. Wheat grain yield based on long term multi location experiments

Studies by Saxena (1995) also support the concept of balanced fertilization in achieving higher yield in crop plants (Fig.3).

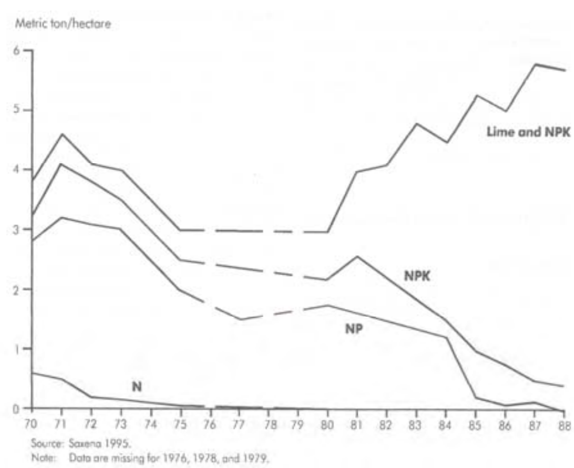

Fig. 3. Long term effect of balanced fertilization on wheat yield, 1970-88 (Saxena,1995)

Balanced fertilization, used in conjunction with other best management practices (BMPs), is essential for optimum N utilization. It should take into account the crop removal of nutrients, the economics of fertilizers and profitability, farmer's investment ability, agro techniques, soil moisture regime, weed control, plant protection, seed rate, sowing time, soil salinity/alkalinity, physical environment, microbiological condition of the soils, soil status of available nutrients, cropping sequence, etc. The BMP system will encourage quicker ground cover, more crop residues, greater root growth and more leaf area, all of which will improve N use efficiency and reduce erosion.

Organic Inputs in Soil Fertility Management

The organic inputs to soil (animal manure and composts, crop residues, green manures, urban wastes etc.) are known to have favorable effects on soil physical, chemical and biological processes and its overall health. Organic materials generally improve the soil organic matter (SOM), a basic indicator of soil health and resilience, in addition to supply of substantial quantities of plant nutrients to enrich soil fertility. Though abundant quantities of organics are generated annually, the entire quantity is not available for returning to soils because of several competing alternate uses in rural India. Tandon (1997) estimated organic resources availability to be 246 and 307 Mt in 2010 and 2025 AD, respectively in India (Table 4). If used properly, these quantities of organic resources can supply plant nutrients ($N+P_2O_5+K_2O$) to the tune of 6.24 and 7.75 million tones in 2010 and 2025 AD, respectively and certainly help minimize the negative nutrient balances.

Table 4. Some projections on the tappable* organic resources and their nutrient supply ($N+P_2O_5+K_2O$) for agriculture in India during 2010 and 2025 AD

Resource	2010 AD		2025 AD	
	Tappable quantity (mt)	Nutrient supply (mt)	Tappable quantity (mt)	Nutrient supply (mt)
Human excreta	15	1.80	17	2.10
Livestock dung	119	2.10	128	2.26
Crop residues	112	2.34	162	3.39
Total	246	6.24	307	7.75

* Tappable = 80% of excreta, 30% of dung and 33% of crop residues *(Source : Tandon,1997)*.

According to Krishnamurthy *et al.* (2001), substituting 50 per cent NPK with organic sources proves to be beneficial in terms of soil quality and nutrient uptake, both in rice and mustard after six years (Table 5).

Table 5. Soil fertility status after rice- mustard cropping systems under integrated nutrient management

Treatment	Soil nutrient status					Nutrient uptake (kg/ha)					
						Rice			Mustard		
	pH	EC (dsm^{-1})	O.C (%)	P (kg/ ha)	K (kg/ ha)	N	P	K	N	P	K
Initial	8.1	0.37	0.52	18.0	304	-	-	-	-	-	-
Control	8.2	0.45	0.53	9.8	135	54.6	5.0	37.1	13.7	1.5	15.7
100% NPK	8.0	0.39	0.48	21.5	179	97.8	21.9	99.3	42.4	9.1	35.4
50% NPK + FYM	8.0	0.36	0.48	25.6	210	105.9	23.1	97.4	51.7	8.6	38.4
50% NPK	8.2	0.32	0.46	21.2	188	131.0	16.3	100.1	44.8	11.6	32.9
Crop residue + 50% NPK + green manure	8.0	0.47	0.45	23.9	174	128.5	28.1	131.1	50.0	14.9	39.1

Addition of organics enhances the soil microbial population. Chowksey (1991) reported a decline in the count of bacteria and actinomycetes with inorganic fertilizer application. The counts of all the microbes were substantially increased when inorganics was combined with organics (Table 6).

Table 6. Effect of INM on viable microbial population in soil

Treatments	Microbial population (number / g of soil)			
	Bacteria ($x10^9$)	Actinomycetes ($x10^6$)	Fungi ($x10^6$)	Rhizobia ($x10^6$)
No fertilizer application	32.08	2.90	0.17	16
NPK 20:80:20 kg/ha	21.60	1.40	0.53	104
NPK 20:80:20 FYM 15 t/ ha	95.25	6.20	0.83	150

Integrated Nutrient Management

Integrated Plant Nutrient Supply (IPNS) system refers to the maintenance or adjustment of soil fertility and plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner (Roy, 1995). Conceptually, the IPNS strives to achieve: (a) regulated nutrients supply for optimum crop growth and productivity, (b) maintenance or some times an improvement in soil fertility, and (c) minimum adverse impact on agro-ecosystem quality by means of striking a balance among various nutrient sources viz., soil fertilizers, organic manures and bio-inoculants (Fig.4).

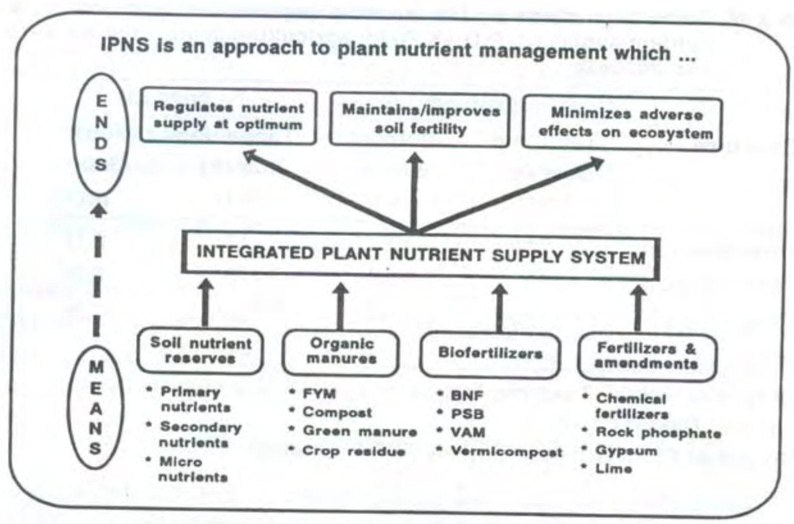

Fig. 4 .The concept of Integrated Plant Nutrient Supply

(Source : Subba Rao and Damodar Reddy, 2005)

Green Manures

Green manures, especially the leguminous green manures are of great value for improving soil fertility. The beneficial effects of green manures include the build up of organic matter content and available plant nutrients and improvement in the microbiological and physical properties of soil. Green manures are particularly recognized for their nitrogen supplying capacity. Sunnhemp (*Crotalaria juncea*) and kolingi (*Tephrosia purpurea*) are the important drought tolerant leguminous green manures for rainfed areas. About 45 to 60 days old crops can accumulate about 100 to 200 kg N ha^{-1}. Green leaf manures like *Gliricidia maculata* can be grown in the roadsides and bunds.

Nitrogen accumulation ranges from 25 to 199 kg/ha for tropical legumes, 56 to 330 kg/ha for winter legumes, 134 to 295 kg/ha for tree legumes, 40 to 240 kg/ha for green legumes and 98 to 532 kg/ha for stem nodulating legumes (Yadvinder singh *et al.* 1992). Following are the relative biomass production and N accumulation of some common green manures (Table 7).

Table 7. Biomass production and N accumulation in some common green manures

Local Name	Botanical Name	Season	Out put in 45 – 60 days	
			Green matter (t/ha)	N accumulation (kg/ha)
Sunnhemp	*Crotolaria juncea*	Wet	21.2	91
Daincha	*Sesbania aculeata*	Wet	20.2	86
Pillipesara	*Phaseolus trilobus*	Wet	18.3	201
Greengram	*Vigna radiata*	Wet	8.0	42
Cowpea	*Vigna unguiculata*	Wet	15.0	74
Guar	*Cyamapsis tetragonoloba*	Wet	20.0	68
Senji	*Melilotus alba*	Dry	28.6	163
Khesari	*Lathyrus sativus*	Dry	12.3	66
Berseem	*Trifolium alexandrium*	Dry	15.5	67

According to Yadav *et al.* (2000), incorporation of green manure resulted in additional increase in grain yield of rice and prevented yield decline in wheat. Green manure and farmyard manure applied along with reduced rate of NPK were able to reduce the mineral fertilizers as much as 50 per cent (Table 8).

Table 8. Grain yields in long term rice-wheat system fertilized with NPK alone or with different organic materials

Treatment	Yield (t/ha)	
	Rice	Wheat
Control	1967	1065
50 % NPK	3180	2321
100 % NPK	451	3506
50 % NPK+ Farmyard manure	4242	3629
50 % NPK + Crop residues	4007	3468
50 % NPK + Green manures	4465	3532

Tanie *et al*. (2001) has reported about the *in situ* growing of common green manures, neglected green manures and cover crops in the coconut basin, their nutrient accretion and available nutrient contents in soil and suggested *in situ* organic matter production as a component of INM (Table 9).

Table 9. Biomass and nutrient accumulation in green manures and available nutrient content in coconut basins (0-15cm depth) two months after incorporation of green manures

Treatment	Bio mass (kg/basin)		Available nutrient content (g/basin) (2MAI)		
	Fresh wt	Dry wt	N	P	K
Sesbania aculeata	13.66	2.73	110.64	38.6	490
Sesbania speciosa	6.91	1.72	50.73	31.2	480
Crotolaria juncea	5.50	1.10	38.87	31.3	390
Crotolaria striata	15.08	3.77	122.92	83.5	430
Cassia tora	18.50	3.07	63.66	47.0	440
Pureria phaseoloides	23.00	4.60	150.83	77.8	540
Calapagonium muconoides	16.50	3.30	83.38	39.6	460
Mimosa invisa	18.25	3.65	68.83	45.8	440
Control	-	-	21.84	17.3	320
CD (0.05)	3.96	0.53	20.66	9.10	110

Short duration legumes like cowpea and greengram are very effective in higher biomass production and N contribution in cropping systems (Table 10).

Table 10. Quantity of nitrogen fixed by different pulse crops

Crop	N fixed (kg/ha)
Alfa-alfa	100-300
Black/Greengram	50-55
Clover	100-150
Cluster bean	37-196
Chickpea	85-100
Cowpea	80-85
Fenugreek	44
Groundnut	50-60
Lentil	90-100
Pea	52-57
Pigeonpea	168-200
Soybean	60-80

The effect of preceeding legumes on succeeding non-legumes is well established. In ICRISAT, Hyderabad, maize grown after groundnut had the residual effect equivalent to 15 kg N ha^{-1}. Sole crop of cowpea left a residual effect of 25-50 kg ha^{-1}. According to Reddy and Surekha (1999), rotation with legumes like chickpea confers increased P availability by its acidic root exudates in addition to N benefit (Table 11).

Table 11. Rice yields and soil available N and P in chickpea – rice rotation

Treatments	Rice grain yield (kg/ha)	Soil available N (kg/ha)	Soil available K (kg/ha)
Control (fallow)	775	163	7.6
Chickpea + P -0	1543	192	13.4
Chickpea + P -20	1726	202	16.2
Chickpea + P -40	2226	2012	16.6
CD (0.05)	178	7.35	2.08

Biofertilizers

Biofertilizers including Vesicular Arbuscular Mycorhiza (VAM) are known to play a key role in integrated nutrient management in crop plants. Phosphobacteria solubilize phosphorus from the insoluble fraction and render it available to crops. This enhances phosphorus uptake and crop growth. Anthoniraj and Thangaraju(2001) reported the highest yield in sorghum through the application of phosphobacteria (Table 12).

Table 12. Combined effect of inorganic and biofertilizers on rainfed sorghum during rabi season

Treatment	Grain yield (t ha^{-1})		Economics	
	1992-93	1993-94	Net Return	B:C Ratio
Control	2.26	1.06	3139	1.60
Azospirillum + Phosphobactiria	2.63	1.23	4419	1.83
100% N + 100% P	3.57	1.87	7297	2.25
100% N + 50% P	3.30	1.52	6591	2.16
100% N + 50% P + Phosphobacteria	3.65	1.69	7528	2.31
50% N + 50% P	2.98	1.32	5478	2.00
50% N + Azospirillum + 50% P + Phosphobacteria	3.24	1.26	6268	2.10
50% N + 100% P	3.04	1.18	5556	1.98
50% N + Azospirillum + 100% P	3.20	1.23	6117	2.08
C.D. (P=0.05)	2.2	1.8		

Crop Residues

The annual production of crop residues in India is estimated to range from 313 to 356 million t with nutrient potential of 6.3 to 7.5 million t. If about one third of the residues produced is available for direct recycling on the land, it would contribute 3.54 million t of N, P_2O_5 and K_2O annually. Crop residues fed to animals get recycled through FYM whereas residues placed in compost pits are recycled as rural compost.

Continuous addition of crop residues for five years was observed to enhance 25 per cent of maize yield in Bangalore. There was organic matter improvement to the tune of 0.9 per cent when maize residue was added at 4 t ha^{-1}.

At Akola, crop residue addition enhanced sorghum + pigeonpea intercropping by 26 per cent (Singh *et al*., 2000).The soil fertility particularly the available K status of the soil was increased by coir pith application. The available N did not vary much but the available K increased by 80 per cent (Nagarajan *et al.* 1989) (Table 13).

Table 13. Effect of coir pith on soil properties after groundnut crop

Treatments	pH	EC (mhos/cm)	Available nutrients (kg/ha)		
			N	P	K
Control	6.8	0.09	216	72	251
N alone	6.8	0.06	257	85	285
PK alone	7.0	0.07	234	71	275
NPK alone	6.9	0.06	228	56	288
Coir pith	6.8	0.05	187	66	344
Composted coir pith	7.0	0.07	234	71	368
Coir pith + N	6.8	0.06	263	72	384
Coir pith + NP	6.7	0.07	257	82	400
Coir pith + NPK	6.8	0.06	239	63	428
Composted coir pith + N	6.7	0.08	234	78	396
Composted coir pith + NP	6.9	0.06	198	82	388
Composted coir pith + NPK	6.8	0.07	249	82	372
CD	NS	NS	41	NS	36

Rajalingam and Kumar (2001) reported that application of digested coirpith compost and biofertilizers improved the physical, chemical and biological properties of the tea soil including the infection by VAM (Table 14).

Table 14. Certain physical, chemical and biological properties of tea soil as affected by DCC and biofertilizers application

Physical parameters	75% of estate practice + biofertilizers	75% of estate practice along with DCC 3 tonnes + biofertilizers	100% of estate practice along with DCC 3 tonnes
Water holding	52.34 (50.16)*	53.26 (51.32)	53.24 (51.96)
Soil pH	4.80 (4.70)	4.50 (4.80)	4.70 (4.60)
EC	0.16 (0.11)	0.12 (0.12)	0.17 (0.15)
Organic matter	4.22 (7.82)	5.74 (4.10)	4.27 (4.12)
CEC	7.90 (7.82)	9.55 (7.88)	8.30 (8.00)
Percent VAM infection	21.00 (5.30)	27.0 (9.00)	27.00 (13.30)

**Figures in parenthesis indicate the initial value*

Conclusion

So long as agriculture remains a soil-based industry, there is no way that required yield increases of the major crops can be attained without ensuring that plants have an adequate and balanced supply of nutrients. The appropriate environment must exist for nutrients to be available to a particular crop in the right form, in the correct absolute and relative amounts, and at the right time for high yields to be realized in the short and long term.

In this regard it is important to analysis the “nutrient cycles” to have a better basis for determining the flow of plant nutrients in and out of soils. Adequate testing and monitoring systems are to be established to gather data on the nutrient cycle and nutrient balances in representative areas throughout their rural economies. Further, research is to be focused for developing modern varieties and appropriate integrated nutrient systems for harsh climatic environments. Research should also be promoted on biological nitrogen-fixation as a low-cost “organic” approach to increasing nitrogen availability and organic matter content in soils.

The application of targeted, sufficient, and balanced quantities of inorganic fertilizers will be necessary to make nutrients available for high yields without polluting the environment. Necessary steps are to be taken to facilitate the widespread and responsible use of chemical fertilizers. At the same time, every effort should be made to improve the availability and use of secondary nutrients and micronutrients, organic fertilizers, and soil-conservation practices.

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Balanced Fertilization for Horticultural Crops with Particular Reference to Potassium: IPI results

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Introduction

It is well recognized that among all the cultivated crops species, banana removes extremely high amounts of potassium from the soil. Very high amounts of potassium are removed by such fruit crops as citrus and pineapple. Tuber crops like potato, cassava and sweet potato have also high K requirements as do a number of vegetable crops such as cabbage and cauliflower. The root and tuber crops are notable in that they need to take up large amounts of potassium most of which is removed from soils in the roots and tubers. On the whole, the above indicated horticultural crops uptake more potassium than nitrogen or phosphorus. Thus, an adequate fertilization with potassium is a major precondition for obtaining high yields of these crops.

Among the major nutrients, potassium not only improves yields but also benefits various aspects of crop quality. Below are summarized the most important benefits from potash fertilizer application, originated from the key role potassium plays in the growth and development of plants:

- increase in crop yield;
- improvement in both the appearance and marketability of crop production (i.e. size, shape, colour, hygienic properties);
- enhancement of nutritional value of crop production (i.e. the content of vitamin C and antioxidants, starch content in potato);

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- decrease in both the incidence and severity of pest and diseases attacks;
- improvement of plant resistance to drought conditions;
- decrease of storage losses, enhancement of shipping quality and extending of shelf life of crop production;
- improvement in the processing quality of crop production.

The present paper summarizes findings from collaborative projects with IPI partnership conducted during the last 10 years in Europe; Middle East; East, South and South-East Asia; and Latin America. Results from both research field experiments and demo trials laid out in farmers' fields are discussed here within such groups of horticultural crop as fruits (grape wines, apple and citruses), nut crops (cashew) and vegetables (onion, brinjal, cabbage, cauliflower, tomato, okra, carrot, lettuce and watermelon). The importance of balanced fertilization with potassium in tuber crops (potato, sweet potato and cassava) is also discussed as a special chapter. In all the experiments, potassium chloride was used if not mentioned otherwise.

IPI has a long association with India and the institute had several site-specific collaborative projects in horticultural crops in cooperation with local universities and research institutes. Results from these experiments are also presented in this paper.

1. Fruit crops

The effect of different forms of K-fertilizers on the yield of grape wines was studied in the research experiment conducted during three years on alluvial-delluvial soil in Septemvri, Plovdiv County, Bulgaria (Popp, 2002). As compared with the NP treatment, the application of three different forms of potash fertilizers, i.e. potassium chloride, potassium sulphate and kalimagnesia (potassium magnesium sulphate), at a rate of 200 kg K_2O/ha increased grapes yield by 22%, 35% and 41%, respectively (Fig. 1). Generally, especially in dry climatic conditions, potassium sulphate is considered as a preferable form of potash fertilizer for obtaining the highest yield of grape wines compared to potassium chloride. The highest efficiency of kalimagnesia in this trial may be attributed to the deficiency of Mg in the soil. Heavy potassium applications can also reduce the uptake of magnesium by plants. Nevertheless, costs of different forms of potash fertilizer need to be taken into calculation for providing farmers with economically optimal recommendations.

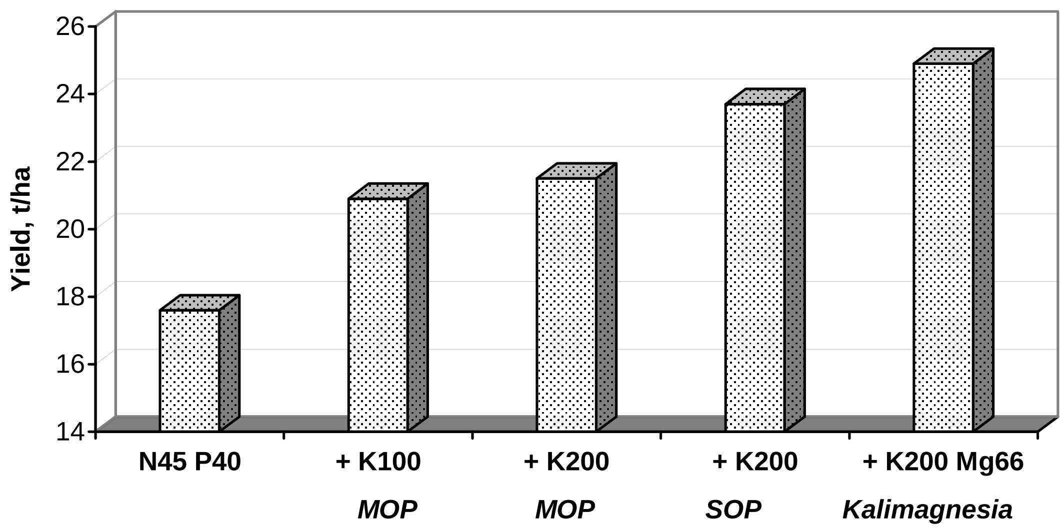


Fig. 1. Effect of different forms of K-fertilizer on the yield of grape wines, Septemvri, Plovdiv county, Bulgaria: ***the average yield for three years, 2000-2002*** **(Popp, 2002)**

The fertigation experiment in young apple trees was conducted on brown soil in Penglai, Shandong province of China (Ivanova, 2006). In this research experiment, 30% of total N, 70% of total P and 40% of total K were applied as a base fertilizer and the rest of NPK was fertigated. As shown in Table 1, the application of the highest rate of K (540 kg K_2O/ha) produced the highest cumulative yield of apples for two years compared to the medium (405 kg K_2O/ha) and lowest K rates (270 kg K_2O/ha), with yield increment by 45% and 63%, respectively. Such apple quality parameters as size and firmness of fruits were also enhanced when 540 and 405 kg K_2O/ha were applied as compared with the lowest rate of 270 kg K_2O/ha.

Table 1. Effect of K-fertilizer application on the yield and quality of apple, Penglai, Shandong province, China (Ivanova, 2006)

Treatment	Firmness, kg/cm^2	Weight, g/apple	Yield*	
			kg/5 trees	t/ha
$N_{315}P_{225}K_{270}$**	13.06	161.1	30.6	4.13
+ K_{405}	14.38	177.8	34.4	4.64
+ K_{540}	13.44	193.7	50.0	6.75

* The cumulative yield for two years (2005, the first year of bearing, and 2006)
** + organic manure

Experiments in different locations of Syria allowed determining the threshold for K-fertilizer recommendations to apple according to the content of exchangeable potassium in soils of various types (Marchand, 2004). Fig. 2 presents the harvest index of mature apple trees referred to the control treatment without K taken as 100% (recommended rates of N- and P-fertilizers were applied at all the treatments). With the highest content of exchangeable potassium in the soil (297 ppm), apple responded to K-fertilizer application only up to the rate of 50 kg K_2O/ha, and the further increase in K rates was not effective. Soils with the lower content of exchangeable potassium (111 ppm and 145 ppm) required K-fertilizer application to apple up to 100 kg K_2O/ha. This experiment well demonstrates the importance of soil analysis for recommending best fertilizer management practices.

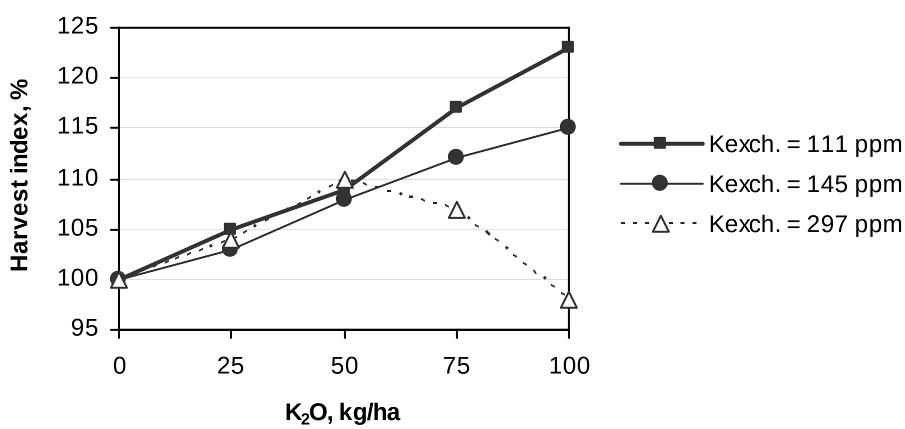
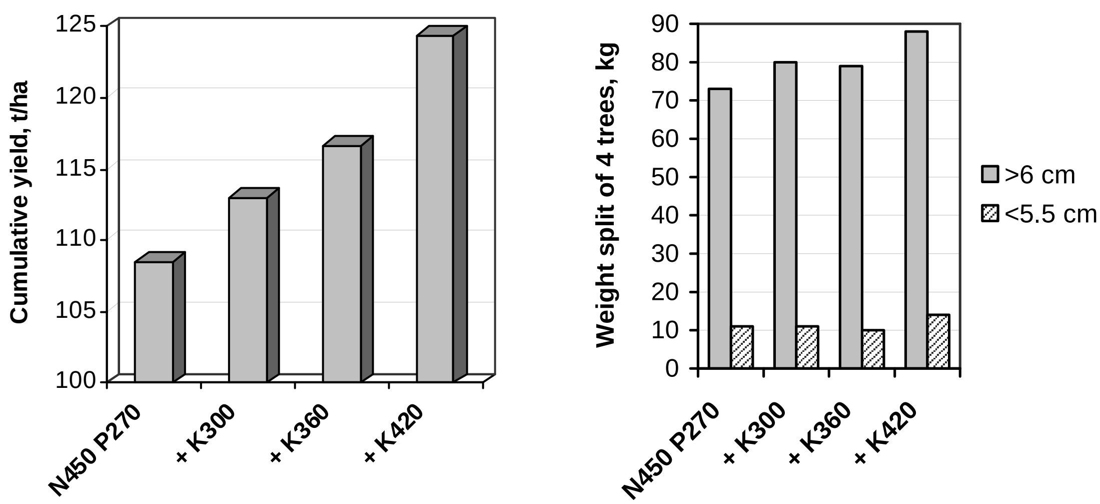


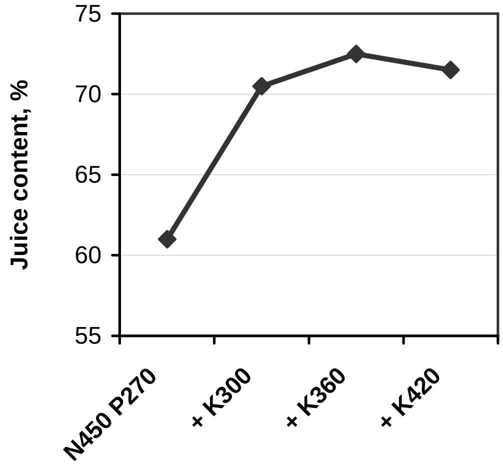
Fig. 2. Apple response to K-fertilizer application at different levels of exchangeable K in the soil, Syria: *results for one year, 2003* (Marchand, 2004)

Magen and Youguo (2001) investigated the effect of potash fertilizer use on the yield and quality of tangerine in the experiment laid out on sandy soil in Quzhou, Zhejiang province, China. The experiment with mature trees was conducted at farmer's field during three years. With the maximum K-fertilizer rate of 420 kg K_2O/ha, the cumulative yield of tangerine for three years was 15% higher as compared with the control treatment in which only N- and P-fertilizers were applied (Fig. 3). The lower rates of K-fertilizer (300-360 kg K_2O/ha) were less effective and gave 5-8% increase in the yield of tangerine fruits. As regards the positive effect of K on fruit quality, farmers harvested up to 21% more large-sized fruits (>6 cm) due to K application. Moreover, juice content in fruits increased by 10-12% when K-fertilizer was applied.

A **B**



C



A: The cumulative yield of fruits for three years (1999-2001)

B: Weight split of 4 trees for large and small fruits (the average for three years, 1999-2001)

C: Juice content (the average for two years, 2000-2001)

Fig. 3. Efficiency of balanced fertilization with K in tangerine, Quzhou, Zhejiang province, China (Magen and Youguo, 2001)

The interaction of nitrogen and potassium in lemon was studied in a research experiment conducted in Famailla, Tucuman province of Argentina (Imas, 2004). In this experiment, fertigation technique was used for N- and K-fertilizer application (the soil had the high content of phosphorus). Results obtained during four years of the experiment starting the first commercial harvest of lemon are shown in Fig. 4. The application of the lowest N-fertilizer rate (60 kg/ha) in combination with the maximum K-fertilizer doze (160 kg K_2O/ha) had practically the same effect on lemon yield as the application of higher N rates (60-120 kg/ha) but without K. Thus, K-fertilizer use considerably increased the efficiency of N application because of higher nitrogen utilization rate by plants when K was applied. The combination of 90-120 kg N/ha with 160 kg K_2O/ha gave the highest yield of lemon fruits in this experiment.

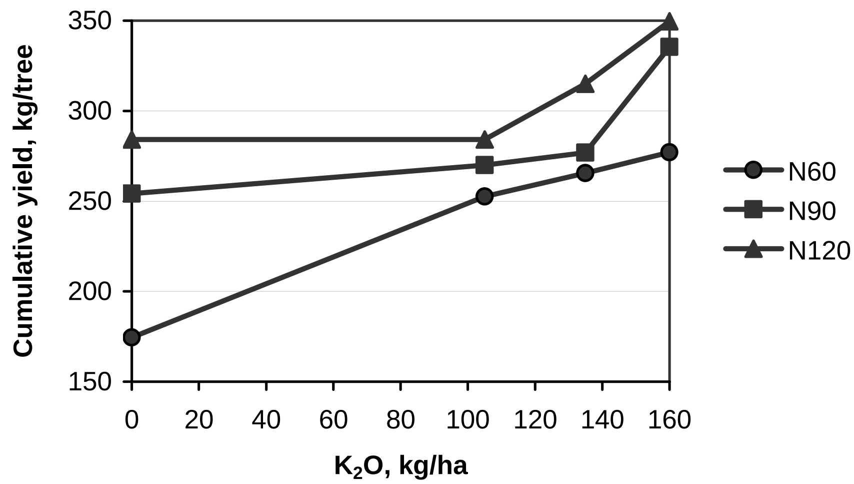


Fig. 4. Interaction of N- and K-fertilizer application on the yield of lemon in Famailla, Tucuman province, Argentina: *the cumulative yield for four years, 2000-2003* (Imas, 2004)

The interesting investigation of the effect of potash fertilizer application on the yield of Satsuma mandarin (mature trees) cropped with saline irrigation water was done in Izmir, Turkey (Marchand, 2005). Salinity is an important problem in arid and semi-arid regions. In this research experiment, two rootstocks (Poncirus trifoliata and T. citrange) were tested under three salinity levels in irrigation water (0, 3.5 and 6.5 dS/m) and three rates of K (0; 600 and 1,200 g K_2O/tree). Recommended rates of N- and P-fertilizers were applied in all the treatments. As shown in Fig. 5, yield increment through the application of K was 3-11% over the control K_0 treatment when the irrigation with fresh water was done. However, the addition of K-fertilizer increased fruit yield by 5-19% when using saline water for irrigation. Thus, potash fertilizer application helped to overcome the salinity stress in citrus trees and the scale of this positive effect depended on the rootstock salt tolerance.

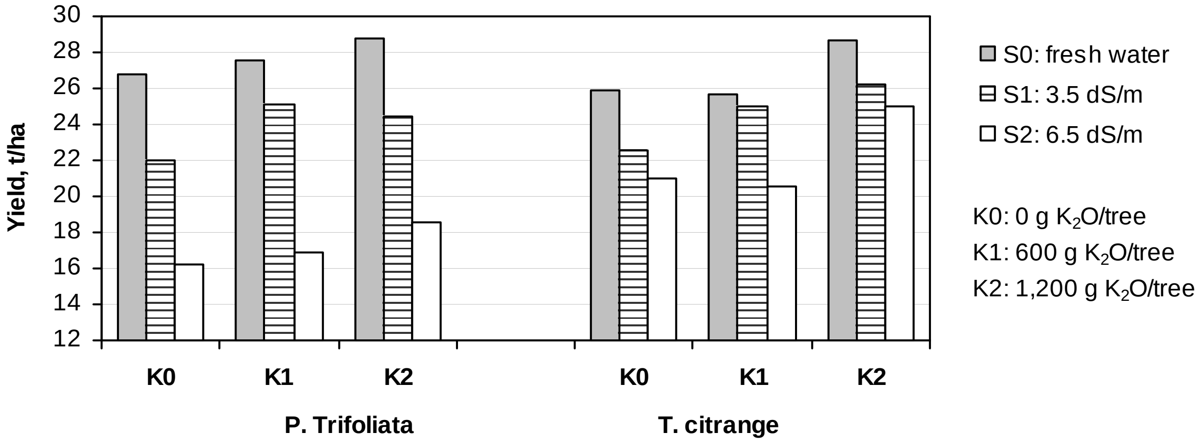
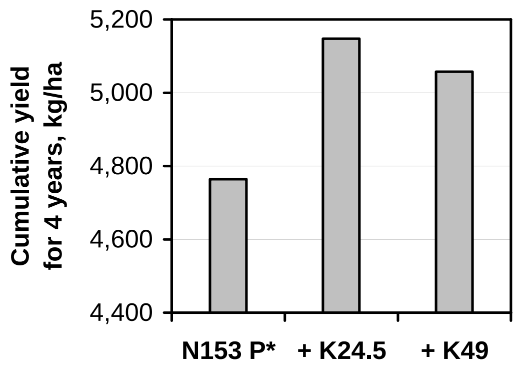


Fig. 5. Yield of the Satsuma mandarin as a function of rootstocks, salinity and doses of K-fertilizer, Izmir, Turkey: *results for one season, 2003-04* (Marchand, 2005)

2. Nut crops

The response of dwarf cashew to potash fertilizer application was observed in an experiment conducted on light textured Red-Yellow Latosol in Pacajus, Ceara state, Brazil (Naumov, 2003). Cashew was grown under rainfed conditions. A four-year cumulative nut yield, starting the forth year after transplanting, is shown in Fig. 6 (A). As compared with the NP treatment, K-fertilizer application at 24.5 kg K_2O/ha increased the cumulative nut yield of cashew by 8% but the higher K rate of 49 kg K_2O/ha was 2% less efficient. The effect of potash fertilizer use on the yield of cashew considerably increased during plant development and the most noticeable influence of K was observed over the last year of the experiment (Fig. 6, B). One explanation of this effect is growing crop demand in nutrients with increasing age of the trees. The nut yield of cashew plants reached maximum six years after seedling transplant. A depletion of soil potassium reserves can be also a reason for increased efficiency of potash fertilizer use after several years of observation.

A



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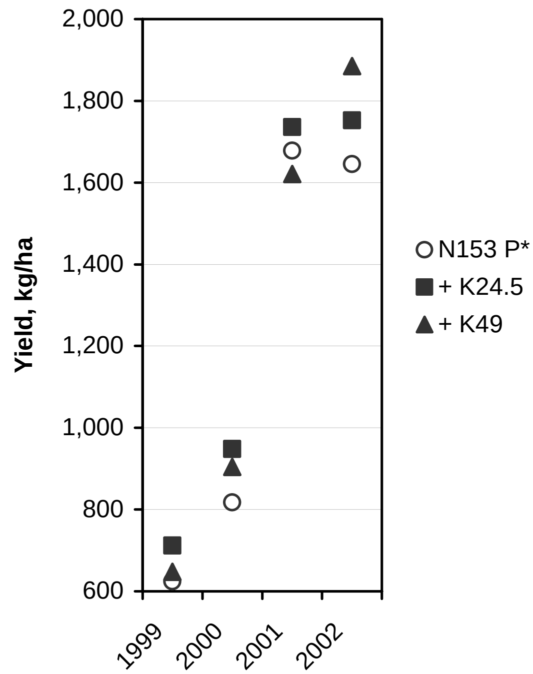

A: The cumulative yield of nuts for four years, 1999-2002 (transplanting in 1995)

B: Annual yield

*P-fertilizer rate: 150 g P_2O_5/plant/year

Fig. 6. Response of dwarf cashew to K-fertilizer application, Pacajus, Ceara state, Brazil (Naumov, 2003)

3. Vegetable crops

The on-farm field demonstrations (2004-05) were conducted in winter and summer season vegetables on Alfisols, Inceptisols and Entisols in Raipur district of Chhattisgarh state, India. Results obtained in onion, brinjal, cabbage and okra are discussed below.

As shown in Table 2, potash fertilizer use at a rate of 30-90 kg K_2O/ha considerably increased the yield of onion over the control NP treatment, up to 14-23%. With balanced fertilization, onion bulbs noticeably increased in size. Of the treated plots, where K-fertilizer was applied, an application of 60 kg K_2O/ha produced the highest average bulb diameter of 8.5 cm as compared with 6.9 cm at the zero K treatment. Moreover, the storage behavior of onion was appreciably improved due to K application.

After 60-days storage at room temperature, the percentage of rotted bulbs was 17% when using potash fertilizers at a rate of 90 kg K_2O/ha compared to 31% rotted bulbs at the zero K treatment.

Table 2. Effect of K-fertilizer use on the growth, yield and quality of onion, Raipur, Chhattisgarh state, India (Sarnaik and Nosov, 2007)

Treatment	Plant height, cm	Number of leaves per plant	Neck girth, cm	Bulb diameter, cm	Bulb weight, g	Yield, q/ha	Rotting after storage*, %
$N_{100}P_{80}$	17.6	8.5	1.39	6.9	83.0	136	31
+ K_{30}	18.0	8.4	1.39	7.5	96.0	155	26
+ K_{60}	19.1	9.4	1.57	8.5	121.5	167	21
+ K_{90}	20.0	9.2	1.61	8.2	133.0	167	17

* Storage at room t^o during 60 days

Note: The average results of 6 farmers' fields per one season (2004-05)

In brinjal demonstrations from the same set of experiments in Chhattisgarh state of India, the highest yield of fruits of 376 q/ha was obtained when using 75 kg K_2O/ha as compared with the yield of 233 q/ha harvested at the zero K treatment (Table 3). Application of K noticeably improved such growth and quality parameters of brinjal as plant height; number of branches per plant; length, girth and weight of fruits. It is important to indicate that crop resistance to diseases and insects was slightly increased as resulted from potash fertilizer application.

Table 3. Effect of K-fertilizer use on the growth, yield and quality of brinjal, Raipur, Chhattisgarh state, India (Nosov, 2004)

Treatment	Plant height, cm	No. of branches per plant	Fruit length	Fruit girth	Fruit weight, g	Diseases incidence*	Insects damage*	Yield, q/ha
			cm			%		
$N_{150}P_{100}$	55.8	7.0	12.9	16.6	125.6	0.9	8.3	233
+ K_{50}	49.3	8.9	14.2	16.8	137.4	0.7	8.0	277
+ K_{75}	67.1	11.6	16.9	18.3	185.9	0.4	6.2	376
+ K_{100}	66.5	10.9	15.9	18.3	172.1	0.2	5.8	332

*60 days after planting

Note: The average results of 5 farmers' fields per one season (2004)

The importance of balanced fertilization with K was also revealed in cabbage demo experiments conducted in the same state of India. With increasing potash fertilizer application from 0 to 90 kg K_2O/ha, cabbage yield grew continuously from 196 to 280 q/ha (Table 4). K-fertilizer use increased the girth and especially the weight of cabbage heads. For instance, the average head weight was 1.49 kg at the treatment in which the highest rate of 90 kg K_2O/ha was applied. Without potash fertilizer application, the average head weight reached only 1.16 kg or 0.33 kg less compared to the K_{90} treatment.

Table 4. Effect of K-fertilizer application on the yield and quality of cabbage, Raipur, Chhattisgarh state, India (Nosov, 2005)

Treatment	Leaf length	Leaf width	Head girth	Head weight, kg	Yield, q/ha
	cm				
$N_{150}P_{100}$	9.5	9.0	18.5	1.16	196
+ K_{30}	10.1	9.7	18.8	1.21	229
+ K_{60}	10.0	9.8	20.1	1.33	260
+ K_{90}	10.3	9.8	20.1	1.49	280

Note: The average results of 6 farmers' fields per one season (2004-05)

In the same series of demo experiments, the application of 60 kg K_2O/ha to okra was optimal in terms of both the yield and quality (Table 5). K-fertilizer use up to the above-indicated rate increased plant height and improved all the quality parameters of okra fruits, e.g. length, girth and weight. The marketable yield of okra increased by 13% and 23% over the control NP treatment due to potash fertilizer application at 30 and 60 kg K_2O/ha, respectively.

Table 5. Effect of K-fertilizer application on the growth, yield and quality of okra, Raipur, Chhattisgarh state, India (Nosov, 2005)

Treatment	Plant height	Fruit length	Fruit girth	Fruit weight, g	Yield, q/ha	
	cm				Total	Marketable
$N_{100}P_{60}$	46.6	10.7	5.0	9.6	43	39
+ K_{30}	58.0	11.8	5.2	10.8	46	44
+ K_{60}	70.6	13.5	5.5	11.7	50	48
+ K_{90}	67.8	13.4	4.5	11.4	49	48

Note: The average results of 4 farmers' fields per one season (2005)

A two-year research experiment at Dabuleni, Dolj county, Romania, revealed high efficiency of tomato fertilization with K (Uebel, 1998 & 1999). At the lowest level of N and P application (75 kg N/ha and 60 kg P_2O_5/ha), yield increment due to K addition at a rate of 60 kg K_2O/ha reached 29% (Fig. 7). With two times higher N and P doses (150 kg N/ha and 120 kg P_2O_5/ha), the yield of tomato grew up by 9% as resulted from K-fertilizer application at 120 kg K_2O/ha. Thus, the former combination of NPK was found to be optimal in these conditions.

A one-season field experiment was laid out in Zhangqiu, Shandong Province of China to study whether nutritional factors are able to improve the seed production of Chinese onion (Hardter, 1998). The effect of both K and B on seed yield was investigated in this trial. Onion seed yield was generally low because of bad weather conditions (with many cloudy and rainy days during the onion blooming and fruiting). However, with K application, seed yield was increased by 8% over the control NP treatment and the combined application of both K and B produced the highest seed output (Fig. 8). This experiment well explains that all the limiting factors including micronutrient deficiencies need to be taken into consideration to recommend best management practices for crop fertilization.

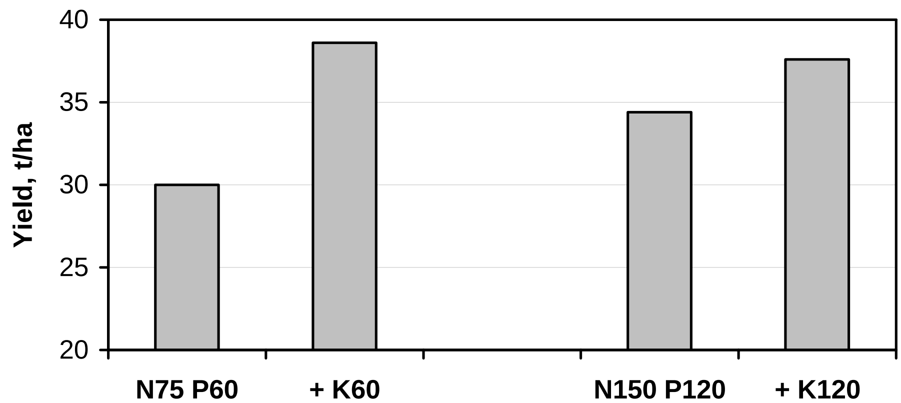

Fig. 7. Efficiency of K-fertilizer application to tomato at two levels of N - and P-fertilizers, Dabuleni, Dolj County, Romania: ***the average yield of fruits for two years, 1998 and 1999*** **(Uebel, 1998 & 1999)**

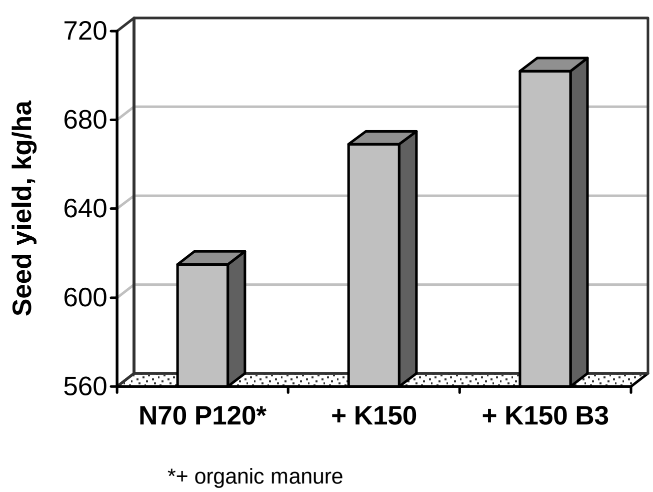

Fig. 8. Efficiency of balanced fertilization with K and B on seed yield of Chinese onion, Zhangqiu, Shandong province, China: ***results for one season, 1998***

(Hardter, 1998)

The efficiency of potash fertilizer application to different vegetable crops was investigated on various soil types in three locations (Qingshen, Pengzhou and Pengshan) in Sichuan province of China (Magen, 2004). Such crops as cauliflower, watermelon and lettuce were grown in three demo experiments at farmers' fields (one in each location) during one-two years. Results from these experiments are presented below.

In cauliflower demonstrations conducted during two seasons, the additional yield due to K application was 5.3-7.8 t/ha depending on the season of observation (Fig. 9). The percentage of yield increase with K addition was 17-24%.

The same series of demo experiments with another vegetable crop, watermelon, demonstrated that farmers achieve the additional yield of 14.4 t/ha through the application of 150 kg K_2O/ha as compared with the zero K treatment (Table 6). The percentage of fruit yield increase due to K was as high as 47%. Such quality parameters as vitamin C and sugar content were also improved as resulted from potash fertilizer application at the above-indicated rate. Importantly, experimental data indicate that the percentage of cracked watermelon fruits at the NP treatment was 44% vs. 25% at the treatment in which K was applied at 150 kg K_2O/ha.

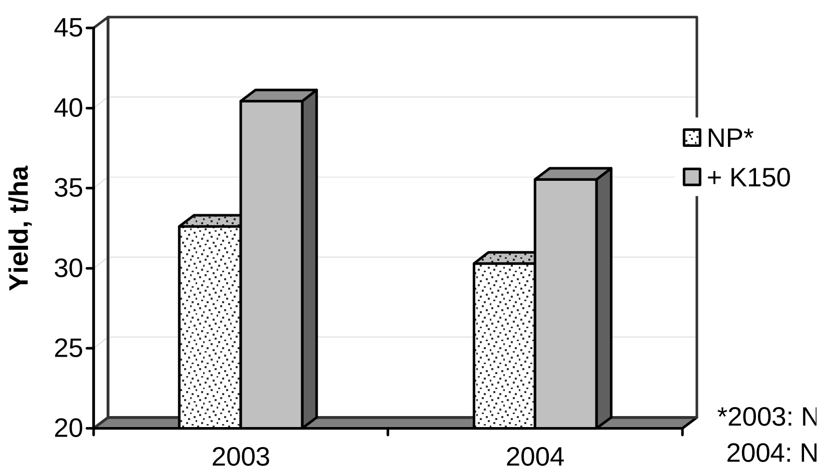

Fig. 9. Response of cauliflower to K-fertilizer use, Sichuan province, China: *the average results of 3 farmers' fields per year* (Magen, 2004)

Table 6. Effect of K application on the yield and quality parameters of watermelon, Sichuan province, China (Magen, 2004)

Treatment	No. of fruits per ha	Cracked fruits, %	Yield, t/ha	Vitamin C content, mg/100 ml	Sugar content, g/100 ml
$N_{465}P_{360}$	5,833	44	30.30	6.48	6.33
+ K_{150}	7,837	25	44.68	7.14	6.80

Note: The average results of 3 farmers' fields per one season (2003)

The same set of demonstrations at farmers' fields in Sichuan province of China also revealed the high response of lettuce to balanced fertilization with potassium. As compared with the NP treatment, the additional lettuce yield obtained by potash application at 68 kg K_2O/ha was 5.8 t/ha that is equivalent to the yield increment by 13% (Table 7). In this experiment, K application decreased the content of nitrates 1.3 and 2.5 times over the control NP treatment in lettuce leaves and stems, respectively. The effect is explained by the higher nitrogen utilization rate by plants when using potash fertilizer at optimal balanced dozes. Hence, with balanced fertilizer practices, less nitrates are accumulated in crop production and crop biomass is safer for human consumption.

It is interesting to indicate the relationship between potassium application and nitrates concentration in crop production in yet one field trial that is a long-term research experiment conducted during 25 years on alluvial loamy soil in Bykovo, Moscow region, Russia (Prokoshev, 2000). On average for 25 years, the application of potassium at 180-250 kg K_2O/ha resulted to 1.3 and 1.2 times less accumulation of nitrates in cabbage heads and carrot roots, respectively, as compared with the zero K treatment (Fig. 10). Of the treated plots, crop production harvested only from treatments in which K-fertilizers were applied in balance with N- and P-fertilizers was acceptable for processing of vegetable mixtures for feeding infants in accordance with country standards for nitrate concentrations.

Table 7. Effect of K application on the yield and nitrates accumulation in lettuce, Sichuan province, China (Magen, 2004)

Treatment	Yield, t/ha	NO_3-N content, mg/kg	
		Leaves	Stem
$N_{248}P_{203}$	46.13	480	2,000
+ K_{68}	51.97	360	800

Note: The average results of 3 farmers' fields per one season (2003)

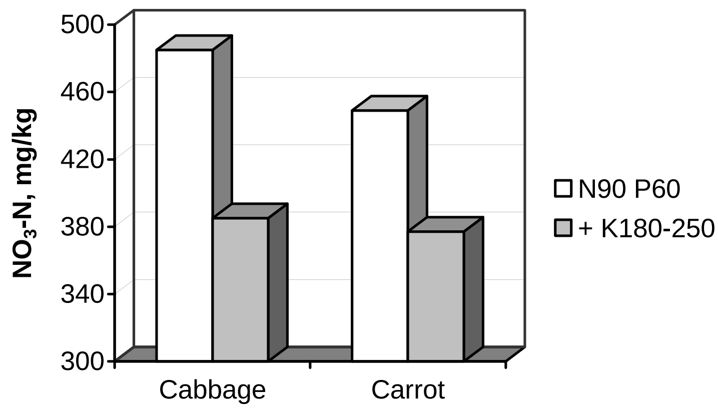

Fig. 10. Nitrates accumulation in vegetables as affected by K-fertilizer application, Bykovo, Moscow region, Russia: ***the average results for 25 years, 1975-2000*** **(Prokoshev, 2000)**

4. Tuber crops

IPI conducted a lot of field experiments in potato as compared with other crops because potato is cropped in both countries within temperate zones and tropical regions of the world. Some of the most important tuber quality parameters positively affected by potassium nutrition are: tuber size, percentage of dry matter, starch content, storability and resistance to mechanical damage. Potassium also decreases such a physiological disorder in potato tuber as internal blackening.

The potato experiment in Jalandhar, Himachal Pradesh state, India, was conducted on Typic Ustrochrepts at farmers' fields (Imas and Bansal, 1999). Three K doses were combined with three levels of N (Table 8). K-fertilizer was applied in two splits (half at planting and half at earthing up). There was a significant positive interaction between N and K: at each level of N increasing levels of K increased the yield of tubers. Application of 150 kg K_2O/ha increased tuber yield over the zero K treatment by 35%, 54% and 61% at 80, 160 and 240 kg N/ha, respectively. K and N application also improved tuber size by increasing the yield of medium and large sized tubers and decreasing the yield of medium and small sized tubers. On average, K application increased the percentage of large tubers from 29% (0 kg K_2O/ha) up to 40% (75 kg K_2O/ha) and further up to 44% (150 kg K_2O/ha).

Table 8. Effect of N- and K-fertilizer use on the yield and tuber size of potato, Jalandhar, Himachal Pradesh state, India (Imas and Bansal, 1999)

Treatment	Tuber yield, q/ha			
	Small (< 25 g)	Medium (25-75 g)	Large (> 75 g)	TOTAL
$N_{80}P_{100}$	14	75	33	123
+ K_0	13	82	58	154
+ K_{75}	15	88	62	166
+ K_{150}	15	82	41	138
$N_{160}P_{100}$	13	106	69	188
+ K_0	16	101	97	213
+ K_{75}	17	81	44	141
+ K_{150}	15	101	94	211
$N_{240}P_{100}$	15	108	104	227
+ K_0	14	75	33	123
+ K_{75}	13	82	58	154
+ K_{150}	15	88	62	166

Note: The average results of 6 farmers' fields per one season (1998-99)

In recent demonstration experiments conducted on Alfisols, Inceptisols and Entisols in Raipur, Chhattisgarh state, India, potash fertilizer application considerably increased the yield of potato (Table 9). Moreover, the storage behavior of potato tubers was also improved through potash fertilizer use. Importantly to indicate that the percentage of rotted tubers after 60-days storage period at room temperature was lower when potash fertilizers were applied. For instance, the percentage of rotted tubers was 15% when using potash fertilizers at 150 kg K_2O/ha compared to 36% rotted tubers at the zero K treatment.

Table 9. Growth, yield and quality parameters of potato as affected by K application, Raipur, Chhattisgarh state, India (Sarnaik and Nosov, 2007)

Treatment	Number of tubers/plant	Tuber weight		Tuber girth, cm	DM, %	Yield, q/ha		Rotting after storage*, %
		g	kg/plant			Total	Marketable (> 25 g)	
$N_{150}P_{100}$	4.9	63.3	0.31	6.2	16.7	145	110	36
+ K_{50}	3.9	97.4	0.38	7.1	18.4	166	132	34
+ K_{100}	5.3	73.6	0.39	7.1	19.1	193	151	24
+ K_{150}	5.6	76.8	0.43	7.7	20.8	182	154	15

* Storage at room t^o during 60 days

Note: The average results of 7 farmers' fields per one season (2004-05)

The role of potassium nutrition in cassava, the important tropical tuber crop, can be shown in a one-season experiment conducted in Hatay province of Vietnam on depleted upland soil, Typical Ferralsol (Hardter, 1998). At N rates of 40 and 80 kg N/ha, the highest K application rate of 160 kg K_2O/ha increased the tuber yield over the control K0 treatment by 32% and 46%, respectively (Fig. 11). The lower K application rate (80 kg K_2O/ha) was slightly less effective at both N levels.

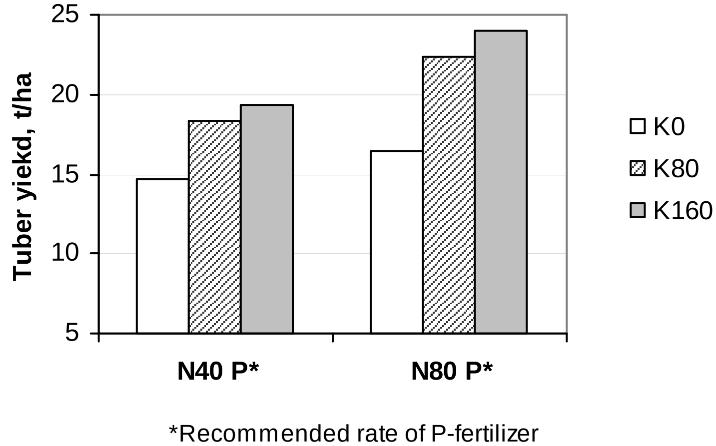

Fig. 11. Response of cassava to K at different rates of N-fertilizer, Hatay province, Vietnam: *results for one season, 1998* (Hardter, 1998)

The high efficiency of balanced fertilization with potassium in sweet potato was found in demonstration experiments conducted on old alluvial yellow soils in Chengdu, Sichuan province of China (Magen, 2000). The demonstrations were laid out at farmers' fields during three seasons. Potash fertilizer application increased the tuber yield of sweet potato over the control NP treatment by 5.4-6.7 t/ha when organic manure was applied (Table 10). Without organic manure application, the yield increment due to K addition was more significant and reached 7.6-8.6 t/ha. Moreover, the share of large-sized tubers was tended to be higher as resulted from potash fertilizer application. At the same time, the share of small-sized tubers noticeably decreased when using K. The yield of sweet potato aerial parts mostly composed of vines (vines may be utilized as animal feed) was also considerably improved in a result of K application: the increment in vine yield due to K application was 3.3-5.3 t/ha.

Table 10. Efficiency of potash fertilizer application to sweet potato, Chengdu, Sichuan province, China (Magen, 2000)

Treatment	Tuber size by grades, % of total yield			Yield, t/ha	
	Small	Medium	Large	Tubers	Vines
$N_{35}P_{45}$	37	33	30	13.78	14.16
+ K_{45}	30	31	40	21.37	18.91
+ K_{65}	31	30	39	22.40	19.43
$N_{35}P_{45}$ + OM*	38	31	31	16.60	14.58
+ K_{45}	35	30	35	22.04	17.83
+ K_{65}	32	31	37	23.28	19.75

* OM = organic manure at 6 t/ha

Note: The average results for three years (1998-2000) with 7 farmers' fields per year

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Balanced fertilization for Mango, Citrus and Sapota

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1. Mango

Mango grows well even in poor soils because of its deep and extensive root system. However, in view of the vegetative growth it makes annually and the removal of nutrients through the harvest, it needs regular fertilization for maintaining proper growth and heavy yield of crop every year. As 82 to 88.5% of the active roots are located within a radius of 300 cm with the highest activity at 120 cm from the trunk, fertilizers are to be applied one meter away from the main trunk under the drip circle and mixed thoroughly. Nutritional requirements vary depending upon the type and nutrient status of the soil and age of the tree etc.

Pre bearing trees

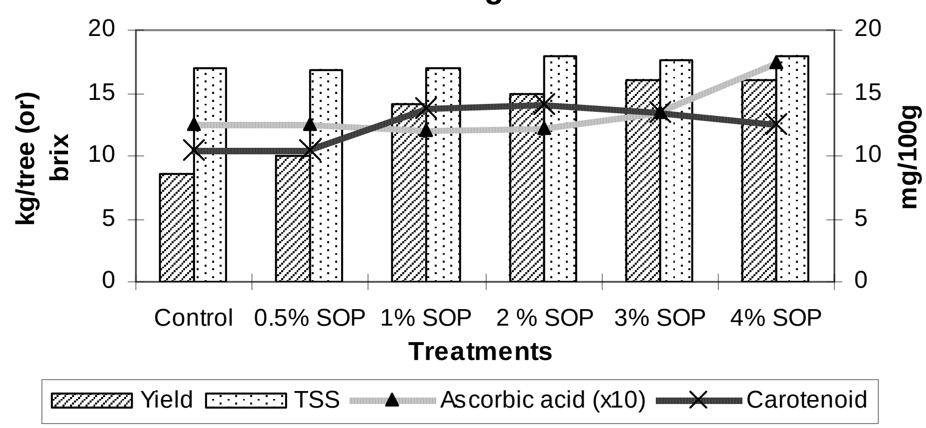
After planting the pre bearing stage extends to 4-8 years depending upon variety and environment. Since the plants during this period continue to grow in size, manurial dose needs to be scheduled according to their age. The Central Institute for Research on Subtropical Fruit Crops, Lucknow recommends that during the non bearing stage the plants should be supplied with 73 g N, 18 g P_2O_5 and 68 g K_2O per tree per year of age. On the other hand, Tamil Nadu Agricultural University recommends 10 kg farm yard manure, 20 g N, 20 g P_2O_5 and 30 g K_2O per tree per year for one year old tree with an annual increase of 10 kg, 0.2, 0.2 and 0.3 kg respectively till it attains fifth year.

Bearing trees

In most parts of India, bearing mango trees are not at all manured, however, evidence indicates that regular manuring of bearing trees is essential to maintain the productivity of the trees. Most of the earlier manurial recommendation for mango consisted of applying farm yard manure, neem cake, bone meal, wood ash, ammonium sulphate, and super phosphate etc, the quantity varying from region to region. Subsequently, recommendations of inorganic fertilizers were made for different regions. The Tamil Nadu Agricultural University recommends 50 kg farm yard manure, 1.0 kg each of N and P and 1.5 kg K year^{-1} bearing tree^{-1} (Anon, 2004). Ladani *et al*. (2004) suggested application of 1.5 kg N, 0.5 kg P and 1.2 to 1.5 kg K tree^{-1} to get higher yield. The ratio of N and K is known to affect the growth and yield in mango. Higher N and low K (1.5 and 0.5 kg per plant, respectively) promoted vegetative growth, whereas higher N and K (both 1.5 kg per plant) promoted fruiting in mango cv. Fazli (Banik *et al*., 1997).

Recently, it has been established that incorporation of SOP at 25-50% of K requirement (*i.e*., 1.5 kg K_2O/plant) of mango increased the fruit yield besides improving the fruit quality particularly T.S.S, ascorbic acid and carotenoid contents etc (Kumar *et al.* 2007). Similarly, foliar spraying of SOP at 2-4% thrice; first during peanut stage followed by two sprays at an interval of 15 days, improved the yield and quality of fruits (Fig-1) especially the pulp colour (Kumar *et al.* 2007).

Fig. 1. Effect of SOP spray on yield and quality in mango



Fertigation studies in mango is lacking. However, Sivakumar (2007) conducted an experiment in mango cv. Ratna planted under HDP during 2005-07 to study the influence of N and K nutrients applied through fertigation. The results showed that fruit weight, number of fruits per tree and per tree yield besides the fruit quality parameters were improved by application of 100 per cent ‘Recommended dose of nutrients’ through fertigation (Table 1 & 2).

Table 1. Effect of fertigation on yield characters in mango cv.Ratna

Treatments	Number of fruits tree^{-1}	Mean fruit weight (g)	Fruit yield (kg tree^{-1})	Estimated fruit yield (t ha^{-1})
100% of RDF as soil application	116.5	364.6	40.8	17.98
100% N + 100 % P + 50 % K of RDF through fertigation	126.7	340.8	40.2	17.69
100% N + 100 % P + 75 % K of RDF through fertigation	142.7	436.3	54.0	23.78
100% N + 100 % P + 100 % K of RDF through fertigation	160.0	465.3	59.8	26.34
CD(0.05)	6.14	12.50	1.43	0.63

RDF: (800:400:800 g NPK plant $^{-1}$ year^{-1})

Table 2. Effect of fertigation on quality parameters in mango cv.Ratna

Treatments	Fruit TSS (^{o} Brix)	Total sugar content (%)	Titrable Acidity (%)	Ascorbic acid content (mg 100 g-1)	Carotenoid content (mg 100g^{-1})	Fruit shelf life (days)
100% of RDF as soil application	19.66	15.69	0.46	36.95	4.18	6.05
100% N + 100 % P + 50 % K of RDF through fertigation	19.96	15.23	0.46	39.56	4.16	5.38
100% N + 100 % P + 75 % K of RDF through fertigation	22.69	17.36	0.42	44.62	5.28	8.05
100% N + 100 % P + 100 % K of RDF through fertigation	24.93	19.84	0.38	48.92	5.82	14.77
CD(0.05)	1.09	0.57	0.01	2.12	0.15	0.30

RDF : (800:400:800 g NPK plant $^{-1}$ year^{-1})

2. Citrus

The importance of nutrients for citrus has been well established in India. Improper and inadequate nutrition is one of the major causes of citrus decline in India (Chadha *et al.*1970). Studies on the decline of mandarins in Kerala showed that poor nutrient status of soil (Iyer and Iyengar, 1956) and neglect and lack of manuring are the main causal factors. Thirty tonnes of citrus fruits remove 270 kg N, 60 kg P_2O5, 350 kg K_2O, 40 kg MgO and 15 kg S from the soil (Tandon and Kemmler, 1986).

Different states recommend different amounts of NPK for mandarin and other important citrus species in India which vary from 300-400 g of N, 200 to 375 g of P_2O_5 and 100 to 600 g of K_2O per plant per year. Recently, integrated nutrient management (INM) is being advocated in citrus. Studies conducted at Tinsukia (Assam) by Borah *et al.* (2001) revealed that maximum yield with appreciable tree vigour and fruit quality of Khasi mandarin could be obtained from balanced nutrition of the plants through combinations of organic (neem cake) and inorganic fertilizers (Table 3.). Results of a study (Seshedri and Madhavi, 2001) conducted on 20 year old seedling trees of sweet orange cv. Sathgudi revealed that the maximum yield, cost benefit ratio with better fruit quality could be obtained by the balanced nutrition of 400:150:300g NPK plant^{-1} year^{-1} along with organic (castor cake @ 7.5 kg) (Table 4). Similarly, integrated nutrient management studies conducted at Akola revealed that application of neem cake along with chemical fertilizers significantly increased the yield with better quality fruits in acid lime (Ingle *et al.* 2001).

Table 3. Effect of organic and inorganic nutrition on yield and quality of Khasi mandarin plants

Treatments	No of fruits / plant	Yield (kg/plant)	Juice (%)	Ascorbic acid (mg/100g)	TSS (°Brix)
600:300:600g NPK /plant	805	118.01	46.33	48.27	14.35
600:300:600g NPK /plant + Neem cake @15 kg/plant	1072	203.55	55.66	57.26	15.26
CD (0.05)	19.66	10.45	1.05	3.50	0.21

Table 4. Effect of organic and inorganic fertilizers on yield of sweet orange

Treatments	Fruit number / plant	Yield/ plant (kg)	Weight of fruit (g)	Juice (%)	TSS (°Brix)
T_1 (Inorganic fertilizers @ 800:300:600 g NPK/ plant/year)	1960	296.27	160.76	42.04	12.86
T_2 (Castor cake @ 7.5 kg/plant/year + 50 % of T_1)	2539	399.87	170.71	41.68	13.28
F Value	NS	NS	-	-	-

Experiment conducted in Tamil Nadu revealed that application of P enriched farm yard manure (0.5 kg P_2O_5 tree^{-1} mixed with 20 kg farm yard manure) along with 700 g N and 600 g K_2O tree^{-1} recorded the highest yield and improved the fruit quality of mandarin**.** Ingle *et al.* (2003) found that in Nagpur mandarin, number and weight of fruits and total soluble sugars were highest with application of 800 g N, 300 g P_2O_5, and 600 g K_2O along with 7.5 kg neem cake per plant per year. Tiwari *et al*. (1999) also obtained maximum yield of sweet orange with the application of 800 g N, 300 g P_2O_5, 600 g K_2O + 15 kg neem cake tree^{-1} year^{-1} . Mycorrhizal association with citrus species has been well established**.** Shamshiri and Usha (2004) found that application of *G. manihotis, G. gigospora* and their combinations increased the trunk diameter, height and leaf area in Kinnow mandarin.

Integrated nutrient management studies conducted at Andhra Pradesh revealed that 50% of the recommended dose of fertilizers besides 100g each of Azospirillum and Phosphobacteria + 5 kg of vermicompost resulted in higher fruit yield (15.48 t/ha) as against 13.98 t/ha with farmer's practice (Umajyothi *et al*. 2004).

At Lower pulney Hills, Saravanan (2007) investigated the effect of bioinoculants *viz***.,** *Azospirillum lipoferum*, phosphate solubilizing bacteria (*Bacillus megaterium*), Arbuscular mycorrihizae and *Pseudomonas fluorescens* in combination with farmyard manure and inorganic fertilizers on growth, yield and quality of mandarin orange during 2005-2007 and found 100 per cent RDF along with all bioinoculants registered higher fruit number , fruit yield with good quality fruits than the pure inorganically fertilized trees (Table 5).

Table 5. Effect of bioinoculants in combination with organic manure and inorganic fertilizers on yield and fruit quality of mandarin orange

Treatments	Fruit weight (g)	Number of fruits per tree	Yield per tree(kg)	TSS (^{O}Brix)	Ascorbic acid (mg/100 g)
Recommended dose of fertilizers (RDF) (600:200:400 g NPK plant^{-1})	91.50	100.97	9.00	8.89	21.80
100 per cent RDF + Bioinoculants*	84.50	147.95	12.90	9.44	23.13
75 per cent RDF + Bioinoculants *	86.00	140.95	12.00	9.51	22.47
CD (0.05)	01.75	8.06	00.08	0.26	00.62

** Arbuscular mycorrhiza (500 g plant-1) +Azospirillum lipoferum (100 g plant-1) + Phosphate solubilizing bacteria (100 g plant-1) + Pseudomonas fluorescens (100 g plant-1).*

Fertigation has been recently introduced in citrus and varying response has been reported. Shirgure *et al.* (2001**)** found that fertigating Nagpur mandarin with 50:140:70 NPK kg/ha is good in improving the tree vigour, yield and quality of fruits. Application of 75% recommended amount of N and K through drip irrigation was found ideal for sweet oranges under Maharastra, Andhra Pradesh and Punjab conditions.

Secondary and micronutrient deficiencies are common in almost all citrus species. Each state has its own recommendations which involve application of $ZnSO_4$ (0.3 to 0.5 %), Mg SO_4 (0.2 to 0.3%), $MnSO_4$ (0.1 to 0.3%), $CuSO_4$ (0.3%), $FeSO_4$ (0.2 to 0.3%) and Borax (0.05 to 0.1%) two to three times on the new flushes to get good yield and quality fruits (Bojappa and Bhargava, 1993).

3. Sapota

No systematic studies on the nutrient uptake or removal in sapota are available. However, Avilan *et al*. 1980 reported from the analysis of fruits and seeds of 8 to 10 year old sapota trees that the plants required 1.69 kg K_2O, 1.16 kg N, 1.12 kg Ca, 0.17 kg P_2O_5 and 0.14 kg MgO to produce 1000 kg of fruits. Annapurna *et al*. (1988) reported that recently matured leaf which comes out to be 10^{th} leaf position should be utilized for diagnosis and such leaves on healthy trees indicated a levels of 1.66 % N, 0.083 % P, 0.80 % K,0.83 % Ca , 0.48 % Mg and 0.066 % S.

Sapota growing states like Andhra Pradesh, Karnataka, Maharastra and Tamil Nadu recommend different doses for obtaining higher yield (Table 6).

Integrated nutrient management has also gained popularity in many states. In Andhra Pradesh, sapota trees are fertilized with 100 kg farm yard manure, 6 kg castor cake and 2 kg super phosphate per tree (Narasimham, 1966); while in Maharashtra, ten years old trees are fertilized with 40 kg farm yard manure and 6 kg of caster cake (Singh *et al*. 1963). In Karnataka, the recommended dose for trees of 11 years and more is 40 kg farm yard manure, 400 g N, 160 g P and 450 g K per tree (Anon., 1975). According to existing knowledge, a tree of 10 years and above age should be fed with 50 kg farm yard manure, 1000 g N, 500 g P_2O_5 and 500 g K_2O per annum.

Application of 5 kg vermi compost with 150 g N, 40 g P_2O_5 and 150 g K_2O per plant per year for 9 year old trees of Kalipatti at Karnataka and PKM-1 at Tamil Nadu conditions recorded significantly higher growth and yield, while at Gujarat conditions, application of 25 kg farm yard manure per 5 kg vermin compost with 300 g N, 50 g P_2O_5 and 200 g K_2O per plant for 15 years old Kalipatti sapota recorded significantly higher growth.

Table 6. Fertilizer recommendation for sapota in certain states of India

States	Age	N	P_2O_5	K_2O	Farm Yard Manure (kg/ tree)
		Kg/ha			
Andra Pradesh	1-3 year	50	20	75	50
	4-6 year	100	40	150	50
	7-10 year	200	80	300	50
	11 & above	400	160	450	--
Karnataka	1-3 year	50	20	75	50
	4-6 year	100	40	150	50
	7-10 year	200	80	300	50
	11 & above	400	160	450	50
Maharashtra	1-10 year	50 g /yr	--	--	--
	10^{th} year	500	--	--	10-15
Tamil Nadu	Annual increase	30	30	50	10
	I year	30	30	50	10
	Adult	150	150	250	50

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Balanced fertilization for banana

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Bananas and plantains are the fourth most important commodity and are grown in more than 130 countries across the world, in an area of 8.25 M ha producing 97.38 M tones. India is the largest producer of banana, contributing 19.71% of the global production with a total production of 19.19 M tones from 0.565 M ha. The major banana growing areas are: Tamil Nadu, Maharashtra, Andhra Pradesh, Gujarat, Kerala, Karnataka, West Bengal and Orissa. Tamil Nadu has the largest area while Maharashtra is second largest producer with highest productivity level. This is attributed to monoculture of high yielding Robusta and Grand Naine clones coupled with adoption of improved production technologies like use of micro- propagated material under micro – irrigation coupled with fertigation. Adoption of improved technologies has enhanced the production largely due to an increase in productivity during the decade. However, there is a regional disparity in adoption of technologies indicating variation in productivity level ranging from 7.6 to 62.90 tones, but still there is a wide gap between the potential yield and the average yield obtained in farmers' field. This would need immediate attention so that production could be increased from the same area by increasing productivity. Another aspect under concern is the per capita consumption which is very low (9 kg) in India compared to other countries (15 kg). It is projected that our requirement could be 25 M tones by the year 2020. This also warrants us to increase the production and productivity of banana.

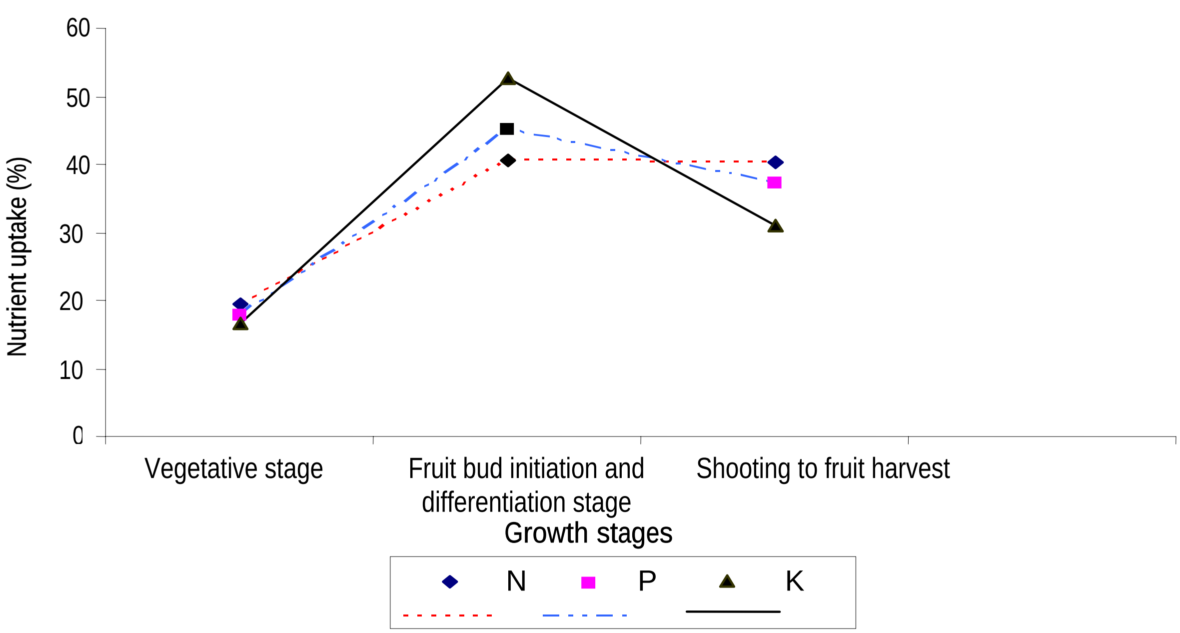
Judicious nutrient management is often regarded as one of the important aspects to increase the productivity of fruit crops particularly banana. Efficient and rational use of the fertilizers is imperative not only for obtaining more yields per unit area on a sustainable basis, but also to ensure safe food and to conserve the environment. Banana generally requires high amount of mineral nutrients for proper growth and production. Studies conducted by different authors indicated that banana crop requires more of 'K' than 'N' and 'P' (Table 1).

Table 1. Variations in the uptake of nutrients by banana

Yield (t/ha)	Nutrient uptake (kg/ha)			Reference
	N	P	K	
30.00	50-75	15-20	175-200	Jacob and Vonvexkull (1960)
25.00	50	12.50	150	Martin-Prevel (1964)
25.00	250	60	1000	Montagut and Martin-Prevel (1965)
28.00	250	90	350	Martin-Prevel *et al.* (1968)
16.75	38	8	285	Joseph (1971)
30.00	300	80	800	Shanmugam and Velayutham (1972)
25.00	300	80	800	Veeraraghavan (1972)
57.50	321.84	72.86	1179.67	Veerannah *et al.* (1976)
77.00	180-450	49-309	964-2440	Martin-Prevel (1992)

These nutrients are also varyingly required at different growth stages (Fig.1), more during the fruit bud initiation and differentiation stage.

Fig 1. Nutrient uptake in banana at different growth stages



Studies on uptake of nutrients in tissue culture banana cv. Robusta (AAA) also revealed that N, P, K uptake increased up to shooting stage (Nalina, 2002). The distribution of N, P, and K within different organs of banana plant is found in the order of the bunch > leaves > pseudostem > corm for N and P, and pseudostem > bunch > leaves > corm for K.

Banana cultivation in India is polyclonal with an array of varieties under different methods of cultivation. The systems of culture are diverse; therefore, fertilizer recommendations are also diverse. However, it is indicated that, in all fertilizer recommendations, the quantity of 'K' fertilizers are higher than nitrogenous fertilizers. Further, as banana is cultivated under different production systems in Tamil Nadu, TNAU recommends different NPK doses for different systems and varieties (Table 2).

Table 2. Fertilizer recommendations for banana under different methods of cultivation

Details	N	P	K
	(g/plant/year)		
Garden land			
Varieties other than Nendran	110*	35*	330*
Nendran	150	90	300
Wetland			
Nendran	210	35	450
Rasthali	210	50	390
Poovan, Robusta	160	50	390
Hill bananas			
After forming semicircular basins on uphill side, apply 375 g of 40:30:40 NPK mixture, plus 130 g muriate of potash per clump per application during October, January and April. Apply *Azospirillum* and *Phosphobacteria* 20 g each at planting and 5th month after planting preceding chemical fertilizer application.			

*For tissue culture banana apply 50% extra fertilizers at 2nd, 4th, 6th and 8th month after planting

The time of fertilizer application and availability of nutrients in adequate amounts in accordance with the crop needs during different growth stages are vital for optimum growth and productivity in any crop particularly for banana. Though banana requires nutrients throughout its growing period, application of N and K before shooting, especially during flower bud initiation (4-6 MAP) ensures uninhibited growth and has greater influence in deciding the bunch size, number of fingers and hands per bunch, ultimately the yield (Simmonds, 1982). Splitting of N, P and K helps in accumulation of photosynthates and also helps in better availability of nutrients during crop period and thus favours the yield and quality improvement (Agrawal *et al*. 1997).

Leaf nutrient concentration in banana plant provides information on the nutrient status of the plant. Any management practice, especially with nutrient programme should reflect on optimum leaf concentration of major nutrients to aid in proper growth and development of banana crop. Scanning of literature on the above line showed that critical levels of N varied from 2 to 3 %, P from 0.08 to 0.5 % and K from 3 to 4.5% for banana (Table 3).

Table 3. Critical level of nutrients in banana cv.Robusta

Leaf (%)			**Reference**
N	**P**	**K**	
2.85	0.20	4.69	Kohli *et al*. (1981)
2.80	0.52	3.80	Ray *et al*. (1981)
2.09	0.10	4.48	Nalina (1999)
2.98	0.32	2.53	Mahalakshmi (2000)
3.01	0.36	2.28	Kavino (2001)

Banana, being a potassium loving crop, the farmers in India are applying potassium @ 800 to 1600 kg per ha depending upon the available soil K status. As Muriate of Potash (MOP) is commonly used as the source of potassium, the chloride toxicity is often met in banana, hindering crop growth, yield and quality especially at amounts greater than 1200 kg per ha (Nalina, 2002). Hence, SOP has been tested as a substitute for MOP in banana at TNAU. Ramesh Kumar (2004) tried various combination of SOP and KCl to supply the recommended dose of K_2O *i.e.* 330 g of K_2O per plant to cv. Robusta and found that soil application of SOP improved the bunch weight and quality (Fig. 2 and 3) as compared to 100% through MOP. But, the prohibitive cost of SOP is the limiting factor.

Fig 2. Influence of sources of potassium (SOP *vs* MOP) on bunch and finger weight in banana

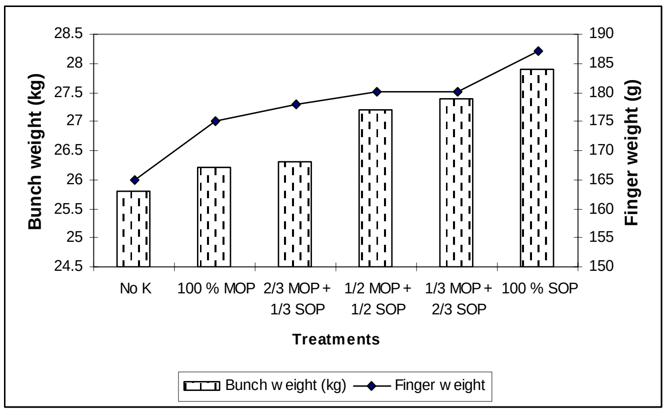
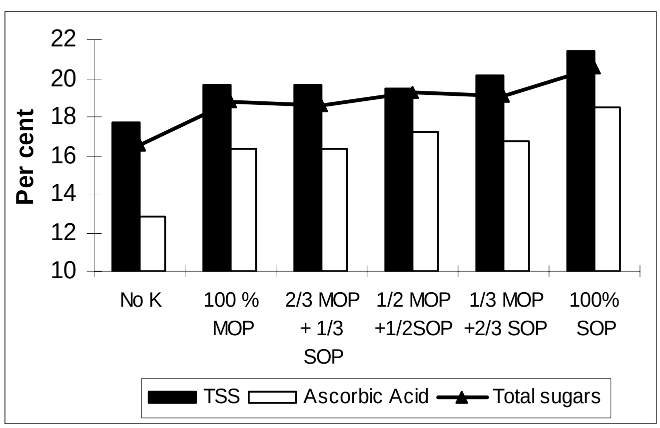


Fig 3 . Influence of sources of potassium (SOP *vs* MOP) on quality traits in banana



As potassic fertilizers are exclusively imported, their exorbitant cost and scarcity at times especially during the critical growth period of banana is a serious limitation as many farmers are not able to apply potash timely and in adequate quantities. This will lead to nutritional imbalance in soil and deteriorate the soil fertility also. As most of the Indian soils are rich in K, this problem may not be visualized in the early stage, but in the long run, it cannot be solved by simple means. In such a situation, potash rich industrial wastes are found to be an alternate source of potassium in agriculture. One such industrial waste, Cement Kiln Flue Dust (CKFD), containing nearly 20% potassium may prove as an useful alternative. Shanthi (2004) found that application of 50% K through MOP + 50% K through CKFD had a positive response to plant growth in terms of height, girth, number of leaves, bunch weight and number of fingers in banana cv. Karpooravalli and Poovan (Table 4).

Table 4. Influence of Cement Kiln Flue Dust on yield characters of banana

Karpooravalli

Treatment	Bunch weight (kg)	No. of hands	No. of fingers	Finger weight (g)
100 % K through MOP	19.42	13.59	174.08	120.07
50 % K through MOP + 50 % K through CKFD	23.46	14.39	187.93	129.73
SEd	0.92	0.93	2.51	1.02
CD (0.05)	2.12	NS	5.78	2.05

Poovan

Treatment	Bunch weight (kg)	No. of hands	No. of fingers	Finger weight (g)
100 % K through MOP	15.83	12.00	144.66	103.14
50 % K through MOP + 50 % K through CKFD	19.14	12.65	179.13	118.09
SEd	0.72	0.42	7.83	2.84
CD (0.05)	1.65	NS	18.05	6.56

Sources of nitrogen

It is well known that next to potassium, nitrogen is required in larger proportions for banana. However, Simmonds (1966) indicated that under tropical conditions, application of nitrogen in the soil will be leached rapidly due to various factors. Urea, Ammonium Sulphate and CAN are the various sources of nitrogenous fertilizers used, however, the most common being Urea only.

The efficiency of different sources of nitrogen on banana cv. Ney Poovan was assessed at TNAU and the result showed that combined application of 25 per cent of N as CAN + 25 per cent of N as Urea + 50 per cent of N as Ammonium sulphate had resulted in better vegetative growth, physiological attributes, soil and leaf nutrient status culminating in an increased yield in terms of bunch weight and other economical traits (Table 5) (Keshavan, 2004).

Table 5. Influence of different 'N' sources on yield characters of banana cv.Ney Poovan

Treatment	Bunch weight (kg)	No. of hands	No. of fingers	Finger weight (g)
Control	8.44	10.20	44.32	157.93
25 per cent of N as CAN + 25 per cent of N as urea + 50 per cent of N as ammonium sulphate	12.10	11.82	59.25	173.25
SEd	0.39	0.29	1.01	4.12
CD (0.05)	0.81	0.60	2.11	8.58

Fertigation for banana

Banana production needs a shift from the present peasantry farming system to large-scale corporate cultivation to meet worldwide consumer demands. This cannot be achieved with cultural operations *viz*., annual replanting, manual fertilizer application, irrigation and weeding, etc, which are highly labour intensive and constitute a major portion of the input costs. Adoption of a new system for an easy, efficient and cost-effective cultivation of banana with considerably minimum labour involvement for increasing productivity at lesser cost is essential. One such improved technology is fertigation (application of soluble fertilizer through micro-irrigation system). In this context, fertigation experiment conducted with cv. Robusta (AAA) revealed that fertigation treatment with 50 to 75 % of recommended NPK (200:30:300g NPK/plant) registered the maximum bunch weight, more number of hands and fingers both under normal and high density planting system (Table 6) (Mahalakshmi *et al*. 2001).

Table 6. Influence of fertigation on banana cv. Robusta (AAA)

Water + Fertilizer	Bunch weight (kg)	Yield (t/ha)	% increase over conventional	No. of hands	No. of fingers	TSS
Normal planting system (Single plant / pit)						
Plant crop 25LPD + 100:30:150 g NPK*	38.00	95.00	61.07	9.34	163.94	19.29
Ratoon crop 25 LPD + 150:30:225 g NPK **	44.42	111.05	61.07	13.47	261.27	20.10
High density planting system (3 plants / pit)						
50 LPD + 450:90:675 g NPK**	34.99	174.88	196.51	10.22	173.38	21.20
Conventional (Single plant / pit)						
200:30:300 g NPK/ plant	23.59	58.98	-	8.12	118.01	22.13

* 50 percent recommended dose ** 75 percent recommended dose

The effect of fertigation on the growth, yield, quality and physiological parameters of banana cv. Red banana (AAA) revealed that planting of one plant / pit along with 100% of RDF (110:35:300 g NPK) through fertigation resulted in higher bunch weight (22.55 kg), number of fingers (98.92) and finger weight (255.36 g) (Suganthi, 2002). Conventional fertilizers are equally effective as that of water soluble fertilizers for fertigation in banana besides reducing the cost (Kavino, 2001).

Further, fertigation experiments conducted at various parts in India revealed that application of 75 per cent recommended dose of fertilizer (RDF- 200 g each of N and K_2O per plant per year) at Arabhavi (Robusta), Gandevi (Gandevi selection), Jalgaon (Grand Naine) and Kannara (Robusta) and 50% recommended dose of fertilizres at Kovvur through drip was sufficient for Karpura Chakkerakeli (AAB, Mysore).

Balanced nutrition for tissue cultured bananas

Tissue-cultured (TC) banana cultivation is expanding in India as farmers are now realizing its advantages due to its rapid growing, early and high yielding characters. As they produce significantly high yields than the conventional suckers, the requirements of macro as well as micronutrients might be more. Application of 150% of recommended doses of NPK (*i.e.*165:52.50:495 g) in four splits was found essential to increase the plant's growth and development, yield and quality in the plant and ratoon crops of TC banana (Table 7) (Nalina, 2002). The dose of 300 g N and K_2O each and 100 g P_2O_5 per plant per crop was observed to be optimum for tissue culture banana cv.Robusta under irrigated, low fertility, lateritic soils of coastal Orissa (Pandey *et al*. 2005).

Table 7. Response of Tissue culture derived banana to increased dose of nutrients

Treatments	**Bunch weight (Kg)**			**TSS in fruit (°Brix)**		
	PC	**R_1**	**R_2**	**PC**	**R_1**	**R_2**
Recommended dose (110:35: 330 g N, P_2O_5, K_2O) in 3 split doses	26.87	30.0	17.55	18.10	18.46	18.16
150% of recommended dose (i.e. 165:52.5:495 g N, P_2O_5, K_2O) in 4 split doses	35.18	37.0	25.28	20.50	20.63	20.18
CD (0.05)	1.09	1.22	1.55	0.25	0.28	0.27

PC: Plant crop R_1: First ratoon R_2: Second ratoon

Balanced fertilization by foliar nutrition

Banana is known to respond well to foliar nutrition especially for the major, secondary and micro nutrients. To assess the effect of post-shooting spraying of sulphate of potash (SOP) on yield and quality of banana and to integrate SOP into the nutrient management practices, an experiment was conducted in banana cv. Ney Poovan (Ramesh Kumar and Kumar, 2007). Plants were sprayed twice, initially after the opening of the last hand (*i.e.* 7^{th} month after planting) and 30 days later. The entire plant canopy was sprayed including the developing bunches. Foliar spray concentration had a significant and positive impact on bunch weight, total number of fingers and finger weight (Table 8).

Table 8. Effect of foliar spraying of SOP on bunch traits of banana cv.Ney Poovan

Treatment	Bunch weight (kg)	Total no. of fingers	Finger weight (g)	TSS (%)
Control	10.80	182.30	55.70	24.40
0.5% SOP spray	11.53	209.00	67.70	27.90
1.0% SOP spray	12.63	221.00	71.40	27.90
1.5% SOP spray	14.27	233.30	75.10	28.90
SEd	0.50	4.30	4.58	1.01
CD (P=0.05)	1.02	8.79	9.36	2.06

Similarly, post- shoot application of KH_2PO_4 + Urea + 2, 4-D had significant influence on the bunch weight and TSS of commercial banana cultivars (Fig.4&5) (Ramesh Kumar, 2004).

Fig. 4. Influence of post shooting spray of certain nutrients on bunch weight

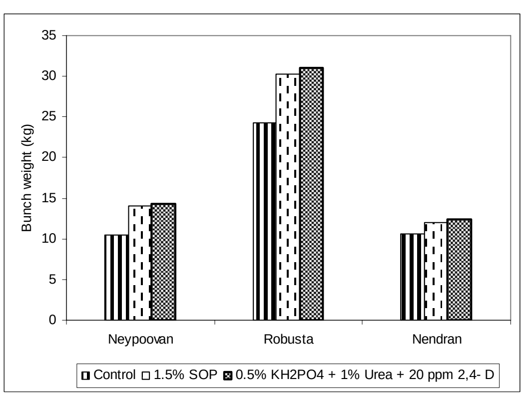
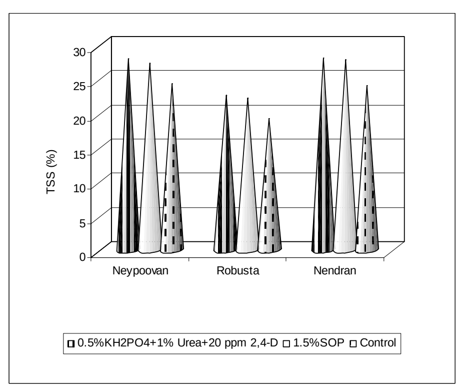


Fig.5. Influence of post shooting spray of certain nutrients on TSS of fruits



Kumar and Jeyakumar (2001) assessed the importance of micronutrients in banana and 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 fertilizer dose of NPK@ 110:35:330g/plant/year improved the leaf micronutrient status and resulted in higher bunch weight besides better fruit quality.

Influence of plant growth regulators / bio regulators on nutrient use efficiency

Cavendish group of bananas are known to be very vigorous and foliar spray of certain growth regulators play a significant role in improving the yield through increasing the fertilizer use efficiency. Foliar spray of chlormequat chloride @1000 ppm during 4th and 6th month after planting (MAP) in addition to the soil application of NPK@ 110:35:330g/plant/year resulted in improved physiological efficiency, nutrient status and fruit yield including fruit quality (Jeyakumar *et al*., 2003) (Table 9).

Table 9. Influence of chlormequat chloride application on banana

Treatment	N (%)	P (%)	K (%)	CEC (me g^{-1})	Bunch weight (kg)	TSS (°brix)
Control	1.51	0.505	2.01	9.25	24.80	20.00
Chlormequat chloride 1000 ppm	1.94	0.745	2.98	16.43	33.62	23.60
SEd	0.02	0.01	0.03	0.70	0.81	0.68
CD(0.05)	0.04	0.03	0.07	1.42	1.76	1.40

Sea weed based bioregulators are widely used in the recent years to increase the nutrient use efficiency in various agricultural and horticultural crops. Foliar spray of 0.2 % plantozyme during fourth and sixth month after planting, in addition to the fertiliser dose of 200:40: 200 g N: P_2O_5 : K_2O per plant per year revealed the influence of nutrients and amino acids in plantozyme on higher cell wall plasticity and dry matter accumulation resulting in better yield besides improving the leaf nutrients status (Jeyakumar and Kumar, 2002) (Table 10).

Table 10. Effect of bio regulator application on leaf nutrient, yield and quality of banana

Treatments	N (%)	K (%)	NR (μg NO_2 g^{-1} h^{-1})	Bunch weight (kg)	Total sugars (%)	TSS (%)
Control	1.72	3.11	7.52	18.0	14.0	19.7
Plantozyme 0.2%	2.07	3.92	9.63	26.3	16.6	25.7
SEd	0.018	0.031	0.57	0.77	0.28	0.63
CD(0.05)	0.038	0.064	1.18	1.56	0.54	1.22

Bio fertilizers for balanced fertilisation

Continuous application of inorganic fertilizers to soil can cause ecological niche and reduce the beneficial soil microbes population. Hence, integrated approaches are needed to involve organic amendments and biofertilizers for sustainable crop production. Vidhya (2004) found that application of 100 per cent of the recommended dose of fertilizer (RDF) along with 50 g in each of *Azospirillum*, phosphate solubilizing bacteria and Vesicular Arbuscular Mycorrhizae (VAM) in banana cv. Robusta resulted in better yield traits (Table 11).

Table 11. Influence of bio fertilizers on yield characters of banana

Treatment	Bunch weight (kg)	No. of hands	No. of fingers	Finger weight (g)
100 percent of recommended dose of fertilizers alone	24.47	9.14	137.08	164.85
100 per cent of the (RDF) along with 50 g in each of *Azospirillum*, phosphate solubilizing bacteria and Vesicular Arbuscular Mycorrhizae	26.10	10.63	142.75	173.36
SEd	0.34	0.21	0.94	2.06
CD (0.05)	0.75	0.46	2.04	4.49

Conclusion

Balanced fertilization, which takes care of all nutrients according to site and crop-specific assist the farmer to comply with the demand from the consumer. Higher yields and improved quality due to balanced fertilization indicate the better use efficiency of the natural resources (land and energy) coupled with environmental safety. The future research on nutrition on banana should encompass:

1. Systematic long term experiments with graded levels of primary, secondary and tertiary nutrients so as to assess the individual effect of these nutrients and also their interaction on yield and quality.
2. Considering the present situation of environmental security, it is necessary to go for integrated nutrient management, involving various sources of organic manures, organic cakes and bio fertilizers including mycorrhiza besides chemical fertilizers in almost all tropical fruit crops.
3. Nutrient recycling as the high biomass sometimes affect the nutrient response.
4. Improvement of nutrient use efficiency through water management and plant growth regulators.

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Balanced fertilization for Papaya

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India is emerging as a large papaya producing country, ranking fourth place in the world. It is grown in about 70,300 ha with an annual production of 1.7 million tonnes in India, accounting for four per cent of gross fruit production in our country and occupying itself at fourth position; first three being banana, mango and citrus. Papaya is mostly consumed as a table fruit besides small quantities are exported. Recently, there is a heavy demand for its latex, which has got high export potential.

The nutritional demand of papaya differs from other fruit crops because of its tremendous yield potential, precocious bearing and indeterminate growth habit with simultaneous vegetative growth, flowering and fruiting. The nutrient uptake studies conducted at Tamil Nadu Agricultural University (Veerannah and Selvaraj, 1984) revealed that uptake of N, P, K, Ca and Mg is more between flowering and harvesting stages, more so between fruit development and harvest stages (Table 1).

Table 1. Nutrient uptake by whole plant of papaya cv. CO 1 (kg $^{-1}$ha^{-1})

Growth stage	N	P	K	Ca	Mg
Seedling	0.02	0.0005	0.02	0.02	0.02
Vegetative	0.29	0.074	0.67	0.05	0.05
Pre flowering	9.04	0.808	18.58	1.46	0.99
Flowering	53.37	15.41	203.36	4.10	2.30
Fruit development	56.76	44.59	515.19	30.74	6.32
Harvest	305.58	103.68	524.02	327.40	183.34

Among the important nutrients, the demand for K was more nearly twice as that of nitrogen in papaya (Fig-1).

The nutrient requirement for papaya has been recommended by many workers in different parts of India (Table -2). It is evident that N requirement varies from 200 g/plant to 375 g/plant, P_20_5 from 110-375 g/plant and K_20 from 200 to as high as 500 g/plant.

Fig 1. Total removal of nutrients by papaya plant

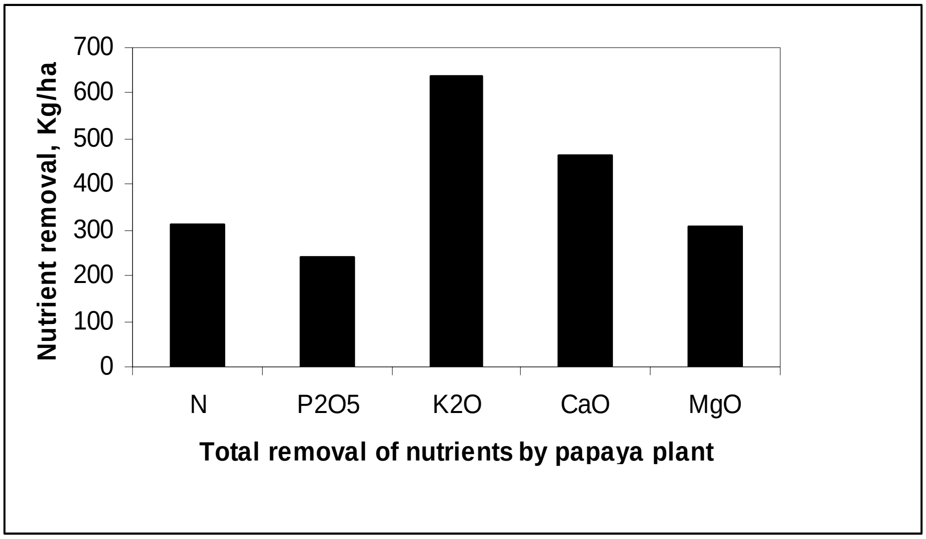
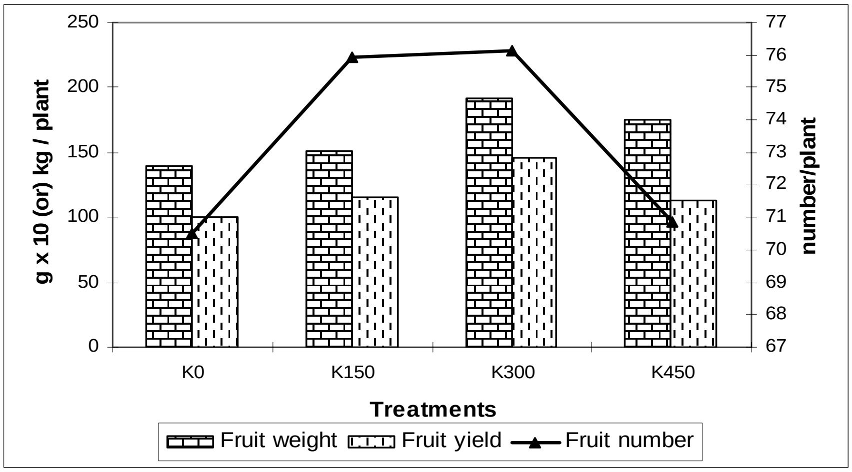


Table 2. Nutrient requirement for papaya

Sl.No.	N	P_2O_5	K_2O	Authority
	g/plant/year			
1.	250	110	415	Purohit (1984)
2.	250	250	250	Irulappan *et al.* (1992)
3.	375	250	250	Balamohan *et al.* (1992)
4.	375	375	375	Kumar (1995)

Role of balanced fertilization with N, P and K has been well established in many crop plants. However, information on this line is lacking in fruit crops like papaya. Trials conducted at Tamil Nadu Agricultural University in collaboration with IPI revealed the importance of potassium nutrition in papaya (Kumar *et al*. 2006). Experiments conducted with two cultivars (CO-2 and CO-7) at four locations of Tamil Nadu showed that potassium nutrition significantly influenced fruit weight, fruit number and fruit yield per plant (Fig 2).

Fig 2. Effect of potassium on yield traits in papaya (Average of results with four farmers' field)



Potassium is recognized as a quality element .In the above mentioned experiments potash fertilizer use improved major quality parameters of papaya fruits such as pulp thickness, i.e., edible part size of papaya fruits, the sweetness of papaya (TSS) besides decreasing acidity content(Table-3).The increase in pulp thickness may be related to the role of potassium in influencing the developing fruit which is acting as a stronger sink for K than for other nutrients. Potassium is also known to help in sugar translocation in plants, thus its application increased the sugar contents as well as TSS in the papaya fruit.

Table 3. Effect of potash fertilizer application on fruit quality of papaya cv.Co-2 (Average results with four farmers' field)

Treatment	Pulp thickness (cm)	TSS^{o} Brix	Acidity (%)
N_{300} P_{300}	2.21	10.81	0.65
$+k_{150}$	2.48	11.57	0.52
$+K_{300}$	2.59	11.87	0.47
$+K_{450}$	2.60	12.50	0.33

Demonstration experiments laid out at farmers' fields at two locations (a)Thondamuthur and (b) Chandrapuram of Tamil Nadu state indicated that balanced fertilization is very much important for papaya latex production and quality(Table 4).

Table 4. Effect of Potash application on the yield and quality of Latex

Treatment	(a)Thondamuthur(11 months after planting)		(b)Chandrapuram(14 months after planting)	
	Yield,Kg/ha	TSS^{o} Brix	Yield,Kg/ha	TSS^{o} Brix
N_{300} P_{300}	32.0	15.84	181.2	16.7
$+K_{150}$	36.6	15.76	181.0	16.8
$+K_{300}$	35.0	16.62	155.2	16.9

The quality of latex is assessed in terms of Total Soluble Solids (TSS) content. It's the important quality criterion by which the latex procuring industries make the payment to the growers. With increased potash fertilizer level, there was an increase in the TSS content, highlighting the role of potassium nutrition on the TSS of the latex. Papain produced from papaya latex is useful in tenderizing meat and other proteins through the process of hydrolysis (or breakdown) of proteins. Thus, enzyme activity is an important quality parameter of papain. The enzyme activity of latex as assessed in terms of Tyrosine unit/mg of papain (Table.5) revealed that during two seasons, the influence of potassium nutrition was perceptibly noticed on it. With the increase in potassium level, there was an increase in the tyrosine activity of latex upto K_{300} thereafter it declined at K_{150} (Table 5).

Table 5. Effect of potash application on the enzyme activity (Tyrosine unit / mg of papain) in the latex of cv.C0-2

Treatment(g/plant/year)	Tyrosine,Tu/mg (Dec'06)	Tyrosine,Tu/mg (June'07)
N_{300} P_{300}	99.54	109
$+K_{150}$	100.44	129
$+K_{300}$	136.62	185
$+K_{450}$	195.90	172

With the increased application of potassium fertilizers, there was a dramatic increase in tyrosine activity, highlighting the role of potassium on the enzyme activity of papaya latex.

Split application of Fertilizers

Papaya being a perennial crop and the nutrient is required at all stages of growth continuously, split application of fertilizer is found beneficial. In Solo variety, 250 g N, 250 g P_2O_5 and 200 g K_2O per plant per year applied in 6 split doses was the best when spaced at 2x 2 m (Sulladmath *et al*. 1984). Results of experiments conducted at Tamil Nadu Agricultural University, Coimbatore revealed that six split applications (Irulappan *et al*., 1984) was found to be good while Ravichandrane *et al*.,2002 recommended twelve splits instead of six as it resulted in higher yield and quality of fruits in CO2 papaya (Table 6).

Table 6. Effect of split application of nutrients on yield and quality of papaya cv.Co2

Treatment	Number of fruits/plant	Yield of fruits (Kg)	Fruit weight (kg)	TSS (°Brix)	Carotene (mg/100g of pulp)	Enzyme activity (TU/mg)
300 g each of NPK/plant/year in six split doses	86.59	167.01	1.97	12.25	3.39	231.49
300 g each of NPK/plant/year in 12 split doses	101.29	213.64	2.11	14.40	3.64	266.96
CD (0.05)	3.28	16.55	NS	NS	-	-

Recently, studies conducted at West Bengal with cv.Coorg Honey Dew revealed that application of 250 g of nitrogen, 500 g of phosphorous and 250g of potassium per plant in six splits resulted in production of higher yield with heavier and better quality fruits.

Fertigation

Drip irrigation is known to improve the fertilizer use efficiency, fruit yield and quality of many fruit crops. Fertigation studies conducted at Tamil Nadu Agricultural University with CO7 revealed that 75% of recommended doses of N and K through fertigation along with soil application of super phosphate 278 g per plant at bimonthly intervals improved growth, yield and quality characteristics in papaya cv. CO7 (Jeyakumar *et al*. 2001). The fertigation of nutrients (N and K) were scheduled here at weekly intervals.

Integrated Nutrient Management

Papaya plants receiving inorganic nutrients alone (200 g each of N, P_2O_5, K_2O plant^{-1} year^{-1}) recorded the highest yield, but inclusion of an organic source of nutrient (farmyard manure/neem cake) produced better quality fruits. Tamil Nadu Agricultural University recommends application of 300g in each of NPK per plant per year at bimonthly intervals along with application of 20 g *Azospirillum* and 20 g Phosphobacterium at planting and again after six months. Manivannan(2005) investigated the use of humic acid, an organic product derived from lignite on enhancing the biological growth, fruit yield and quality of papaya cv.Co-3.The study highlighted foliar spraying of humic acid at 0.2% concentration once in 15 days from the third month after planting improved the biometric characters, fruit yield and quality attributes *viz*. TSS, sugar acid ratio and ascorbic acid content besides enhancing the shelf life of the matured fruits.

Micro nutrients

Micronutrient deficiencies in papaya are not serious as compared to other fruit crops. However, it may affect the growth and development of papaya crop if soils are found deficient. Kavitha *et al* 2000 a and 2000 b studied the influence of foliar spraying of Zinc and Boran and found significant effect on yield and quality of papaya (Table 7).

Table 7. Effect of certain micro nutrients spray on yield and fruit quality of papaya cv. Co5

Treatments	Number of fruits/plant	Yield of fruits (Kg)	Latex Yield per fruit (g)	TSS^{o} Brix	Ascorbic acid(mg/g pulp weight)	Tyrosine, Tu/mg
Control	136.98	230.17	12.54	12.30	45.11	204.32
Foliar spraying of Zn 0.5 % + B 0.1 % at 4, 8, 12, 16th Month After Planting	166.75	330.68	15.23	14.80	47.14	205.11

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Balanced Fertilization for Hybrid Vegetable Production

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The achievements in enhanced agricultural output at the global level, especially in the developed world, are attributed to three main factors: *expansion of irrigation, development of improved higher-yielding, disease - resistant crop cultivars* and use of *chemical fertilizers*. Despite the advances that have been made in agricultural production through research and technology transfer in the past half century, many areas of the world still fail to meet the nutritional needs of their people; in some countries the spectra of hunger and malnutrition looms large. If low-income, food-deficit nations are able to feed themselves, Borlaug stressed increase in several fold a chemical fertilizer in the coming decades. The remaining crop nutrients came from organic sources, native soil reserves, and biological nitrogen fixation (Stewart *et al.* 2005). This scenario underlines the need for emphasizing efficient fertilizer use in order to produce an adequate and quality food supply bearing in mind environmental implications of excessive or inappropriate fertilizer use. The fact that crops need variable amounts of nutrients and that no one essential nutrient can substitute for another raises the issue of "balanced fertilization", in essence a concept that implies tailoring individual nutrient needs of crops according to their physiological requirements and expected yields.

Vegetables account for 6245 million hectares of area in India with a total production of 93921 million tonnes and productivity of 13.6 t/ha during 2002-03. The per capita consumption of vegetables is only 210 g/day as against the daily requirement of 285 g/day. To bridge this gap, the production and productivity of vegetable crops need to be increased substantially. In this extent, apart from the high yielding genetic material, the role of nutrition is also highly felt.

The balanced fertilization to vegetables can be given either through conventional method or by fertigation. The fertilizer application through fertigation should be scheduled during various stages of crop growth like establishment stage, vegetative stage, pre-flowering, flowering and harvest. The role of balanced fertilization in important hybrid vegetable crops is discussed below:

1. Tomato

Tomato responds well to applied nutrients. The F_1 tomato hybrids are generally more responsive to fertilizer application and thus creating more biomass for higher photosynthetic activity. In high yielding cultivars, 65 to 75 per cent of total dry matter is accumulated in the fruit end. A crop of tomato yielding 37.8 t/ha removed 104 kg N, 22 kg P and 141 kg K. The recommendation for tomato by TNAU is 150:100:50 kg/ha NPK for open pollinated varieties and 200:300:50 kg/ha NPK for hybrid/varieties.

Rajesh Kanna (1999) conducted an experiment in tomato hybrid COTH 1 at HC & RI, TNAU, Coimbatore imposing different N levels (200, 250 and 300), P levels (200, 250 and 300) and K levels (200, 250 and 300 kg/ha) in all possible combinations and reported that economic yield per hectare with the highest BCR was observed with the application of 200:300:200 kg NPK ha^{-1} (Table 1). The entire quantity of P and K are given as basal while N is applied in three equal split doses at planting, 30 and 60 days after planting.

Table 1. Effect of NPK on yield characters and shelf life of tomato hybrid COTH 1

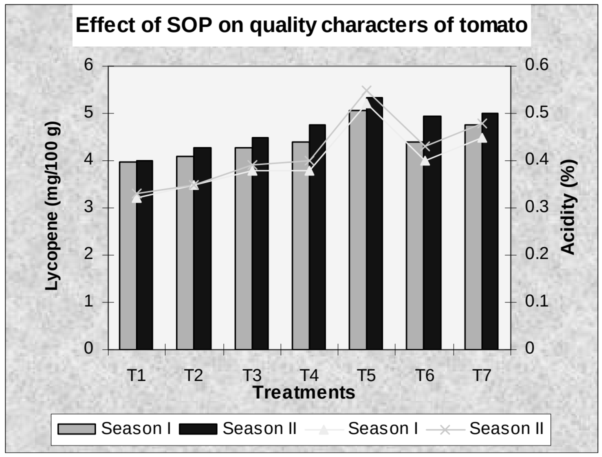
Treatments	No. of fruits/cluster	Yield (t/ha)
NPK @ 200:300:200 kg/ha	6.21	117.30
NPK @ 300:250:200 kg/ha	4.13	73.49
CD (0.05)		

Another experiment on hybrid tomato COTH 2 conducted at HC & RI, TNAU, Coimbatore during 2006 (Anon, 2007) revealed that application of SOP 100 kg/ha basal + SOP 50 kg/ha top dressing on 30 DAP + SOP 50 kg/ha top dressing on 60 DAP registered the highest number of fruits per plant, single fruit weight, yield per hectare, TSS, lycopene and firmness (Table 2 and Fig. 1).

Table 2. Effect of SOP on yield attributes of tomato hybrid COTH 2

Treatment No.	Treatments	Fruit per plant	Single fruit weight (g)	Fruit yield (t/ha)	BCR
T_1	Control (No K2O)	32.00	43.12	61.20	3.09
T_2	200 kg MOP (basal)	41.87	51.37	70.83	3.54
T_3	200 kg SOP (basal)	46.00	55.62	74.52	3.73
T_4	100 kg (basal) + SOP 100 kg (top dressing) on 30 DAP	50.15	59.66	78.10	3.90
T_5	SOP 100 kg (basal) + SOP 50 kg (top dressing) on 30 DAP +SOP 50 kg/ha (top dressing) on 60 DAP	60.20	70.24	87.29	4.36
T_6	SOP 100 kg (basal) + SOP 50 kg (top dressing) on 30 DAP + SOP 2% (foliar spray) on 60 DAP	55.45	64.10	81.20	4.06
T_7	SOP 100 kg (basal) +SOP 50 kg top dressing on 30 DAP + SOP 2% (foliar spray) on 60 DAP and 75 DAP	56.32	65.16	83.85	4.19
	SEd	1.46	1.63	1.43	
	CD	3.52	3.12	3.05	

Fig. 1. Effect of SOP on acidity and lycopene content of tomato hybrid COTH 2



Fertigation experiments carried out at TNAU, Coimbatore, revealed that 50 kg each of NPK/ha through straight fertilizers as basal, remaining 250 kg NPK/ha as water soluble fertilizer through fertigation along with black polyethylene mulch registered the highest number of fruits/plant (71), yield per hectare (186 t) and BCR (1.76) as compared to control in tomato hybrid SH 7711 (Table 3) grown under polyhouse (Natarajan *et al*. 2005).

Table 3. Effect of growing media, irrigation regime, fertigation and mulching on growth and yield of tomato hybrid SH 7711

Treatment	No of fruits / plant	Estimated yield/ha (t)	B/C ratio
Soil:FYM: Saw dust + 20 kPa + 50kg/ha SF (basal) + 250 kg/ha WSF (fertigation) + Mulch	63.0	113	1.58
Soil:FYM: coir pith + 20 kPa + 50kg/ha SF (basal) + 250 kg/ha WSF (fertigation) + Mulch	71.0	186	1.76
CD at 5%	4.7	-	-

2. Chilli

Chilli has a long growing season and therefore, needs a judicious management in the application of manures and fertilizers. The fertilizer recommendation for chilli is 120:60:30 kg/ha NPK. Studies on the use of SOP vs MOP revealed the efficacy of SOP even at 60kg/ha in increasing the number of fruits, yield, quality and benefit cost ratio (Ananthi, 2002) (Table 4).

Table 4. Effect of different potassium treatments on yield and quality of chilli

Treatments	No. of fruits (%)	Yield (t ha^{-1})	Capsaicin (%)	BCR
NPK@60:30:30 as Urea, SSP & MOP + FYM@ 25t/ha	92.00	1.99	0.58	2.08
60 kg K_2O ha^{-1} as SOP	135.00	5.09	0.85	5.11
SEd	4.33	0.23	0.03	
CD (5%)	8.98	0.47	0.06	

3. Sweet pepper

Capsicum is one of the most important vegetable crops grown in winter season in Tamil Nadu. TNAU recommends 120 kg N, 60 kg P and 30 kg K for capsicum hybrids.

Sasikala *et al.* (2007) reported that package consisting of Soil:FYM:Coir pith (2:1:1) as growing medium, irrigation at 20 kPa, INM with 50 kg each of NPK ha^{-1} as basal with straight fertilizer and 150 kg each of NPK ha^{-1} through fertigation with water soluble fertilizer and mulching in capsicum hybrid 'Indra' recorded the highest number of fruits per plant (48.3), average fruit weight (148 g), yield per hectare (144 t) and B/C ratio (3.72) (Table 5).

Table 5. Effect of growing media, irrigation regime, fertigation and mulching on growth and yield of capsicum hybrid 'Indra'

Treatment	No of fruits / plant	Avg. fruit weight (g)	Yield/ha (t)	B/C ratio
Soil:FYM: coir pith + 20 kPa + 50kg/ha SF (basal) + 250 kg/ha WSF (fertigation) + Mulch	48.3	148	144	3.72
Soil:FYM: Saw dust + 20 kPa + 50kg/ha SF (basal) + 150 kg/ha WSF (fertigation) + Mulch	43.2	134	116	3.21
CD at 5%	3.6	10.6	-	-

4. Brinjal

Brinjal being a long duration crop requires a good amount of manures and fertilizers. Macro and micronutrient deficiencies had adverse effect on plant height, branch production and finally yield. TNAU recommends 100:50:30 kg/ha NPK for hybrid Brinjal production and 100:50:30 kg NPK/ha for the open pollinated varieties.

Prabhu (2001) reported that the highest yield in brinjal hybrid COBH 1 was obtained at 200:100 kg NP ha^{-1} (Table 6). In TNAU under the precision farming project, 200:150:100 kg/ha NPK was found to be the best in recording the highest number of fruits per plant and yield per hectare in hybrid brinjal.

Table 6. Effect of N and P on yield characters of Brinjal hybrid COBH 1

Treatments N and P *(Kg/ha)	Number of fruits			Yield / ha		
	P_{50}	P_{75}	P_{100}	P_{50}	P_{75}	P_{100}
N_{100}	21.13	25.12	23.73	15.98	18.17	22.11
N_{125}	24.73	26.07	27.43	24.05	26.24	27.68
N_{150}	28.60	30.60	32.47	29.71	33.51	37.02
N_{175}	32.23	36.34	40.48	41.24	46.87	58.42
N_{200}	34.73	38.22	40.71	46.06	57.56	58.51
	N	P	N X P	N	P	N X P
S.Ed.	0.234	0.182	0.406	0.170	0.132	0.295
CD	0.479	0.371	0.830	0.348	0.269	0.602

* Common dose of 100 kg K_2O/ha

5. Potato

Potato is an exhaustive crop. The tuber yield as well as its quality depends upon the application of various NPK fertilizers and organic manures. TNAU recommends 120:240:120 kg NPK/ha. The entire quantity is normally applied as basal or in two splits by the farmers. Mahendran and Kumar (1998) reported that application of 100 per cent recommended dose of NPK in combination with Azospirillum and Phosphobacteria increased the starch content whereas the highest tuber yield was obtained when 100 per cent recommended dose of NPK was applied in two equal splits alongwith Azospirillum and Phosphobacteria (Table 7).

Table 7. Effect of biofertilizer on tuber yield and quality in potato

Treatments	Tuber yield (t/ha)	Starch content (%)	Crude protein (%)
100 per cent recommended dose* of NPK in combination with Azospirillum and Phosphobacteria	21.07	19.30	9.17
Two equal splits of 100 % recommended dose of NPK + Azospirillum + PB	21.27	19.00	9.19
CD (0.05)	0.24	0.21	0.26

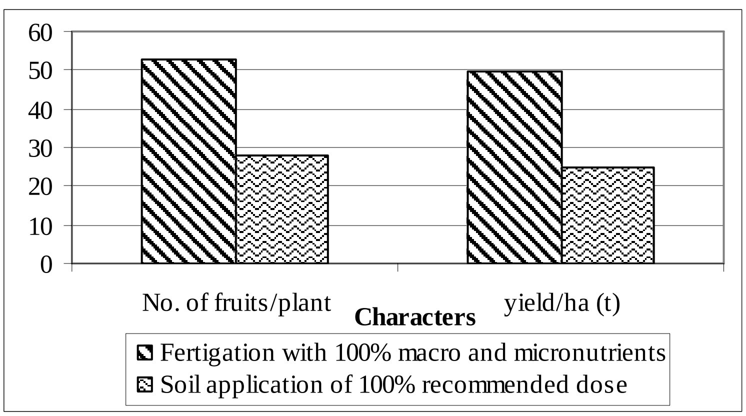
** Recommended dose – 120:240:120 kg NPK/ha*

6. Cucurbits

All gourds, melons etc., respond well to manuring and fertilizer application. It is difficult to be specific about fertilizer recommendation because of variation in soil types, soil fertility and system of cultivation. However, TNAU recommends 100 g of NPK mixture 6:12:12 per pit as basal and 10 g of N per pit 30 days after sowing for OP varieties/hybrids.

Fertigation trial conducted by Meenakshi, 2002 in bitter gourd hybrid, COBgo-H 1 revealed that application of 100 per cent of recommended dose of NPK fertilizer (120:120:60 kg NPK/ha) in water soluble form with micronutrients (polyfeed) recorded maximum number of fruits per plant and yield per hectare (Fig. 2).

Fig. 2. Effect of macro and micronutrient fertigation on fruit number and fruit yield of bitter gourd hybrid COBgo-H 1



7. Cassava

Potassium is an important nutrient element for the growth and development of root and tuber crops. The productivity is the highest (38.45 t/ha) in Tamil Nadu, which however offers scope for further increase in yield through adoption of improved production practices like integrated nutrient management. CFTRI recommends 100:50:100 kg/ha N, P_2O_5 and K_2O whereas TNAU recommends 90:90:240 kg/ha N, P_2O_5 and K_2O.

The research on nutrient management in cassava revealed that application of recommended dose of NPK (100:50:100 kg/ha) + FYM @12.5t/ha which was on par with the application of half the recommended dose of ‘P’, with full dose of N&K and combined application of VAM and Phosphobacteria (Saraswathi, 2005).

Table 8. Effect of biofertilizer in cassava

Treatments	Tuber yield (t/ha)	Starch content (%)
Recommendation dose of N,P,K (100:50:100 kg NPK/ha) + FYM (12.5 t/ha)	29.70	24.0
Half the recommendation dose of P+ VAM + Full recommendation dose of N&K	27.10	23.0
CD (0.05)	0.74	NS

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Balanced Fertilization for Spices

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No use or low use of fertilizer input is one of the main reasons for the low productivity of spices in the country. Nutrient plays a key role in improving yield and quality of spices. Therefore, proper management of plant nutrients is very important. In spice cultivation, mulching and use of organic manure is a common practice because covering with leaf mulch and terracing not only conserves soil moisture but also enriches the soil on decomposition.

Majority of spices are grown in slightly acidic soils. These soils are generally deficient in available P, Ca and Mg. Intensive survey in spice growing areas of Kerala indicated that 57 per cent of sample collected were low in P and judicious application of P is vital in these soils to sustain productivity.

The need for balanced fertilization in important spice crops excepting turmeric is described below:

1. Black Pepper

Black pepper grows well in well drained virgin red, lateritic and alluvial soils rich in humus content. These soils are acidic and poor in content with respect to P, K, secondary and micronutrients especially zinc. The major pepper growing soils of India can be broadly classified viz., Red loam (Alfisol), Forest loam (Mollisol) and Laterite (Oxisol). Pepper is a nutrient demanding crop. An adult pepper vine removes 233.4 g N, 16.8 g P, 171.9 g K, 18.3 g Mg, 75.0 g Ca, 3656 mg Fe, 281 mg Mn, 104 mg Zn, 89 mg Cu and 60 mg B and hence the major nutrients must be applied in amounts sufficient to meet the uptake in addition to the allowance made for nutrient losses through leaching. Further, the quantities of macro and micronutrients removed through harvesting of produce are directly proportional to the yield. Hence, yield based fertilizer recommendation for black pepper is essential (Mathew *et al*. 1995). A leaf nutrient concentration of 2.7, 0.1, 3.0, 1.0 and 0.2% of N, P, K, Ca and Mg respectively are essential for its proper growth but exhibiting deficiency symptoms if their levels are below. NPK recommendations have been standardized for pepper by various workers under Indian conditions (Table 1) which revealed that K fertilizers are required more, followed by nitrogenous and phosphatic fertilizers in order.

Table.1 NPK fertilizer recommendations for pepper

Sl.No.	Dose recommended (kg/ha/year)	References
1.	N: 100 ,P_2O_5 : 40 K_2O : 140	Pillai and Sasikumaran (1976)
2.	N: 50 ,P_2O_5 : 50 K_2O : 200	Pillai *et al*. (1987)
3.	N: 140 ,P_2O_5 : 55 K_2O : 270	Sivaraman *et al*. (1987)
4.	N: 140 ,P_2O_5 : 55 K_2O : 270	Sadanandan (1993)

These fertilizers should be applied 10-15 days after pruning of the live supports. The rate, composition and interval of fertilizer application should be suited to the vine requirement.

Other important considerations are:

1. During the first year (on the year of planting)1/3rd of the dosage only should be applied during September.
2. 2/3rd in the second year in two equal splits (i.e., one during May-June and other during September- October).
3. The full dose is given from 3rd year onwards.
4. The fertilizers have to be applied in two split doses.
5. Fertilizers should be applied only when there is sufficient soil moisture.
6. The fertilizers are applied at a distance of about 30 cm all around the vine and covered with a thick layer of soil.
7. Care should be taken to avoid direct contact of fertilizers with the roots of pepper.
8. If the soil is highly acidic 500g lime per vine also applied in alternate years. Being a surface feeder, most of the feeding roots are distributed on the top 50-60cm layer of the soil.

Experiments conducted in AICRP on Spices highlighted the fertilizer requirement under each situation (Table 2).

Table 2. Fertilizer recommendations for black pepper developed for different regions under AICRP on Spices

Region / State	NPK (g/vine)
Panniyur and similar areas	50 : 50 : 200
Medium fertile soil	100 : 40 : 140
Arecanut and pepper mixed cropping system for heavy rainfall Sirsi region of Karnataka	200 : 80 : 280
Karnataka (under irrigation)	150 : 60 : 210
Andhra Pradesh (under rainfed conditions)	50 : 50 : 150
Chintapalli area of Andhra Pradesh	100 : 60 : 160
Lateritic soils of Kerala where soil N and K are low	140 : 55 : 270

The above table insists site specific application of essential instead of a blanket recommendation. This is highlighted by many workers especially for K response. Pillai et al.(1987), after conducting field trials with Panniyur-1 pepper, found that 200 g of K_2O per vine was optimum dose for obtaining maximum yields.Sadanadan (1993) reported that 270 kg K_2O /ha was the optimum for obtaining high yields in pepper by fitting response function (Fig.1).

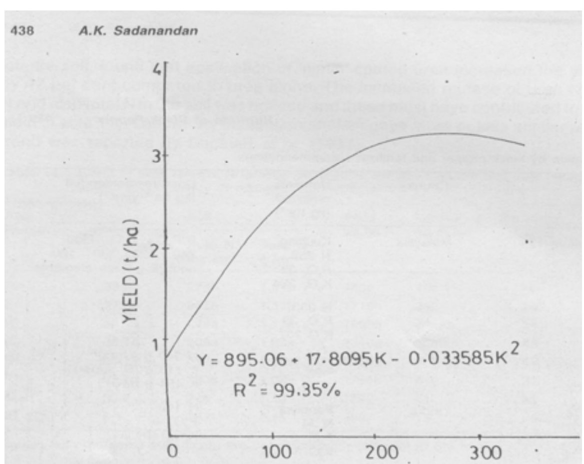


Fig 1. Yield response curve for K application in black pepper

Experiments conducted at NRCS have shown that application of Ca and Mg increase the exchangeable Ca and Mg in the soil as well as in the plant indicating the necessity of these elements in balanced dose of black pepper (Table 3). Therefore, application of lime at 600 g per vine during April-May in alternative year is recommended.

Table 3. Effect of application of Ca and Mg on soil organic matter, soil and leaf status of Ca and Mg

Treatment	Organic matter (%)	Soil Ca (mg/kg)	Leaf Ca (g/kg)	Soil Mg (mg/kg)	Leaf Mg (g/kg)
check	2.75	268	27.0	64	2.8
N_{50}:P_{50}:K_{140}	3.35	986	22.0	46	3.0
N_{50}:P_{50}:K_{140} : Ca $_{50}$:Mg $_{0}$	3.01	1278	34.0	45	2.9
N_{50}:P_{50}:K_{140} : Ca $_{0}$:Mg $_{50}$	3.18	742	22.0	65	3.5
N_{50}:P_{50}:K_{140} : Ca $_{50}$:Mg $_{50}$	3.35	1368	24.0	79	2.8

In early years of cultivation, prawn dust , fish and bone meal, farm yard manure, liquid cattle manure, compost, castor, soyabean, cotton seed, coconut and groundnut cakes are used besides green leaves to replenish the soil nutrient status. Liberal manuring with a mixture of cowdung, compost and oil cakes increased the yield under Assam conditions (Choudhury, 1947). Studies conducted at IISR, Calicut also highlighted the importance of use of organic manures particularly goat, poultry and pig (Sadanandan and Hamza, 1999). Further studies conducted at IISR, Calicut also highlighted the significance of INM in pepper (Table 4). Another experiment was conducted on eight year old pepper vines Panniyur 1(P1) and Panniyur 2 (P2) on the INM aspects of pepper at TNAU. The results revealed that application of *Azospirillum*, FYM and chemical fertilizers as N, P and K in addition to FYM resulted in the highest dry berry yield in pepper (Table 5) .

Table 4. Effect of integrated nutrient management in pepper

Treatment	Yield (t /ha)	Piperine (%)	Oleoresin (%)
Check	2.33	6.94	9.19
NPK	3.62	6.74	9.08
FYM+CC+NPK	2.98	7.12	7.11
FYM+CC+1/2 NPK+BF	4.03	6.99	7.08
CD (P=0.05)	0.41	0.15	0.19

Table 5. Organic and Biofertilizers on yield of Black Pepper

Treatment	Dry Yield(Kg/vine)	
	Panniyur 1	Panniyur 2
T_1-50% N as FYM +Azospirillum+50% P as inorganic +P solubilizers +100%K as inorganic	1.001	2.077
T_2-50% N as FYM + Azospirillum + 50% N and P as inorganic + Azospirillum + P solubilizers + AMF+100%K as inorganic	1.355	1.427
T_3- Recommended package of practices	1.216	1.097

2. Cardamom

The major soils of cardamom area come under the order alfisol with pH from 5 to 6.5 and organic matter 3.2 to 7.8 percent. Deep soils with good drainage are well suited.

Cardamom is commonly cultivated as undergrowth of shade trees in the forest generally high in fertility status due to addition of leaf fall and recycling where on an average, 5-8 tonnes of dry leaves fall from shade trees annually in a hectare of cardamom estate adding 100-160 kg nitrogen, 5-8 kg phosphorus, 100- 160 kg potash, 10-16 kg calcium and 25-40 kg magnesium per hectare, taking a modest estimate leaf nutrient status of forests litter as N 2.0 per cent, P_2O_5 0.1 per cent, K_2O 2.0 per cent, CaO 0.2 per cent and MgO 0.5 percent, respectively. These shade trees add to the surface soil, the nutrients they take up from lower horizons through leaf shedding and thus help in maintaining a fairly high fertility particularly nitrogen status and a favorable soil pH. The shade trees thus have a dual function- the regulation of solar radiation and maintenance of soil fertility (Korikanthimath, 1994). Survey in major cardamom growing areas of Kerala, Karnataka and Tamil Nadu reported that 68% soils are deficient in zinc, 49% deficient in boron, 28% deficient in Mo and 9% deficient in manganese (Srinivasan *et al*. 1998). Micronutrient deficiency in cardamom growing areas is one of the limiting factors of cardamom production as average productivity of cardamom could reach only 120 kg/ha in spite of regular NPK application.

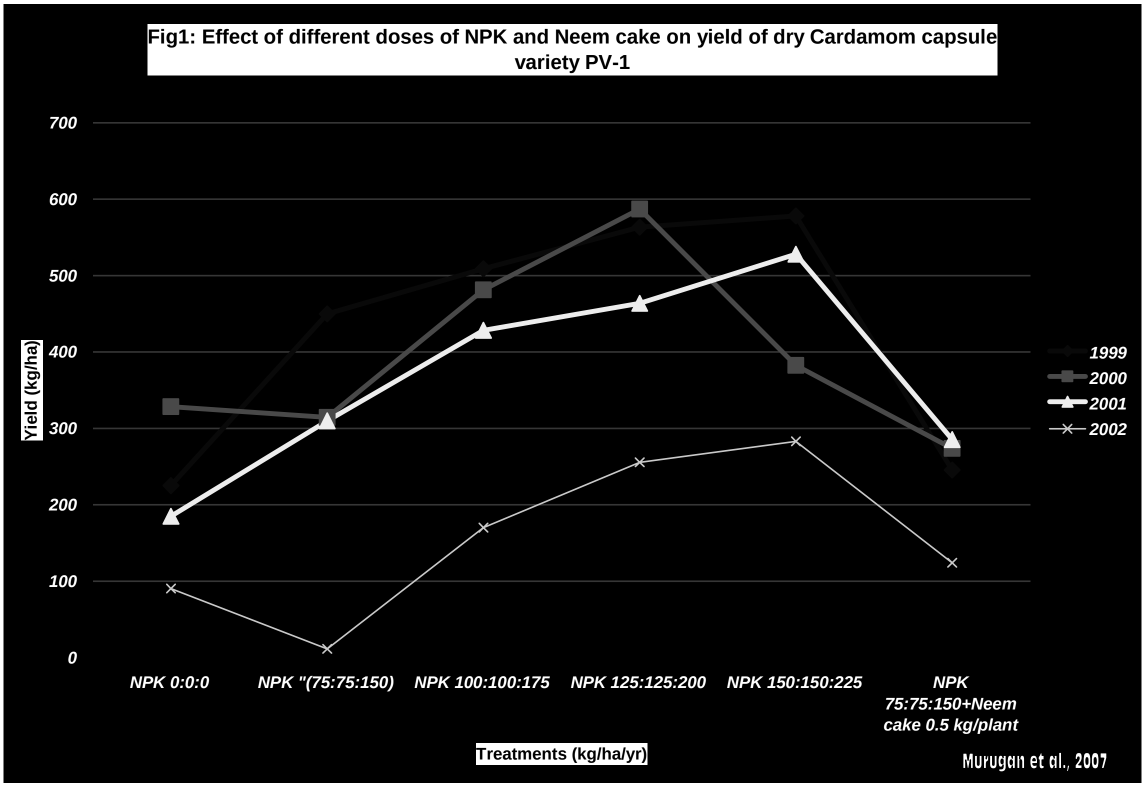
Cardamom is considered as a nutrient exhaustive crop. The total uptake by bearing clumps were 26 kg N, 4.4 kg P, 52 kg K, 14 kg Ca and 3.5 kg Mg per hectare(Kulkarni *et al*. 1971).The ratio of uptake of N,P,K, Ca and Mg is as 6:1:12:3:0.8 respectively. It has been also estimated that for production of one kg cardamom capsule, 0.122 kg N, 0.414 kg P, 0.20 kg K are removed by the plant which highlighted the need for judicious nutrient management practices.

Besides, continuous cultivation of cardamom on the same piece of land leads to depletion of nutrients resulting in poor growth and yield. Studies conducted over a period indicated that there is a steady absorption and utilization of nutrient through out the life cycle of cardamom, and for sustained productivity regular fertilizer application is essential. Considering all these factors, various fertilizer recommendations are made by different cardamom growing states (Table 6).

Table 6. Fertilizer recommendations for cardamom developed for different regions

Region / State	NPK (kg/ha)
Mudigree , Karnataka	75 : 75 : 150
High density planting, (5000 plants/ha) Karnataka	120 : 120 : 240
Pampadumpara, Kerala	100 : 100 : 175
Tamil Nadu	75: 75: 150 in two splits during June-July and October – November

Application of fertilizer nutrients at the rate of 125: 125: 200 kg/ha/year in two splits (just before and after summer monsoon) increased the yield significantly under Pampadumpara rainfall climatology (Murugan *et al.* 2007) (Fig.2).



Studies also confirmed that boron and molybdenum play an important role along with other management practices in increasing yield. Application of boron in the form of disodium tetraborate @ 20 kg/ha and molybdenum in the form of sodium molybdate @ 0.25kg/ha mixed with appropriate quantity of FYM @ 1kg/plant applied with onset of monsoon increased cardamom yield by 20%. Organic manures like compost or cattle manure may be given @ 5kg/clump. Neem oil cake may also be applied @ 1kg/clump. Application of 500 or 750 ppm of zinc (Zinc sulphate) foliar application is found to enhance yield and quality of cardamom (Srinivasan *et al*. 1998). Based on DRIS norms Sadanandan *et al*. (2000) found that the optimum levels for high yield are Fe 253 ppm, Mn 371 ppm, Zn 33 ppm, Cu 28 ppm and Mo 0.56 ppm.

3. Ginger

Ginger adapts widely to different soils like sandy loams, clay loams and literate soil but virgin forest soils that are rich in fertility are ideal. Higher yield requires well drained and deep friable soils. Shallow soil can also be used satisfactorily by proper bedding and mulching. The development of ginger follows three distinct growth phases namely active vegetative growth (90-120 DAP), slow vegetative growth (120-180 DAP) and senescence (180 DAP to harvest) in which the rhizome development continues till harvest (Sushama and Jose, 1994)). The uptake of N, P and K in leaf and pseudostem increase up to 180^{th} day and then decrease, whereas that of rhizome uptake steadily increases till the harvest. Ginger rhizomes were mainly N and K exhausting, intermediary in P and Mg removal and the least in Ca removal (Nagarajan & Pillai, 1979). A heavy ginger crop removes 35-50 kg P/ha).

Fertilizer response of ginger varies with variety, soil type and climate and hence the fertilizer dose also vary in different states of India (Table 7).

Table . 7 Fertilizer recommendations made in different regions/ states for ginger

Region / State	FYM (t/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Kerala	10-30	50	50	100
Orissa		125	70	150
Punjab		100	50	50
Karnataka		150	75	50

Organic nutrition has been reported to increase the yield and improve the quality of ginger. Ginger performs well with good supply of humus and organic matter, which is positively correlated with yield. The various organic sources used for ginger cultivation In India are FYM, poultry manure, press mud, oil cakes and bio fertilizers. The quantity of organic manures applied varies between 5-30t/ha, depending upon the availability of the material and cost. However, cultivators of Maharashtra apply heavy dose of FYM to the extent of about 40 to 50t/ha. Application of organic cakes increased nutrient availability, improved physical condition of the soil, increased the yield and oleoresin production and reduced the rhizome rot incidence. However recently through AICRP on Spices revised its recommendations for various states as indicated in Table 8.

Table 8. Manure and fertilizer recommendations developed for ginger through AICRP on Spices

Region / State	Fertilizer / Manure
Kerala	FYM 30 tons/ha, NPK 70: 50: 50kg/ha. The entire dose of P and K are applied at planting. Half the quantity of N is applied at 60DAS. The remaining quantity of N and K are applied at 60DAS.
Karnataka	FYM / compost 25 tons/ha, NPK 100: 50: 50 kg/ha. The entire dose of P and K is applied at planting, Half quantity of N is applied at 30 40 DAS and other half at 60-70 DAS.
Orissa	FYM 25 tons/ha, NPK 125: 100: 100 kg/ha. Full P and half K applied as basal in furrows before planting and N and K in 2 splits at 45^{th} and 90^{th} day.
Himachal Pradesh	FYM 20-30tons/ha, NPK 100: 50: 60 kg/ha. Superphosphate and potash are applied at the time of planting and N in 3 equal doses first at the time of planting and subsequent 2 doses in 1 month interval, K_2O also applied in splits half at sowing and other half at rhizome initiation.
Bihar	NPK @ 60: 60:120 kg/ha
Andhra Pradesh	75: 50:50 N, , P_2O_5, K_2O kg/ha
Chattisgarh	NPK @ 150: 125: 125 kg/ha

Application of micronutrients such as Zn, B and Mo @ 5, 2 and 1 kg/ha also increased rhizome yield by 48 per cent (5.2t of dry rhizome/ha) and oleoresin content over control.

4. Garlic

Garlic is an important crop grown in the hills of Tamil Nadu. The recommended application is 50t /ha of FYM, 75, 75, 75 kg/ha of NPK+ Neem cake 1t/ha + 50kg of $MgSO_4$ /ha. Rubbering is a serious problem and whenever this disorder is noticed, the following recommendation can hold good. 120: 50:50 kg NPK + $ZnSo_4$ @ 12.5 kg and biofertilizers (Azospirillum and phosphobacterium) @ 2kg each per hectare (Table 9) (Mahendran & Kumar, 1996).

Table 9. Effect of biofertilizers on Garlic

Treatment	Recommended dose	Yield / ha	Nutrient Uptake (Kg/ha)		
			N	P	K
T1	120:50:50 Kg N&K and $ZnSo_4$ @12.5Kg/ha	5.52	207	39.2	184
T2	120:50:50 Kg N&K and $ZnSo_4$ @12.5Kg/ha + biofertilizers (Azospirillum and Phosphobacterium @2Kg each/ha	6.35	240	45	205

5. Vanilla

Decomposed mulch is the main source of nutrients to vanilla. It also retains enough moisture for the vines and gives a loose structure for the roots to spread out. Therefore, it is very important that easily decomposable organic matter is deposited around the vines at two or three times in a year. However, care should be taken not to apply animal manures, as the orchids in general, do not favor them.

The quantity of fertilizer to be applied may vary according to the fertility status of the soil. However, general recommendation is 40 to 60 g N, 30 g $P_2 O_5$ and 60 to 100 g K_2O per grown up vine annually. If fertilizer is given in two or three splits, it will increase the efficiency of uptake. Vanilla responds well to foliar applications and therefore it is recommended that a part of the fertilizer dose to be given as foliar spray before the flowering season.

Nutritional studies carried out at Indian Cardamom Research Institute, Pampadumpara has indicated that vanilla yield can be enhanced by soil application of 20: 10: 30 g NPK per vine per year and foliar application of urea, single super phosphate and muriate of potash at the rate of 1.0, 0.5 and 1.5 % respectively during January, May and September. Fertigation, employing conventional and water soluble fertilizer is known to improve the yield by 14% with harvesting of more percentage of “A” grade pods (Kumar, Personal communication, 2002).

6. Seed Spices

Coriander

Coriander is a tropical crop and can be cultivated as a Rabi crop. A dry weather favours high seed production. Irrigated coriander can be cultivated almost all types of soil by giving sufficient organic manure. Unirrigated crop survives only on heavier type of soil having good water retention capacity.

For getting economic yield of coriander N @ 20-30 kg, P 40 kg and K_2O 20 kg/ha along with 10 tonnes of FYM as basal dose are recommended under Andhra Pradesh condition. In Madhya Pradesh recommendation of NPK is @ 10, 30, 20 kg/ha for irrigated crop and 10 kg each of N & P/ha for rainfed drop. Thakar *et al.* 1991 reported that application of 60 kg N/ha in two equal splits, half at sowing and another 60 days after sowing gave maximum yield. Tamil Nadu recommends FYM 10t/ha, 20: 40: 20 NPK kg/ha. In respect of other minor seed spices, Gujarat and Rajasthan are the leading states and their recommendation are presented in Table 10.

Table 10. Fertilizer recommendations for seed spices in different growing regions

Region	Cumin				Fennel				Fenugreek			
	FYM t/ha	N (kg/ha)	P (kg/ ha)	K (kg/ ha)	FYM t/ha	N (kg/ ha)	P (kg/ ha)	K (kg/ ha)	FYM t/ha	N (kg/ ha)	P (kg/ ha)	K (kg/ ha)
Gujarat	-	25	20	20	25	30	30	-	-	20	60	30
Rajasthan	-	30(2 splits)	-	-	-	90 (3 splits)	-	-	-	20	50	-

Rethinam & Sadanandan(1994)

7. Tree spices

Tamil Nadu and Kerala Agricultural University recommended the following balanced fertilization for these crops (Table 11).

Table 11. Balanced fertilizer recommendations for tree spices

Region	Nutmeg			Clove			Tamarind		
	FYM Kg/ tree	**N : P : K g/tree**	**biofertilizer g/tree**	**FYM Kg/tree**	**N : P : K g/tree**	**biofertilizer g/tree**	**FYM Kg/ tree**	**N : P : K g/tree**	**Bioferti -lizer g/tree**
Tamil Nadu									
i. First year of planting	15	20: 20: 60	-	15	20: 20: 60	-			
ii. Adult trees	50	300:300 : 960	50 g in each of Azospirillum and phosphobacteria	50	300 : 300 : 960	50 g in each of Azospirillum and phosphobacteria	25	200: 150 : 250	-
Kerala									
i. First year of planting	15	20: 18 : 50	-	15	20 : 18 : 50	-	-	-	-
ii. Adult trees (15 years)	50	500:250: 1000	-	50	300 : 250 : 75	-	-	-	-

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Balanced Fertilization for Turmeric

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Turmeric is considered as a major and sacred spice of India and is exploited for its manifold uses. India is the leading producer, consumer and exporter of turmeric in the world. Curcumin (diferuloylmethane) is the major principle responsible for the yellow colour and it is present normally at a range of 3–4% in the rhizomes. It is shown to have excellent pharmaceutical attributes with its antioxidant, antiarthritic, antimutagenic, antitumorous, antithrombotic, antivenomous, antimicrobial properties and acts against Alzheimer's disease. Research on turmeric is primarily focused on improving rhizome yield and quality attributes. Besides improved cultivars, good nutrient management especially balanced fertilization is of paramount importance to sustain productivity and quality.

Turmeric is considered as a nutrient exhaustive crop. It is a heavy feeder of N and K nutrients and comparatively, K uptake is higher than N (Table.1).

Table 1. Uptake of Nutrients by Turmeric at Harvest

Location	**Soil Type**	**Nutrients (N: P_2O_5: K_2OKg/ha)**			**Reference**
Kasargod	Laterite	124	30	236	Nagarajan and Pillai (1979)
Vellanikkara	Laterite	72-115	14-17	141-233	KAU (1991)
Bhavanisagar	Sandy loam	166	37	285	Sivaraman (1992)
Coimbatore	Clay loam	187	37	327	Sivaraman (1992)

According to Saifudeen (1981), the uptake of nutrients increased with the increase in dry matter production and generally the phase of active vegetative growth is the period during which there is maximum uptake of nutrients. Further, it was evident from studies conducted that the uptake of nutrients was higher up to third month for potassium, up to fourth month for nitrogen and up to fifth month for P indicating the need for earlier application of N, P and K fertilizers for improving the plant growth (Rao and Rao, 1988). Turmeric is reported to remove 16.5 kg N, 3.1 Kg P_2O_5 and 44.5 kg K_2O per tonne of produce (PPIC, 2001). Many studies have clearly brought out that the nutrient uptake is also influenced by factors such as size and type of planting material, climate, soil fertility level, water quality, crop growth stages, shade levels and cropping systems.

Fertilizer recommendations

Different states recommend various NPK dosages for turmeric. Researchers have also made specific recommendations for a locality or a variety in many instances (Tables 2 &.3).

Table 2. Fertilizer Recommendations for Turmeric in different states in India

State	FYM (t/ha)	N	P_20_5	K_2O	N: P_2O_5:K_2O ratio	Reference
Andhra Pradesh - Rudrur	25	250	80	200	3.12: 1 : 2.5	APAU (1989)
Andhra Pradesh - Anathrajpet	25	300	125	200	2.4:1:1.6	APAU (1989)
Assam	20	30	30	60	1:1:2	Rathaiah (1986)
Kerala	40	30	30	60	1:1:2	KAU (2002)
Maharshtra	NA	120	60	60	2:1:1	(Yamgar and Pariwar (1991)
Meghalaya	NA	40	20	60	2:1:3	Govind *et al* (1990)
Mizoram	NA	90	60	90	1.5:1:1.5	Saha (1988)
Tamil Nadu	15-20t	125	60	108	2.1: 1:1.8	TNAU (2004)
Uttar Pradesh	NA	100	60	60	1.6:1:1	Singh & Singh (1988)
A- not mentioned / information not available						

Table 3. Recommendations based on soil type and variety in India

Soil Type	Variety	Location & State	N: P_2O_5:K_2O (Kg /ha)	N:P_2O_5:K_2O applied ratio	Reference
Clay loam, laterite	Armoor	Wynad, Kerala	100:100:120	1:1:2	Muralidharan and Balakrishnan (1972)
Laterite	Sudharsana & Suguna	Calicut, Kerala	60:60:120	1:1:2	NRCS (1991,1992)
Red Sandy Loam	Lakadong	Barapani, Meghalaya	60:40:60	1.5:1:1.5	Govind *et al.* (1990)
Red Sandy Loam	CL-325	Tirupathi, Andhra Pradesh	375 :175:237 .5	2.14:1:1.9	Rao and Reddy,(1977)
	Gorakhpur & Mydukur		187.5:62.5:125	3:1:2	Rao and Swamy, (1984)
Sandy Loam	Local	Bhavanisagar, Tamil Nadu	124:30:51	4.1: 1: 1.6	Subramaniam *et al.* (1978)

Research on balanced fertilization in turmeric

At TNAU, many experiments were conducted to study the influence of balanced fertilization in turmeric.

Nitrogen

Studies taken up at Coimbatore,Tamil Nadu on effect of nitrogen on turmeric revealed that the response was higher at 100 to 140 kg/ha (Ahmed Shah and Muthuswamy, 1981; Balashanmugam and Chezhiyan, 1986). On the contrary, in another study taken up at Bhavanisagar, Erode district, Tamil Nadu, Muthuvel *et al.* (1989) found no significant response to higher nitrogen levels of 120 or 150 kg/ha when compared to 90 kg/ha. The differences in response in these two studies reflect probable influence of soil conditions and varieties involved on nutrient uptake.

Table 4. Yield and Yield components of turmeric as influenced by Nitrogen levels

Treatments	**Yield of fresh rhizomes (t/ha)**	**Per cent increase over control**
No Nitrogen (control)	14.60	--
N at 100 kg /ha	22.32	52.88
N at 120 kg/ha	21.98	50.55
N at 140 kg /ha	22.91	56.92
N at 160 kg/ha	21.92	50.14

Note : 10 t FYM + 60 kg in each of P_2O_5 and K_2O was common for all the treatments

(Ahmed Shah and Muthuswami, 1981)

Table 5. Influence of varied doses of N and K on turmeric at Bhavansisagar

N levels	**Raw Rhizome yield (t/ha)**			**Mean**
	84-85	85-86	86-87	
N 90 kg/ha	51.1	33.4	34.9	39.8
N 120 kg/ha	51.1	33.2	38.2	40.8
N 150 kg/ha	53.4	33.6	38.4	41.8
SE	2.7	1.25	3.38	
CD	NS	NS	NS	

K levels	**Raw Rhizome yield (t/ha)**			**Mean**
	84-85	**85-86**	**86-87**	
K60 kg/ha	50.9	33.1	36.3	40.1
K90 kg/ha	52.8	33.8	38.1	41.6
SE	2.7	1.25	3.38	
CD	**NS**	**NS**	**NS**	

(Muthuvel *et al.* 1989)

In a pot culture study involving labeled ^{15}N, Jagadeeswaran *et al.* (2004) demonstrated that split application of nitrogen keeps the nutrient availability throughout the active growth stages. Maximum crop recovery and soil retention coupled with minimal loss of N can be achieved with application of N in four splits.

Phosphorus

In general the response to applied phosphorus seems to be lesser than compared to N and K nutrients. In studies taken up at Andhra Pradesh, the response to applied phosphorus has been reported up to 175 kg /ha in combination with other nutrients (Rao and Reddy, 1977). The requirements of phosphorous in Tamil Nadu seem to be lesser and in general 60 kg P_2O_5/ ha is recommended. Phosphorous is not applied as top dressing but given as a basal dressing as its uptake is better and higher in the early growth phase of the crop.

Potassium

Potassium application in turmeric has significantly increased plant height, number of tillers, number of leaves and number of primary and secondary rhizomes (Rathinavel, 1983). Though potassium application at 240 kg / ha registered highest numbers for the above parameters, increases were not significant beyond 180 kg K_2O /ha at Coimbatore (Mohan Babu 1981, Rathinavel, 1983).

Rathinavel (1983) also observed a steady increase of curcumin, oleoresin and essential oil content of the rhizome upto 180 kg K_2O /ha. However, Ahmed Shah *et al.* (1988) registered higher curcumin content in mother rhizomes and primary rhizomes at a dosage of 60 or 90 kg K_20/ ha than at a higher dosage of 120 or 150 or 180 kg/ ha.

Muthuvel *et al.* (1989) recommended 60 kg K_2O /ha for CO.1 turmeric at Bhavanisagar conditions as they did not observe any significant difference over the application rate of 90 kg K_2O /ha (Table 5).

Field experiments were conducted during 1987-88 at Agricultural Research Station, Bhavanisagar to study the effect of potash fertilization on growth and yield attributes of BSR 1 variety. The experiment involved three dosages of potash viz., 30, 60 and 90 kg applied in either full or in three or four or five splits. A common dosage of 120 kg N/ha was applied in five splits at monthly intervals up to 120 day and 60 kg P_2O_5/ha applied basally. It was found that the application of 90 kg K_2O/ha in four splits resulted in higher uptake and yield of 28.9 t/ha (Balashanmugam and Subramanian, 1991).

These studies illustrate that the demand and response to nutrients can be variety / location specific.

Table 6. Influence of K levels on Yield of BSR.1 turmeric and K uptake

K levels	Yield / ha (t)	Total uptake of K by whole rhizomes at Harvest (Kg/ ha)	Total uptake of K by whole plant at Harvest (Kg/ ha)
30 kg K_2O/ha	23.5	226.3	421.5
60 kg K_2O/ha	24.9	299.2	387.2
90 kg K_2O/ha	29.7	262.1	320.9

(Balashamugam and Subramanian, 1991)

Micronutrients

Micronutrients such as iron, zinc and boron are required in sufficient levels for proper growth and development of turmeric and very often the crop suffers when these nutrients are limiting. Iron deficiency is usually observed in turmeric grown in calcareous or alkaline soils. The symptoms of iron deficiency first appear as interveinal chlorosis of young leaves, which then leads to chlorosis of entire leaf and make it to turn almost white. Application of $ZnSO_4$ at the rate of 15 kg / ha was recommended to overcome Zinc deficiency (Velu, 1988; Balashanmugam *et al.* 1990).

A general recommendation for correcting deficiency of micronutrients especially Boron, Iron and Zinc has been prescribed (TNAU, 2004). This involves application of 375 g Ferrous sulphate, 375 g Zinc sulphate, 375 g Borox, 375 g of Urea dissolved in super phosphate slurry solution (15 kg super phosphate is dissolved in 25 lit of water stored overnight and the supernatant solution is made upto 250 lit). Spraying of the above solution twice at 25 days interval is recommended.

Senthil Kumar *et al* (2004 a) computed nutrient norms for N, P, Ca, Mg, Na, S, B, Zn, Cu, Fe and Mn in turmeric by Diagnosis and Recommendation Integrated system (DRIS) and Compositional Nutrient diagnosis (CND) approaches from a data base generated by sampling 500 commercial turmeric growing plots across Erode district, Tamil Nadu. The evolved CND norms for important major and important micronutrients are given in Table 7.

Table 7 . Optimal CND norms for leaf nutrient concentration in Turmeric

Nutrient	Deficient	Optimum Range	Excess
N (%)	<1.19	1.20-2.99 %	>3.00
P(%)	<0.44	0.45-1.31 %	>1.32
K(%)	<3.61	3.62-6.99%	>7.00
Ca (%)	<0.19	0.20-0.31%	>0.32
Mg (%)	<0.67	0.67-1.24%	>1.25
Zn (ppm)	45.3	45.4-92.4	>92.5
Fe (ppm)	313	45.4-92.4	>92.5
Mn (ppm)	65.9	65.8-250	>251
B (ppm)	<14.4	14.5-27.2	>27.3

(Senthil Kumar *et al.* 2004a)

They reported zinc and boron deficiencies to the extent of 72 and 62 % respectively and that the availability of these two micronutrients were suppressed due to higher pH, Na , Ca and Mg . Based on computed nutrient imbalance index (NII) values of the leaves, 17 % of the growing areas were classified as severely limited by mineral nutrition and about 32 % of the growing areas were identified as having possible imbalances. Based on the order of requirement the predominance of Zn deficiency was well indicated by CND than DRIS.

In a study to find out the effect of Zn enriched organic manures on yield and curcumin content of turmeric at Agricultural Research Station Bhavanisagar, it was found that application of Zn SO_4 at 50 kg / ha and $FeSO_4$ at 100 kg / ha as zinc and iron enriched coir pith (1 t /ha) as basal dressing along with recommended dose of NPK + FYM and a zinc solubilizing bacteria (ZSB- *Bacillus* sp) resulted in higher rhizome yield and better soil and plant nutrient status. Application of FYM, FYM+ ZSB and soil and foliar application of 0.5%Zn SO_4 and 1%$FeSO_4$ enhanced the uptake of all the major nutrients right from the early phase of crop growth to harvest (Senthil Kumar *et al*. 2004 b).

Table 8. Effect of FYM and Zinc in Turmeric

Treatment	Rhizome Yield (t/ha)	Curcumin content (%)
M1-control	23.5	4.04
M2-NPK+FYM	25.6	4.38
M3-NPK+FYM+Zn solubilizer	28.6	4.53

(Senthil Kumar *et al*. 2004 b)

Integrated Nutrient Management

In conventional turmeric farming, usually large quantities of organic manures are applied to the field. The organic manures such as FYM, oil cakes, vermicompost etc have been known to play a crucial role in maintaining soil health and beneficial microbial population leading to improved soil characteristics and enhanced fertility levels. It is a common practice in many turmeric-growing areas in Tamilnadu to add tank silt to improve soil fertility. Sheep penning is also practiced to improve soil fertility. The general recommendation in many states is 25- 30 t of FYM or compost along with inorganic fertilizers. In addition to organic manure, addition of plant residues also helps to improve the fertilizer use efficiency in turmeric. Addition of organic matter to the soil by way of incorporating green manures and mulching with leaves of daincha (*Sesbania aculeata)* and sunnhemp (*Crotalaria juncea*) were found to be useful. In rainfed cultivation at Kerala (Wyanad), application of 100 kg N/ha along with a basal dose of 15 t/ha of FYM and 50 t of green leaves mulch applied at planting and again 60 DAP was found to maximize yield (Muralidharan and Balakrishnan, 1972).

Trials conducted at TNAU also highlight the importance of INM in turmeric. Balashanmugam *et al.* (1989) reported 37 per cent higher fresh rhizome yield by addition of 25 t FYM/ ha over the recommended NPK doses applied as inorganic form.Sadanandan and Hamza (1998) from Kerala reported higher curcumin yields with application of neem cake, groundnut cake and cotton cake when compared to NPK fertilizers but rhizome yield was highest with NPK fertilizers as compared to the oil cakes.

In a study conducted at farmer's field by Krishnamurthy *et al*. (1999) at Gobichettipalayam of Erode district, Tamil Nadu in red sandy loam soil with low available Nitrogen (192 kg/ha), medium phosphorus (12.6 kg/ha) and high potassium (296 kg/ha) , the highest fresh rhizome yield of turmeric was registered in the treatment of NPK with poultry manure as compared to NPK + sheep manure or FYM or cattle manure or compost. Digested coir pith compost was also found to increase the yield of turmeric rhizomes (Krishanamoorthy *et al*. 2002).

Selvarajan and Chezhiyan (2001) studied the effect of Azospirillum along with graded doses of nitrogen on growth and yield of turmeric cultivar BSR 2 and indicated that 50 % of nitrogenous inorganic fertilizer could be saved by application of Azospirillum @ 25 kg /ha. Addition of biofertilisers viz., Azospirillum (10kg /ha) and Phosphobacteria (10 kg /ha) along with FYM 15 t /ha and digested coir compost (10t /ha) and 125 : 60 : 90 kg of NPK was reported to enhance the uptake of nutrients and physiological parameters in turmeric accession CL 147 leading to higher yields. This was attributed to better mobilization of nutrients by increased level of microbial population in the organically amended soil (Padmapriya, 2004).

Fertigation

Not much published information on the influence of fertigation studies is available. However, fertigation studies taken up at ARS, Bhavanisagar revealed the significance of fertigation (Table 9).

Table 9. Influence of Irrigation & Fertigation levels on Turmeric yield (t/ha)

Irrigation & Fertigation Levels	100 % N& K	75 % N&K	50 % N & K	Mean
Irrigation at 80 % PE	32.91	34.76	33.62	33.76
Irrigation at 60 % PE	33.26	33.69	34.12	33.69
Irrigation at 40 % PE	29.70	29.98	29.49	29.72
Mean	31.96	32.81	32.41	
Surface irrigation, 5 cm, 0.90 IW/CPE, 100% of N & K through soil	22.50	CD – 3.54		

The required N and K fertilizers were divided into 20 equal splits and applied at weekly intervals through fertigation commencing from 30 days after sowing. The studies revealed that at even at 50 % of the recommended dosage of N & K when supplied through drip resulted in higher yields as compared to application of 100 % recommended NPK dose through soil application of fertilizers and surface irrigation.

This study clearly reveals that it is possible to enhance nutrient and water use efficiency and improve yield by adopting fertigation in turmeric.

Future Thrust

There has been a good progress made so far in assessing and understanding major and micronutrient requirements, uptake pattern, influence of organic sources and biofertilizers on turmeric. Not many studies have been taken up on fertigation. While much information on fertilizer requirements of turmeric has been generated across the country, popularization of correct nutrient management practices among growers is essential.

As in the case of many other important field or horticultural crops, research on nutrient inflows and outflows and nutrient balance estimates in various turmeric growing regions is lacking. If proper estimates could be arrived at, then it may be possible to improve the level of nutrient use efficacy in these areas by strategic research and reduce wastage and pollution.

Studies have revealed that it is possible to effectively employ DRIS and CND norms to arrive at Nutrient Imbalance Indices. Similar studies are necessary in all turmeric growing zones to identify and solve nutrient related problems. It is necessary to popularize fertigation and INM practices, which have proven to improve yield and enhance nutrient use efficiency.

Research on response to graded dosages of nutrients in problem soils and studies on influence of addition of organics, bio regulators and other amendments in nutrient uptake is worth pursuing to formulate effective nutrient management strategies.

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Balanced Fertilization for Coconut

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Coconut is cultivated in 159 districts, 17 states and 3 Union territories in India , accounting for 1.947 million hectares with an annual production of 14811 million nuts and an average productivity of 7608 nuts /ha. The southern states of Kerala, Tamil Nadu Karnataka, and Andhra Pradesh are the leading states in coconut production, however, the average productivity of Kerala and Karnataka is lower than the average national productivity of 7608 nuts/ha, while rest of the states exceed the same. Coconut is a small holder's crop, as nearly 90 % of the five million coconut holdings in the country are less than one ha in size. In Kerala 89.90 %, Karnataka 95.4%, Tamil Nadu 95.20 % and Andhra Pradesh 97.90 % of the holdings are less than one ha. In majority of the cultivated area, palms receive mostly organic manures and later dressings with mineral fertilizers often fail to increase yields to desired levels. Since the crop is mainly concentrated in the small sector, its production is one of the most important activity at the farm level. The average productivity in India for the past 10 years is only around 6200 nuts/ha or less than one ton copra / hectare.

The general variation in productivity is mainly due to variation in climate (number of sun shine hours, rainfall), irrigation, soil type and adoption of cultural practices. The variation in productivity can be further elaborated due to predominance of small and marginal farmers in this sector, rain-fed cultivation, low income coupled with less investment, continuing disease problems in Kerala (root wilt disease) and Tamil Nadu and Andhra Pradesh (Basal Stem Rot (Thanjavur wilt) : *Ganoderma*), pests like Eriophyid mite**,** unprecedented drought conditions (Tamil Nadu), drought and semiarid conditions in parts of Karnataka, low inputs, poor technology adoption, general fertility status of soil, cost of labour in adopting technologies and unscientific management.

These constraints in productivity of coconut gardens will continue to remain and shall be the major issue to be addressed in the years to come (Nampoothiri and Khan, 2002).

Why productivity should be increased?

1. Around 30 % of the palms in the premier coconut growing states are senile and showing declining trend in productivity.

2. Of the 14800 million nuts produced in the country, 50 % is used as raw nut of which 95 % goes for domestic consumption and 5 % for industrial use. While 10 % is used as tender coconut and 35- 40 % is converted as copra which is further used for oil extraction and a fraction as edible copra. Thus a marginal amount of production is available for other value added products for export.

3. More production and change in supply of coconuts will bring changes in processing and marketing sector and pressure to innovate.

4. The technology to produce virgin coconut oil, diet coconut fiber and its health benefits are being realized through out the world (Kabara, 2000; Rethinam *et al.* 2004; Rajan,2006) and in India through the campaigns of the Coconut Development Board**.** This is going to increase the demand for coconut oil more in the western countries and in India.

5. Export and trade analysts say that the demand for lauric oils (63% of which is shared by coconut oil) is bound to increase by 2.3 % a year (Boceta, 2003).

6. Inability of the industry to meet the demand for coconut oil, thereby increase its price in domestic market.

7. Coconut farming will continue to be a major profession and hence its productivity has to be increased to improve the standard of living of the coconut farmers.

8. Studies on the age of plantations and net return in Kerala suggest that it will ideal to replace coconut palms with new plantings after 65 years.

9. The productivity analysis indicates that the over all contribution of area to production is higher than that of productivity. The domestic demand for coconut, copra and coconut oil in India by 2025 AD would be 21971 million nuts, 1241 ('00 mt copra) and 745 ('00 mt oil) (Sairam *et al.*2004).

10. Thus to meet the domestic requirement of coconut and its products , the country needs to further augment its productivity through balanced nutrition, better adoption of technologies in its production, processing and marketing sectors.

Balanced nutrition of the palms is one of the priority areas to be addressed in sustaining productivity. Plants should be provided with the correct balance of nutrients to increase crop yield and quality and to increase farm income productivity. It is also observed that deficiency of any one of the essential nutrients would limit growth and utilization efficiency of other nutrients. Assessing and managing a balanced nutrition for perennial crop like coconut is different from that of annual crops. Information has to be obtained through well planned agronomic experiments over a period of research at nursery stage, pre-bearing and adult stage of the palms.

Balanced nutrition for coconut starts from the nursery itself. The seed nut contains adequate nutrients to meet the growing needs of the plant at least up to field planting stage. As their nutrient reserve form the endosperm decreases from the fourth month onwards after germination and as also indicated by the leaf analysis of the growing parts of seedlings in the nursery, it is stressed in reports from India, Sri Lanka, Philippines and IRHO, Ivory Coast to fertilize the nursery to produce healthy and vigorous seedlings. Application of balanced fertilizers consisting of N, P, K, Ca and Mg to the nursery seedlings improved the vigour and quality of seedlings. The seedlings obtained from seed nuts collected from palms manured with K displayed better vigour and growth than those obtained from un-manured plots (Nelliat, 1973). Further, it is indicated that to produce healthy seedlings, facilitate better establishment, faster growth and early bearing in the main field, application of 40 kg N, 20 kg P_2O_5 and 40 kg K_2O/ha to the nursery was suggested thrice (December, February, April) under west coast conditions.

Nutrient management of palms at pre-bearing age

Young transplanted seedlings require adequate nutrients for better growth on all soils. With a very active root system, they respond well to manuring, grow better and start bearing early. An enhanced rate of leaf production leading to larger number of leaves on the crown results in larger total leaf area, which may probably increase building up of adequate carbohydrate reserves in the stem. Since there is a correlation between chlorophyll content in the leaves, rate of apparent photosynthesis and annual yield, our efforts should be such that the vegetative phase is completed early managed by a good balanced nutrition. Studies suggest that N driven systems are not desirable (Remoney and Smith, 1965) and damage caused by K deficiency in the early stages cannot be fully repaired by later K dressings (Table 1) (Fremond and Ouverier, 1971). Although later applications of K enabled re-establishment of good physiological functioning, the palms which suffered from K deficiency during pre-bearing age remained on an average 15 % less productive than those which never suffered from K deficiency.

Systematic studies at Veppankulam, Tamil Nadu under the All India coordinated research project on palms indicated that application of 0.34 kg N, 0.23 kg P_2O_5 and 0.45 kg K_2O/ palm induced flowering one year ahead of unfertilized-control plots (Hameed Khan, 1993). When the fertilizer dosage was doubled, pre-bearing age was further reduced by four months. In a comparative performance of D x T, T x D and WCT fertilizer application indicated that 50% of D x T palms receiving 500 g N, 500 g P_2O_5 and 1000 g K_2O/ palm flowered in the eighth year while T x D and high yielding WCT palms flowered in 9^{th} year and in unfertilized palms 50 % of flowering stage was not recorded even at the end of 10 th year in any of this cultivars.

Table 1. Timing effects of first potash fertilizer application on the performance of young coconut palms

Year	Characteristics observed	Time of K application	
		From field planting	From bearing age only
1956	No. of fronds	8.89	7.69
1958	Length of frond (cm)	256	233
1959	Girth (cm)	124.1	105.4
1960	No. of fronds in a year	11.7	10.7
1962	kg copra/ ha	2,560	272
1966	kg copra/ ha	2,480	2,272
1970	kg copra/ ha	-	2,096
1961-1970	Cumulative yield (kg /ha)	17,344	12,704

Based on the extensive research conducted at CTCRI, Kassorgode, the need for balanced application to young prebearing palm has been stressed (Table 2).

Table 2. Fertilizer recommendation for Coconut (CPCRI / Kerala)

Age seedling/palm	Nutrients gram/palm/year		
	N	P_2O_5	K_2O
3 month old seedling*	50	40	135
Second year*	160	120	405
Third year*	330	240	910
Fourth year onwards* (Adult palm dosage)	500	320	1200
For sandy soils *(Onattukkara)##*	500	300	1000
*For average management **	*340*	*170*	*680*

* Fertilizers applied in two splits: 1/3 dose in May and 2/3 dose in September-October
** Green leaves or compost 50 kg/palm/year in August-September

apply additional 3 kg Mg SO4/palm/year

TNAU also recommends balanced fertilization for pre-bearing palms (Table 3).

Table 3. Fertilizer recommendation for coconut in Tamil Nadu

Age seedling/palm	**Nutrients gram/palm/year*, ****		
	N	**P_2O_5**	**K_2O**
Second year	140	80	300
Third year	280	160	600
Fourth year	420	240	900
Fifth year onwards (adult palm dosage)	560	320	1200

*Fertilizers applied in two splits: 50 % June-July and 50 % dose in November- December

**Green leaves or compost 50 kg/palm/year in October-November

Source: TNAU Crop Production Manual

Nutrient Management of Adult Palm

Before proceeding further one has to understand the nutrient removal by the palm, its distribution to various parts etc which will serve as a guide for approximating the quantity of nutrients and the proportion in which they are to be applied.

Coconut palm produces fronds and nuts through out the year and hence demands continuous supply of nutrients from the soil. In a coconut system nutrient replacement needs increase at a faster rate than uptake and removal and due to limited root area for absorption, it is important to maintain nutrient supplies at a level of slight luxury consumption (Hameed Khan, 1993).

The nutrient removal values indicate a close agreement on the ratio of N and K removed by the palms (Table 4).

Table 4. Nutrient exhaust by coconut palms reported in different countries

Country	Yield	Nutrients (kg/ha)			Ratio		
		N	P	K	N	P	K
India [1]	175 palms/ha	97.3	21.0	121.1	1.0	0.22	1.24
India [2]	40 nuts/palm 1.2 t copra (173 palms/ha)	56.0	12.8	70.19	1.0	0.23	1.25
Ivory Coast [3]	Hybrid palms (PB 121) 6-7 t copra/ha	174	20.0	249	1.0	0.12	1.43
Sri Lanka [4]	70 palms/ha	10.2	2.4	12.9	1.0	0.23	1.26

In studying nutrient balance and evolving a recommendation one has to consider the substantial proportion of nutrients retained in the growing part of the stem, besides leaves, parts of inflorescence and nuts which are removed from the garden. It is interesting to note that hybrid palms (PB 121) require more N and P as compared to tall palms and utilize higher proportion of absorbed N and P for the production of more nuts (Table 5). In tall palms these nutrients are utilized more or less equally in the production of nuts and for growth. For both cultivars, the K removal through bunches is 78 % of K uptake.

Calcium is utilized more for the production of leaves and stem and least for nuts. About 60 % of Mg removed is utilized for the growth of stem and leaves to meet the photosynthetic needs. The total chlorine exhausted by coconut is equal to that of potassium and equally partitioned for vegetative and reproductive growth of the palm. Its importance is next to K and hence Cl bearing fertilizers assume significance in coconut nutrition.

Sodium and sulphur are more utilized for the growth of stem and leaves than for the development of nuts (Table 5). This comparison of the data of Pillai and Davis (1963) from India and Ouvrier and Ochs (1978) form Ivory Coast suggest that the dominant requirement of the palm is for potassium and probably chlorine. The above data further suggest that regular fertilizer application is necessary to maintain a balanced supply of nutrients for sustained productivity (Hameed Khan, 1993).

Table 5. Coconut nut yield and copra yield as influenced by integrated management practices in root wilt affected palms

Cultivar	Part(s) of palm	Nutrients							
		N	***P***	***K***	***S***	***Ca***	***Mg***	***Na***	***Cl***
West Coast Tall	Stem + leaves	49	50	22	-	77	59	-	-
	Nuts	51	50	78	-	23	41	-	-
PB 121* (MAWA hybrid)	Stem + leaves	38	25	22	70	87	62	63	50
	Nuts	62	75	78	30	13	38	37	50

Application of 340 g N, 340 g P_2O_5 and 680 g K_2O/palm/ year improved the nut yield by 35 % and copra out turn by 44 % in the cultivator's gardens where the palms were hitherto un-manured. Further, where response to fertilizer application was not observed, significant increase was obtained when K level was raised to 900 g K2O/palm/year (John and Jacob, 1959).

In a 3^3 NPK factorial experiment on sandy loam soil at Kasaragod, higher level of N had an adverse effect on copra content while K levels showed positive response (Muliyar and Nelliat, 1971). Further, they reported that potassium improved all the nut characters studied *viz*. weight of whole nut, weight of husked nut, volume of husked nut and copra weight per nut, whereas nitrogen had an adverse effect.

The palms yielding less than 60 nuts annually, the optimum dose of N ranged between 400 and 650 g and that of potash between 890 and 1210 g per palm per year. In a long term fertilizer experiment in red loam soil, Wahid *et al*., (1988) recorded significantly higher nut yield with potassium application. Further, they observed that early bearing was also achieved with increased levels of K application. The yield was 7, 68 and 77 nuts palm^{-1} year^{-1} in the 21st year after planting under no fertilizer, 450 g K_2O and 900 g K_2O palm^{-1} year^{-1} respectively.

In a recent study at Veppankulam in Tamil Nadu potash response to coconut in soils adequately supplied with potassium has been established (Table 6) (AICRPP, 2000).

Table 6. Response of coconut to application of potash (Selected treatments) – Veppankulam

Sl. No.	Treatment	Plant nutrient (%) (Frond 14)		Soil available nutrients (ppm)		Yield nuts/palm
		N	K	N	K	
1	$N_OP_OK_O$	0.91	0.81	164	84	108
2	$N_OP_OK_1$	1.28	0.92	173	99	126
3	$N_1P_OK_1$	1.26	0.96	170	102	149
4	$N_OP_OK_2$	0.98	0.99	144	118	134
5	$N_1P_OK_2$	1.26	1.10	179	122	154
6	$N_1P_1K_1$	1.26	0.96	174	108	159
7	$N_2P_2K_2$	1.62	1.20	276	135	201

N_1 : 500g; N_2 : 1000 g; P_1 : 250 g; P_2 : 500 g; K_1 : 1000 g; K_2 : 2000 g

In coastal sandy soils of the Konkan region of Maharashtra, importance of N on coconut yield was well established from the results of a long term fertilizer experiment. The behavior of N in the nutrition of the palms and its interaction with P and K in the balanced nutrition is well established (Table 7).

A field experiment with Chawghat Orange Dwarf x West Coast Tall (var. Chandra Sankara hybrid) was started in 1988 from the seedling stage with different combinations of N, P and K. Results of 14 years of fertilizer application in different combinations indicated that a combination of 500 g N with 250 g P_2O_5 and 1000 g K_2O per palm per year produced a yield of 155 nuts per palm compared to 49 nuts per palm under control treatment. No further increase in yield was also observed when the fertilizer.

Table 7. Effect of fertilizers on yield of coconut in a long term experiment at Ratnagiri

Treatment/ palm/year	P_2O_5 g/palm/year				K_2O g/palm/year			
	0	225	450	mean	0	225	450	mean
--Yield nuts / palm /year--------------------------------								
N O	32.8	25.3	27.9	25.7	36.9	19.0	30.2	28.7
N 375 g	78.2	87.1	86.1	83.8	90.6	76.4	84.5	89.0
N 750 g	89.8	89.8	88.7	90.3	89.6	76.1	95.3	89.6
Mean	66.9	67.0	68.1	-	67.8	63.5	70.7	-

SE plus for main effect 1: CD at 5 % for main effect 11.9 : SE for interaction of NP and NK 7.1

dose was doubled. Further an increase in 11 nuts was recorded when the N dose was increased to 1000 g N per palm. Application of phosphorus though beneficial in combination with N and K had only marginal effect on yield (Venkitaswamy, 2004). This study also indicates the involvement of time factor in evolving a balanced nutrient schedule for (hybrid) coconut.

Irrigation is widely practiced in the country for sustaining productivity of coconut especially in the east coast of India and depending upon the rainfall pattern in the northern districts of Kerala. One is well aware of the influence of judicious irrigation in enhancing the efficiency of balanced nutrition. Venkitaswamy and Khan (2004) observed that the VHC-2 hybrid palms with recommended dose of fertilizer application (Table 3) when brought under drip irrigation equal to 100% Eo, yielded 130-140 and in situations of water scarcity 122 and 89 nuts palm / year with drip irrigation at 66% Eo and 33% Eo respectively (Table 8). The corresponding quantity of water applied to realize the yields was 13591, 8970 and 4484 litres palm / year. With drip irrigation at 66%, 100% Eo and basin irrigation, the palms were in sufficiency range of nutrition for N and P and in a slightly higher status for K as judged by leaf analysis. The benefit cost ratio for drip irrigation equal to 100 % Eo was 2.11.

Table 8. Summary of yield parameters influenced by different levels of irrigation to coconut VHC-2 hybrid, Aliyarnagar

Treatment Water applied/palm	Mean values for four years VHC hybrid coconut					
	Leaf production	**Functional leaves**	**Bunch production**	**Female flowers**	**Nuts / palm**	**% increase**
No irrigation	13.38	32.48	8.63	174	68	-
Drip 33 % Eo 4485 L*	13.68	33.52	9.83	196	89 (+21)	31
Drip 60 % Eo 8790 L	14.33	36.55	11.5	253	122 (+54)	79
Drip 100 % Eo 11359 L	15.08	38.25	12.78	306	147 (+79)	116
Basin irrigation 13533 L	15.11	37.23	13.03	315	146 (+78)	114

*Exclusive of rainfall contribution of 5848 litres **Source:** Venkitaswamy and Khan (2004)

The necessity and importance of integrated nutrient management is well conceived in coconut. In the perennial crop husbandry practices fertilizing the palms with bulky organic manures is a traditional practice in coconut growing states especially in Kerala. The coconut system offers excellent scope for INM practices in view of the biomass generated with in the system (Biddappa *et al.* 1996). To evolve appropriate technology of INM to improve and sustain productivity of coconut groves utilizing the resources available in different areas, country wide experiments were started under the aegis of the AICRPP during 1996. The interim results of these experiments presented in table 10 are to be viewed on merits for individual centers. A comparison of the results of different areas is not intended here (Table 9). Thomas *et al.* (2006) compiled the information on low cost technologies for sustainable coconut cultivation mostly employing organic resources available in the coconut growing system.

Table 9. Yield of coconut under Integrated Nutrient Management treatments

Treatments	Yield nuts / palm			
	Aliyarnagar Tamil Nadu	**Arsikere Karnataka**	**Veppankulam Tamil Nadu**	**Ratnagiri Maharashtra**
Farmers Practice	171	60	89	70
Recom. Chemical Fertilizers (CF)	180	81	113	91
Composted Coir Pith (CCP)	178	101	*	71**
50 % CCP + 50 % CF	174	99	*	88**
Neem cake + Bone meal + Ash	159	93	99	88
50 % Composted Coir Pith (CCP)	*	*	96	*
CD	NS	24.4	21.76	6.99
CV	13.8	18.7	-	-

Aliyarnager: Res Sandy loam **Arsikere:** Red sandy loam (semi arid) **Veppankulam:** Alluvial soil **Ratnagiri:** Castal alluvium (sandy loam) *** :** Treatments not imposed **** :** Ccoconut wastes cut and spread instead of CCP

The productivity of coconut in Kerala is low mainly because of prevalence of root (wilt) disease, a non-lethal, debilitating malady caused by phytoplasma, a vascular limited pathogen. There are no therapeutic control measures for the disease. A comprehensive study on the nutritional factors of the disease by Pillai *et al.* (1975) indicated that the palms in the disease affected areas, whether apparently healthy or visibly diseased, were in a state of imbalanced nutrition, possibly the result of a relatively higher content of N, P and K on the one hand and lower content of Ca, Mg and S on the other. Balanced nutrition in diseased palms could be achieved following integrated nutrient management practices. Rethinam *et al.* (1991) reported that integrated management increased the nut yield from 28 to 51 nuts per palm per year within 3 years in mildly affected area and 23.4 nuts per palm per year on an average in disease affected area.

Integrated nutrient management practices coupled with adopting high density multi-species cropping system under root (wilt) affected garden resulted in improvement in growth of palms with reduction in the root (wilt) symptoms (Maheshwarappa *et al.*

2003). The increase in nut yield (five years average) was to the tune of 54.5 %, 52 %, 48.3 % and 40.9 % under apparently healthy, disease early, disease middle and disease advanced palms compared to pre-experimental yield (Table 10).

Table 10. Coconut nut yield and copra yield as influenced by integrated management practices

Disease index	Mean yield (nuts/palm)		Copra content (g/nut) 2001-02	Copra content (kg/palm) 2001-02
	Pre experimental 1991-93	1997-2002		
Apparently Healthy (12 palms)	44	68.0	179.3	15.6
Disease Early (33 palms)	40	60.8	182.4	13.5
Disease Middle (59 palms)	36	53.4	181.7	10.0
Disease Advanced (8 palms)	21	29.6	180.6	4.7

In all the coconut growing regions in the country fertilizer use is low, although responses can be substantial. There is often a tendency to erratic use of inorganics only when the prices are good and or made available under assistance schemes and projects, withdraw when the assistance is stopped. This is common for all crops, but affects the balanced nutrition for a crop like coconut to a large extent considering the time lag between fertilizer application and yield of palms.

Long term studies in the coconut growing tracts have brought out the necessity of balanced nutrition in realizing optimum yields in coconut. In the balanced fertilization concept in relation to perennial crops several aspects are to be considered. For a crop like coconut balanced nutrition should be practiced from the juvenile phase to exploit the full potential of the palm. Creating a soil nutrient rich environment considering the rooting pattern of the crop, type of soil, its interaction with the applied nutrient elements, soil moisture deficit in relation to the crop, time lag between fertilizer application and its reflect on yield, the physiological condition of the crop, past history of nutrient management etc. play a role in evolving a recommendation for adult palms for sustaining productivity. These studies indicate that one has to depend on the results of long term studies and study the crop with reference to the environment in which it is growing, and use ones ingenuity in prescribing a recommendation for a balanced nutrition.

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Balanced Fertilization for Important Cut Flower Crops

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All over the world, the floriculture sector undergoes rapid changes. Due to globalization and its effect on income development in different regions of the world, growing per capita consumption in most countries is realized. The export of floricultural products from India has been on the increase in the past five years with the introduction of new floriculture products and ever increasing demand from the importing countries. This warrants efforts to boost the productivity and quality of the produce which meet the required international standards. To ensure maximization of productivity in any crop, balanced nutrient supply is an important factor and these cut flowers are not an exception. Efficient nutrient use results from balanced fertilization and sound management practices. When balanced fertilization is practiced, it increases the efficiency of others through a synergistic effect. The balanced fertilization in important cut flowers is discussed below:

Rose

Rose is an important cut flower appreciated as Queen of flowers. Under field conditions, roses respond well to fertilizer application. In addition to the basal dose of well decomposed FYM, rose requires 200-400 kg of N/ha. This dose may be split into two, once at pruning and the second dose after about 20 days. The requirement of phosphorus and potash can be met by adding 150 kg/ha of each at the time of pruning.

The above basal dose of fertilizers is supplemented with foliar feeding ; consisting of 2 parts urea, 1 part dihydrogen ammonium phosphate, 1 part potassium phosphate and 1 part potassium nitrate. 3 g of this mixture dissolved in l of water is sprayed at one week or 10 days interval till flowering. Micro nutrients @ 1 part each of ferrous sulphate, manganese suplhate, magnesium sulphate and borax ¼ part is mixed and sprayed at the rate of 1 g/l water from two months after planting.

Field grown roses for cut flower require different nutrients. Application of NPK @ 50, 150, 75 g / m^2 has been recommended for rose cultivar 'Happiness' under Bangalore conditions. Cultivar 'Super Star' receiving 30:12:12 g / m^2 of N : P : K along with 6 or 12 g multiplex responded best in terms of growth, yield and quality of cut roses.In soils deficient in micronutrients, foliar application of a solution prepared from the mixture containing 15 g manganese sulphate, 20 g magnesium sulphate, 10 g chelated iron and 5 g borax at the rate of 2 g/l has been found effective for obtaining good quality foliage and flowers. The concentration of spray solution should never exceed 0.3%.

Gurav *et al*. (2004) observed in 'First Red' cultivar of rose that 400: 200: 200 ppm NPK / plant / week increased the yield of flowers under Pune conditions. Integrated nutrient management tried in rose (Singh and Jauhari, 2005) found the flower production to be influenced by N, Azotobacter and application of FYM (Table 1).

Table 1. Effect of N, *Azotobacter* and FYM on flowering attributes in ROSE

Treatment	Days taken to bud appearance	No. of flowers/m^2 during I flush	No. of flowers/m^2 during II flush	Weight of flowers/m^2 I flush(g)	Weight of flowers/m^2 II flush(g)
20g/m^2	116.14	103.75	195.17	464.57	814.54
40g/m^2	111.24	103.33	210.42	463.90	859.27
60g/m^2	124.01	166.25	226.67	493.58	1081.59
CD at 5%	6.86	12.83	1.52	40.70	43.57
Azotobacter					
Uninoculated	106.63	101.11	199.11	427.56	851.58
Inoculated	127.64	114.44	222.39	508.47	985.35
CD at 5%	5.60	10.48	1.24	33.23	35.57
Levels of					
FYM	106.52	104.78	206.83	448.33	916.05
O Kg/m^2	127.75	110.78	214.67	487.70	920.87
5 Kg/m^2	5.60	NS	1.24	33.23	NS
CD at 5%					

Carnation

Carnation is one of the important cut flowers of the world. The demand is increasing day by day, but the flowers of carnation with proper stalk length, with appropriate size in desired number per plant are not available. Nutrient management plays an important role in production of carnation. An average carnation plant contains 434 mg N, 81 mg K; 253 mg Ca, 74 mg Mg and 46 mg S. Apart from major nutrients like N, P and K, Ca, Mg, B and Fe also play a crucial role in carnation nutrition.

At the time of land preparation sufficient quantity of organic manure must be added. A basal dose of N, P, K at the rate of 20:20:10 g/m^2 is applied three weeks after planting. Fertigation is done with N at 100 ppm and K at 140 ppm twice in a week along with other nutrients like Ca, Mg, Fe, B, Mn, Cu and Zn. Excess potassium cause magnesium and boron deficiency. Carnations are very sensitive to boron deficiency. It may cause excessive calyx splitting and abnormal opening of flower buds. Iron, manganese, boron, copper and zinc are taken as a source from Fe-EDTA, manganese sulphate, boric acid, copper sulphate, zinc sulphate and applied in 30 mg/l, 2.3 mg/l, 2.5 mg/l, 0.98 mg/l and 6 mg/l concentrations, respectively (Singh, 2006).

In TNAU, it was found with cv. Malaga that application of 2 % Panchagavya + 4 % Manchurian mushroom tea in addition to common basal dose of FYM 2 kg/m^2 / yr + DCC 200 g/m^2 + *Azospirillum* 2 g + *Phosphobacteria* 2 g + VAM 2 g / plant at 2 month intervals + *Trichoderma* 20 g /m^2 /year resulted in good vegetative growth, flowering, yield and quality attributes (Table-2). Flowers obtained from this treatment when pulsed with 10% sucrose + 1mM STS + 300 ppm $Al_2(SO_4)_3$ + 25 ppm BAP, treated with a holding solution consisting of 300 ppm $Al_2(SO_4)_3$ and wrapped in polyethylene sleeves of 100 gauge thickness recorded the longest post harvest life under Ooty conditions. (Punitha, 2007).

Table 2. Effect of biostimulants on number of flowers and petals in carnation

Treatments	Number of flowers/ plant	Number of petals/ flower
T_1 - Panchagavya – 2%	7.47	56.27
T_2- Manchurian mushroom tea – 4%	9.03	56.53
T_3 - T1 + T2	11.53	73.83
T4 - Control	7.23	52.63
CD at 5%	0.420	0.940

Sunita Devi *et al.* (2005) reported that number of days taken for initiation of floral bud in carnation was not altered by the application of N & P. But increased levels of N reduced the number of days taken for opening of flower bud besides improving the yield (Table 3 and 4).

Table 3. Effect of nitrogen and phosphorus on number of days taken for opening of Carnation flower from the date of bud initiation

Treatments	**Levels of phosphorus (g/m^2)**			
Levels of nitrogen	0	10	20	Mean
0	27.30	25.50	24.66	25.82
10	23.58	23.38	23.11	23.36
20	22.77	19.30	19.08	20.38
30	19.05	18.80	**18.49**	19.78
CD at 5%	N = 4.57, P = NS, N x P = NS			

Table 4. Effect of nitrogen and phosphorus on number of flowers per plant in Carnation

Treatments	Levels of phosphorus (g/m^2)			
Levels of nitrogen	0	10	20	Mean
0	0.83	1.40	1.83	1.35
10	2.08	2.00	2.66	2.25
20	3.00	3.16	3.66	3.27
30	4.17	4.33	**4.86**	4.45
CD at 5%	N =1.61, P = NS, N x P = NS			

Anthurium

Anthurium is grown for its colourful showy longlasting flower and foliage. For better growth of the plants manuring with dried cow-dung once in a month during the period other than rainy season is followed. In rainy season application of cow-dung causes excess water retention thereby favouring development of fungal growth and mould leading to danger for plant survival. Therefore, in rainy season instead of cow dung, powdered goat manure is fortified with 2-3 g dolomite per pot.

Fertilization is done by means of foliar application upto age of four month. Fertilizers like NPK in ratio of 30:10:10 may be sprayed at 0.05% as a foliar application twice a week. In later stages it should be sprayed at 0.5% once a week. Calcium, magnesium and sulphur are other important elements required in anthurium nutrition.

Split application of nitrogen, phosphorus and potassium at 30, 20 and 50 g/m^2 at 3, 6 and 9 months after planting increased number of suckers, stalk length, length and width of spathe, number of flowers per plant, improved flower weight and resulted in early flowering. Calcium deficiency causes colour break down of the spathe which can be corrected by the application of calcium nitrate @ 5 g per m^2 (Singh, 2006).

In TNAU, application of NPK @ 30:10:10 at 0.2 per cent spray + *Azospirillum* + phosphobacteria + VAM + GA_3 200 ppm in anthurium cultivar 'Temptation' has been found to influence the number of flowers per plant, besides improving the floral attributes (Table 5, Padmadevi and Jawaharlal, 2004).

Table 5. Effect of nutrients, biofertilizers, and growth regulator on flower production in *Anthurium andreanum* cv. Temptation

Treatments	Number of flowers/plant
T_1 - NPK @ 30:10:10 at 0.2 % spray and GA_3 200 ppm	1.33
T_2 - T_1 + *Azospirillum*	2.33
T_3 - T_1 + Phosphobacteria	3.67
T_4 - T_1 + VAM	3.67
T_5 - T_1 + *Azospirillum* + Phosphobacteria	3.33
T_6 - T_1 + *Azospirillum* + VAM	3.33
T_7 - T_1 + Phosphobacteria + VAM	4.00
T_8 - T_1 + *Azospirillum* + Phosphobacteria + VAM	5.67
T_9 - NPK @ 15:10:10 at 0.2 % spray and GA_3 200 ppm + *Azospirillum*	3.33
T_{10} - NPK @ 30:5:10 at 0.2 % spray and GA_3 200 ppm + Phosphobacteria	4.00
T_{11} - NPK @ 30:5:10 at 0.2 % spray and GA_3 200 ppm + VAM	3.00
T_{12} - NPK @ 15:5:10 at 0.2 % spray and GA_3 200 ppm + *Azospirillum*+ Phosphobacteria	4.00
T_{13} - NPK @ 15:5:10 at 0.2 % spray and GA_3 200 ppm + *Azospirillum* + VAM	3.33
T_{14} - NPK @ 30:0:10 at 0.2 % spray and GA_3 200 ppm + Phosphobacteria + VAM	4.00
T_{15} - NPK @ 15:0:10 at 0.2% spray and GA_3 200 ppm + *Azospirillum* + Phosphobacteria + VAM	4.33
T_{16} - Control (no fertilizer + no biofertilizer)	0.33
SE (d) CD (p=0.05)	0.39 0.79

Further study was conducted in TNAU to investigate the effect of nutrients and growth regulator on flowering in Anthurium (Table 6, Anand and Jawaharlal, 2004).

Table 6. Effects of nutrients and growth regulators on days to first flowering in Anthurium

Fertilizer(F)	Growth regulator(G)				Mean
	BA 250 ppm	BA 250 ppm	GA_3 250 ppm	GA_3 250 ppm	
Control	269.20	269.00	270.20	268.30	269.18
NPK@ 20:20:20 at 0.25%	245.00	241.00	225.00	230.00	235.25
NPK@ 20:20:20 at 0.50%	250.00	248.00	230.00	233.00	240.25
NPK@ 20:20:40 at 0.25%	210.00	215.00	186.50	198.00	202.38
NPK@ 20:20:40 at 0.50%	235.50	230.00	210.50	215.00	222.75
NPK@ 20:40:40 at 0.25%	205.00	210.50	220.00	223.45	214.74
NPK@ 20:40:40 at 0.50%	235.00	230.00	225.00	234.00	231.00
Mean	235.67	234.79	223.89	228.82	

	F	G	F X G
SE(d) :	0.72	0.54	1.43
CD(5%) :	1.47	1.11	2.93

Foliar spray of both nutrient solutions and growth regulators drastically reduced the number of days taken for inflorescence emergence to spathe unfurling (Table-6). The nutrient level NPK @ 20:20:40 @ 0.25% with growth regulator GA_3 at 250 ppm took the lowest period of 186.50 days to reach flowering as well as inflorescence emergence to spathe unfurling.

Chrsanthemum

Chrysanthemum is one of the important flower crops of the family Asteraceae. The standard types are used as cut flowers. It is well known fact that the successful growth and flowering depend upon the application of balanced nutrition. Since

Chrysanthemums are heavy feeders of nutrients, use of NPK plays an important role from the beginning. TNAU recommends farm yard manure @ 25t/ha + 125:120:25 kg NPK/ha, half of the N and entire dose of P & K are to be applied basal before planting. The other half of N is to be applied 30 days after planting. The same dose has to be repeated if a ratoon crop is allowed. Experiments conducted with integrated nutrient management revealed that the plants supplied with 50% of recommended dose fertilizers (RDF = 125: 120: 120 kg / ha) + vermicompost (5 t/ha) + 3% Panchagavya was superior in respect of all the economic floral parameters (ICAR Annual report, 2006 – 07, Table 7).

Table 7. Integrated nutrient management studies in chrysanthemum cv.CO1

S. No.	Treatments	Days taken for first bud appearance after planting	No. of flowers/ spray/ plant	Flower diameter (cm)
1.	100% of Recommended dose of FYM and inorganic fertilizers (RDF) (control)	64.55	71.54	1.01
2.	50% (RDF)	65.13	73.27	1.26
3.	50% RDF + 3% Manchurian tea	63.36	81.49	1.64
4.	50% of RDF + 3% Panchagavya	61.92	83.53	2.15
5.	50% of RDF + 3% Panchagavya + 3% Manchurian tea	60.76	89.44	2.55
6.	50% RDF + vermicompost (5 t / ha)	56.89	104.16	4.03
7.	50% of fertilizers + vermicompost (5 t / ha)+ 3% Manchurian tea	59.34	95.96	3.58
8.	50% of fertilizers (500 g/m^2 - twice a year) + vermicompost (5 t / ha) + 3% Panchagavya	54.23	110.36	4.77
	CD (P=0.05)	3.17	2.98	0.24

Gerbera

Gerbera is one of the majestic floricultural crops grown for its cut flower. Application of balanced nutrients plays a prime role in its production.. Phosphorus and Calcium are best given before planting as a basal dressing. Depending upon the Ca levels in the soil, P can be given as TSP (triple super phosphate) or SSP (single super phosphate). Application of 15 g N, 20 g P_2O_5 and 20 g K_2O / m^2 yielded maximum number of flowers per plant in poly house conditions. Magnesium can be given in the form of finely powdered dolomite limestone if pH also needs to be raised. Magnesium can also be added in the form of water soluble magnesium sulphate, either before or after planting (Singh, 2006).

Being a cut flower grown under green house, fertigation holds good. Different researchers have tried to determine the best ratio in N, P and K and their results varied from ratios 1:1:1 to 3:1:5. This indicates that there is no perfect mix but the right fertilizer regime depends on several conditions. Young vegetative plants require a ratio as 20:20:20 or 18:18:18 for the development of a strong root system and foliage. When the plants start to flower, the ratio should be increased in its level of K to increase flower production. Under open ventilation and fan pad system of poly houses, supply of 150 ppm of N, 60 ppm of P_2O_5 and 150 ppm of K_2O per plant on alternate day produced maximum flowers per plant.

Scheduling is done in such a way that up to 2-3 weeks after planting, no fertilizers are applied. From 3-12 weeks, N:P:K with ratio of 20:20:20 should be applied at 0.75 g/l/day and from 12 weeks onwards, 15:8:35 at 1-1.5 g /l/day can be applied. This is a general schedule that has to be amended by taking and analyzing soil samples at regular intervals. Total soluble salt levels (electrical conductivity level) for gerberas should be less than 2 mhos x 10^{-3} at 25^0 C (Singh, 2006).

Maximum number of flowers /plant and per sq. m. was recorded with improved floral characters when applied with higher levels of N & P (10 N + 15 g P_2O_5 / m^2). Maximum flower diameter and vase life were obtained with N & P levels of 10 g N + 12. 5 P_2O_5 g /m^2 and 5 g N + 15 g P_2O_5 /m^2 respectively (Pimple *et al*. 2006).

Gladiolus

Gladiolus is an important bulbous plant cultivated for its beautiful spike and appreciated as cut flower. For successful cultivation nutrient management is of prime importance to obtain good quality flowers.

Corms of gladiolus are rich in stored food which is sufficient to sustain plant growth for initial few days. Though cormels require fairly good amount of fertilizers due to their small size, the macronutrients are needed in large quantity. Organic manure should be mixed through the top soil before planting to improve the structure of the soil. Nitrogen should be applied at 300 kg/ha which may be reduced in medium and heavy soils. It is applied in two doses, first at 3 leaf stage and second at 6 leaf stage. Cormels may be given with nitrogen in 4-5 applications at about 3 weeks intervals starting from one month age of the crop. Mainly N should be applied in nitrate form and application should be stopped at least six weeks prior to harvesting the corms. Phosphorus should be given as basal dose ranging from 150-200 kg/ha depending upon soil test. In heavy soils phosphorus application should be delayed till plants reach 2-3 leaf stage and develop good root system. Potassium imparts resistance to diseases and increases photosynthetic efficiency of leaves. Gladiolus requires around 120-150 kg K_2O/ha at the time of planting of corms.

Vikrant kumar (2006) reported that P levels of 200 kg/ha resulted in maximum vegetative growth, no. of flowers per plant and no. of spikes per corm.

Iron deficiency is common in north-west plains of India and causes interveinal yellowing of new leaves. The deficiency is more pronounced in alkaline soils and in severe conditions emerging spikes turn light green to yellow. This can be corrected by spraying ferrous sulphate at 0.2 per cent, twice or thrice at 10 days interval.

Orchids

Orchids are one of the best known cut flowers. Regular scheduling of nutrients is important for its consistent production and improved quality. The type of nutrients, their quantity and frequency of application depend largely on the type of orchid, potting medium, season of the year, growing conditions, stage of development of the plant, etc.

Since most of the cultivated orchids are epiphytic in nature, the media used are highly porous. Hence, if the nutrients are applied in the media, the nutrients are leached down, making it unavailable to the plants. Hence, in orchids, foliar feeding is ideal. Small quantities of fertilizers should be applied in shorter intervals than using large quantities at longer intervals. This helps the plants to grow steadily without any deficiency throughout their growth period. The quantity also depends upon the frequency of application. Since inorganic fertilizers are applied as foliar spray, the quantity of nutrients used per plant should be relatively very low, otherwise it will be toxic to the plants. For younger plants the concentration should be very low. During rainy period also the requirement is low. In the case of plants that are transplanted or freshly planted, no fertilizer application is necessary till new roots are formed. A fertilizer complex containing nitrogen, phosphorus and potash in equal proportion (like 17:17:17 complex) is ideal for general application. The concentration may be adjusted between 0.2 and 1.0 per cent depending upon the situation. However another recommendation is during vegetative phase a 30:10:10 combination of N, P and K should be used which may be changed to 10:20:20 formulation during flowering stage. A concentration of 0.2% should be sprayed twice a week.

Organic manures like cow-dung, neem oil cake, poultry manure, etc. are also used for orchids. These are found to be more ideal for monopodial types. These may be soaked in water for 4-5 days for fermentation, diluted 10-15 times with water, filtered and sprayed over the plants. Fresh coconut water, cow’s urine (1:20-25 with water) are also useful as foliar spray.

The frequency of application could be from thrice a week to once in two weeks under tropical conditions, though twice a week is the usual recommendation. The type and quality of nutrient and their application time play an important role on the quality of flowers. As flower buds begin to form interior sheaths, a mixture containing more of phosphorus is useful in improving the quality of spike. Application of inorganic fertilizer should be stopped about three days prior to harvest of spikes since it may otherwise reduce the shelf life of flowers.

At TNAU, application of 50% of Recommended dose of fertilizers (RDF) (NPK 30:10:10 @ 0.2% twice a week + FYM spray @ 1:10 ratio once a week) + 3%

vermiwash + 3% panchagavya in Dendrobium variety Sonia 17 was found to be superior in respect of all the vegetative parameters as well as flowering parameters including vase life (Table 8, ICAR Annual report, 2006 – 07).

Table 8. Integrated Nutrient Management in Orchid- *Dendrobium*

Treatments	Plant height (cm)	Internodal length (cm)	Days to flowering
NPK 30:10:10 @ 0.2%*	34.7	2.98	199.42
NPK 30:10:10 @ 0.1% *	31.2	3.12	210.45
NPK 30:10:10 @ 0.1% *+ 3% vermi wash +3% panchagavya	34.4	3.00	197.65
CD (P=0.05)	2.9578	0.5621	13.9150

- *at twice a week + FYM spray @ 1:10 ratio once a week (non flowering stage)*

As Dendrobium is epiphytic in nature, the media or substrate may be devoid of nutrients and it necessitates a regular schedule of fertilizing in liquid form. In Dendrobium hybrid New pink x Emma, maximum no. of shoots (5.5) were produced by spraying with NPK 30:10:10 at 0.2 per cent and 17:17:17 at 0.1 per cent level as alternate sprays (Sobhana *et al*. 2004).

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Physiological Basis of Balanced Fertilization for Horticultural Crops

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The idea of balanced fertilization does not mean a certain definite proportion of nitrogen, phosphorus and potassium or other nutrients to be added in the form of fertilizer, but it has to take into account the crop removal of nutrients, economics of fertilizers and profitability, farmers' ability to invest, agro-techniques, soil moisture regime, weed control, plant protection, seed rate, sowing time, soil salinity, alkalinity, physical environment, microbiological condition of the soil, available nutrient status of soil, cropping sequence, etc. Balanced use of plant nutrients corrects nutrient deficiency, improves soil fertility, increases nutrient and water use efficiency, enhances crop yields and farmers' income, betters crop and environmental quality. To reap the benefits of balanced use of plant nutrients, it is important to have good quality seed, adequate moisture and better agronomic practices with greater emphasis on timeliness and precision in farm operations. Crop production under intensified agriculture over the years has resulted in large scale removal of nutrients from the soil, resulting in negative balance and declining soil fertility.

Benefits of balanced fertilization

- Promotion of more extensive root systems, increasing nutrient and water uptake for higher yields, and holding the soil in place against wind and water erosion
- Providing a quicker canopy cover, exposing more leaf area to sunlight to increase photosynthesis, and covering the soil surface, reducing the erosive impact of rainfall
- Supporting the production of more residue, above and below ground, to build soil organic matter and nutrient reserves and to stabilize the soil
- Improving water use efficiency of the growing crop
- Increasing crop resistance to stresses such as drought, pests, heat and cold

In recent decades, farmers rely primarily on nitrogen fertilizers to maximize crop yields, rather than targeting optimal achievable yields determined by local agronomic, economic and environmental conditions. However, high levels of nitrogen fertilization without appropriate balance may result in negative effects on the soil and the environment (nitrogen losses through leaching or volatilization) and increased incidence of crop lodging, weed competition and pest attacks. In some crops, high nitrogen content decreases quality, in particular storage ability. On the other hand, too little nitrogen results in low yields and farmer profits, inefficient use of other plant nutrients, and potential damage to the environment.

An adequate supply of phosphorus is essential because of its functions in vital molecules such as proteins and nucleic acids that govern plant's life. Phosphorus stimulates root development and is necessary for cell division. Potassium is of vital importance for cells and their enzymatic and metabolic functions. Both phosphorus and potassium help to protect plants against stress, such as that caused by pests, diseases, drought or frost. They also considerably improve the efficiency of nitrogen uptake. Truly balanced fertilization requires supplying adequate amounts of nitrogen, phosphorus and potassium, plus other nutrients such as magnesium, sulphur and micronutrients, as determined by soil tests and crop requirements. Crops require an adequate supply of nutrients. Proper balance is also required to produce optimum yields, while protecting the environment. Fruits play an important role in overcoming iron, zinc, vitamin A and other deficiencies and in achieving nutritional security of Indian population. Unbalanced use of plant nutrients led to low yields with poor quality fruits. Correction of deficiencies of micronutrients is essential to realize the benefits of applied N, P and K. Use of organics helps both substitutions of nutrients and improving fruit quality. Neither soil testing nor tissue testing alone can help in recommending fertilizer application schedule for fruit crops. An integrated soil and tissue testing approach along with economical considerations is needed for recommending fertilizers to fruit crops.

Nutrient uptake mechanisms

The process of nutrient uptake by plants refers to the transfer of the nutrient ions across the soil root interfaces into the plant cell. The energy for the process is provided by the metabolic activity of the plant and in its absence, no absorption of nutrients take place. Nutrient absorption involves the phenomenon of ion exchange. The root surface, like soil, carries a negative charge and exhibits cation-exchange property. The most efficient absorption of the plant nutrients takes place on the younger tissues of the roots, capable of growth and elongation. In this respect, root-systems are known to vary from crop to crop. Hence their feeding power differs. The extent and the spread of the effective root-system determine the soil volume trapped in the feeding-zone of the crop plant. This is indeed an important information in a given soil-plant system which helps us to choose fertilizers and fertilizer-use practices. The absorption mechanisms of the crop plants are fairly known now. There are three mechanisms in operation in the soil-water-plant systems. They are:(i) the contact exchange and root interception, (ii) the mass flow or convection, and (iii) diffusion.

1. Contact exchange and root interception

In the case of contact exchange and root interception, the exchangeable nutrients ions from the clay-humus colloids migrates directly to the root surface through contact exchange when plant roots come into contact with the soil solids. Nutrient absorption through this mechanism is, however, insignificant as most of the plant nutrients occur in the soil solutions. Scientists have found that plant roots actually grow to come into contact with only three percent of the soil volume exploited by the root mass, and the nutrient uptake through root interception is even still less.

2. Mass flow or convection

The second mechanism is mass flow or convection, which is considered to be the important mode of nutrient uptake. This mechanism relates to nutrient mobility with the movement of soil water towards the root surface where absorption through the roots takes place along with water. Some are called mobile nutrients. Others which move only a few millimetres are called immobile nutrients. Nutrient ions such as nitrate, chloride and sulphate, are not absorbed by the soil colloids and are mainly in solution. Such nutrient ions are absorbed by the roots along with soil water. The nutrient uptake through this mechanism is directly related to the amount of water used by the plants (transpiration). It may, however, be mentioned that the exchangeable nutrient cations and anions other than nitrate, chloride and sulphate, which are absorbed on soil colloids are in equilibrium with the soil solution do not move freely with water when it is absorbed by the plant roots. These considerations, therefore, bring out that there are large differences in the transport and root absorption of various ion through the mechanism of mass flow. Mass flow is, however, responsible for supplying the root with much of the plant needs for nitrogen, calcium and magnesium, when present in high concentrations in the soil solution, but does not do so in the case of phosphorous or potassium. The nutrient uptake through mass flow is largely dependent on the moisture status of the soil and is highly influenced by the soil physical properties controlling the movement of soil water.

3. Diffusion

The third mechanism is diffusion. It is an important phenomenon by which ions in the soil medium move from a point of higher concentration to a point of lower concentration. In other words, the mechanism enables the movement of the nutrients ion without the movement of water. The amount of nutrient-ion movement in this case is dependent on the ion-concentration gradient and transport pathways which, in turn, are highly influenced by the content of soil water. This mechanism is predominant in supplying most of the phosphorous and potassium to plant roots. It is important to note that the rhizosphere volume of soil in the immediate neighbourhood of the effective plant root receives plant nutrients continuously to be delivered to the roots by diffusion.

It is a fact that the roots of the growing plants continuously remove nutrient ions from the soil solutions. At the same time, the breakdown of the soil minerals and the generation of more exchangeable cations, the biological activity and the additions made to the anions, e.g. nitrates, continuously change the composition of the soil solution. At a given point of time, therefore, the available plant nutrients in the soil solution may range from a tiny amount to larger quantities. Under favourable conditions, crop plants, in general, require larger amounts of plant nutrients than the quantity found in soil solution at any given time. Hence, the situation of nutrients supply to plants becomes a limiting factor, specially, at the critical stages of plant growth and results in low crop yields. The knowledge of the specific role of each essential element in the growth of crop plants and their amounts required for efficient crop production is considered necessary in adopting scientific fertilizers use.

Physiological roles of essential nutrients

Some elements are essential, meaning that the absence of a given mineral element will cause the plant to fail to complete its life cycle; that the element cannot be replaced by the presence of another element; and that the element is directly involved in plant metabolism. However, this principle does not leave any room for the so-called beneficial elements, whose presence, while not required, has clear positive effects on plant growth.

Major functions of essential nutrients in plants

Nutrient	Functions
Nitrogen	Necessary for formation of amino acids, the building blocks of protein Essential for plant cell division, vital for plant growth Directly involved in photosynthesis Necessary component of vitamins Aids in production and use of carbohydrates
Phosphorus	Involved in photosynthesis, respiration, energy storage and transfer and cell division Promotes early root formation and growth Improves quality of fruits, vegetables, and grains Vital to seed formation Helps plants survive harsh winter conditions Increases water-use efficiency Hastens maturity

Potassium	Carbohydrate metabolism and translocation of starches Increases photosynthesis Increases water-use efficiency Important in fruit formation Activates enzymes and controls their reaction rates Improves quality of seeds and fruit Improves winter hardiness Increases disease resistance
Calcium	Utilized for continuous cell division and formation Involved in nitrogen metabolism Reduces plant respiration Aids translocation of photosynthesis from leaves to fruiting organs Increases fruit set Essential for nut development in peanuts Stimulates microbial activity
Magnesium	Key element of chlorophyll production Improves utilization and mobility of phosphorus Activator and component of many plant enzymes Increases iron utilization in plants Influences earliness and uniformity of maturity
Sulphur	Integral part of amino acids Helps develop enzymes and vitamins Promotes nodule formation on legumes Aids in seed production Necessary in chlorophyll formation
Boron	Essential for germination of pollen grains and growth of pollen tubes Essential for seed and cell wall formation Promotes maturity Necessary for sugar translocation Affects nitrogen and carbohydrate

Chlorine	Not much information about its functions Interferes with P uptake Enhances maturity of small grains on some soils
Copper	Catalyzes several plant processes Major function in photosynthesis Indirect role in chlorophyll production Increases sugar content Intensifies color Improves flavor of fruits and vegetables
Iron	Promotes formation of chlorophyll Acts as an oxygen carrier Reactions involving cell division and growth
Manganese	Functions as a part of certain enzyme systems Aids in chlorophyll synthesis Increases the availability of phosphorus and calcium
Molybdenum	Required for nitrate reductase, which reduces nitrates to ammonium in plant Aids in the formation of legume nodules Needed to convert inorganic phosphates to organic forms in the plant
Zinc	Aids plant growth hormones and enzyme system Necessary for chlorophyll production Necessary for carbohydrate formation Necessary for starch formation Aids in seed formation

Balanced fertilisation and physiological changes

Any crop management practice should aim at keeping the physiological processes of the plants in active mode, so that the plants can produce more biomass with least destructive processes. The physiological efficiency of crops can be improved through balanced fertilization effecting changes in stomatal conductance, photosynthetic rate, plant water status, activities of enzymes such as nitrate reductase, peroxidase, catalase, crop growth rate and total dry matter production. Experiments conducted in different horticultural crops show that applied nutrients have significant role in altering the physiology of the crop resulting in improved yields. Balanced application of plant nutrients is essential to achieve quality fruit production. In many fruit crops, higher levels of N may reduce yield and needs P and K application to produce good quality fruits (Ganeshamurthy *et al.*, 2004). The role of different sources of nitrogen, potassium, micronutrients and plant growth regulators on physiological characters and nutrient use efficiency resulting in better yield and quality are discussed here.

Nitrogen (N)

In banana, plants with medium pseudostem height and more girth are desirable as these traits reflect on the bunch size and other related characters, apart from providing better anchorage. Keshavan *et al* (2006) reported that soil application of 25% N as CAN + 25% N as urea + 50% N as ammonium sulphate (AS) recorded better plant height, girth and LAI due to physiological changes in banana cv. Poovan (Table 2). Higher available nitrogen and magnesium in the soil, leaf nitrogen and magnesium content due to this treatment might be the reason to register higher total chlorophyll content. Higher nitrate reductase (NRase) activity helped the crop to have better photosynthetic efficiency by registering higher soluble protein. Higher NRase indicates higher levels of protein synthesis and accumulation of soluble protein. This in turn indicates that nitrogenous compounds in the plant are utilized for various metabolic activities and resulted in higher bunch weight (Table 1).

Table 1. Effect of different sources of nitrogen on morpho-physiological traits and yield of banana cv. Ney Poovan

Nitrogen sources	Height (cm)	Girth (cm)	LAI	Chl. (mg g^{-1})	NRase (µg NO_2 $g^{-1}h^{-1}$)	Soluble protein (mg g^{-1})	Bunch weight (kg)
100% N as Urea	295.26	58.65	3.164	1.39	825.34	47.73	8.44
25% N as CAN + 25% N as Urea + 50% N as AS	313.15	63.45	3.827	1.90	892.62	60.20	12.10
CD (0.05)	4.06	2.58	0.29	0.02	4.79	2.69	0.81

Tamilselvi (2004) reported that soil application of 200 g N $plant^{-1}$ and 2% urea spray during 3rd, 5th and 7th month after planting + salicylic acid 100 ppm resulted in significant physiological changes and bunch weight in banana cv. Neypoovan. Supplementation of N through urea spray helped the crop to have higher chlorophyll content, soluble protein and NRase (Table 2a). The combination of salicylic acid with urea imparted stress tolerance by registering higher chlorophyll stability index (CSI) and relative water content (RWC). Leaf nitrogen (N) was also found high favouring better physiological efficiency and bunch weight (Table 2b).

Table 2a. Influence of nitrogen and salicylic acid on physiological characters

Treatments	LAI	Chl. (mg g^{-1})	CSI (%)	Fv/Fm	Sol.protein (mg g^{-1})
110: 35: 330 g NPK	2.85	1.35	68.68	0.59	19.91
200 g N + 2% urea + 100 ppm salicylic acid	3.81	1.55	84.40	0.87	33.26
CD (0.05)	0.05	0.02	1.41	0.01	1.23

Table 2b. Influence of nitrogen and salicylic acid on physiological characters and yield

Treatments	NRase (μg NO_2 $g^{-1}h^{-1}$)	IAA oxidase (μg auxin $g^{-1}h^{-1}$)	RWC (%)	Leaf N (%)	Bunch weight (kg)
110: 35: 330 g NPK	164.3	600.1	64.0	1.90	9.85
200 g N + 2% urea + 100 ppm salicylic acid	278.5	853.8	84.0	2.55	13.65
CD (0.05)	4.03	12.59	1.32	0.05	0.17

Potassium (K)

Sources of potassium are also known to influence the physiology of horticultural crops. Ramesh Kumar *et al.* (2006) found that application of 150% of recommended dose of potassium (RDK) as sulphate of potash (SOP) to banana cv. Robusta influenced the physiological parameters and resulted in higher yield (Table 3a). The treatment exhibited significant changes in chlorophyll and soluble protein favouring enhanced photosynthesis. Higher RWC and K/N ratio facilitated better nutrient use efficiency while catalase and peroxidase activities helped for abiotic stress tolerance. The resistance offered by K to biotic stress is due to the role of K on the production of lignin and soluble polyphenols in higher quantities. Accumulation of excess N in the sap due to K deficiency *i.e.* at low K/N ratio causes the tissues becoming soft with little resistance for penetration by nematode like pests. Thus, application of 150% of RDK as SOP favoured for higher bunch weight (Table 3b).

Table 3a. Influence of SOP on physiological characters in banana cv. Robusta

Treatment	Chl. (mg g^{-1})	RWC (%)	Sol. Protein (mg g^{-1})	NRase (µg NO_2 $g^{-1}h^{-1}$)	K/N ratio
110: 35: 330 g NPK	1.265	79.15	51.23	843.38	1.54
110: 35: NP and 150% of RDK as SOP	1.426	87.18	60.81	898.93	1.71
CD (0.05)	0.154	2.02	4.38	25.73	0.43

Table 3b. Influence of sources and levels of potassium on leaf K/N ratio, catalase, peroxidase and bunch weight of banana cv. Robusta

Treatment	Catalase (µmol H_2O_2 $100g^{-1}min^{-1}$)	Peroxidase (µg $g^{-1}hr^{-1}$)	CGR (g m^{-2} d^{-1})	Bunch weight (kg)
110: 35: 330 g NPK	66.40	46.42	4.31	24.81
110: 35: NP and 150% of RDK as SOP	77.30	60.50	5.38	27.14
CD (0.05)	5.38	4.32	0.159	1.00

A recent study at Department of Fruit Crops, TNAU revealed that application of 50% K through MOP + 50% K through Cement Kiln Flue Dust (CKFD) had positive influence on physiological characters and resulted in higher bunch weight in banana cv. Karpooravalli (Shanthi, 2004). Combined application of MOP and CKFD favoured for better plant water status, stomatal conductance (g_s) and net photosynthesis (Pn). The significant alterations in the gas exchange characteristics resulted in higher bunch weight (Table 4).

Table 4. Influence of Cement Kiln Flue Dust on yield characters of banana

Treatment	g_s (mmol m^{-2} s^{-1})	Pn (μmol m^{-2} s^{-1})	RWC (%)	Bunch weight (kg)
100 % K through MOP	536.66	15.75	65.50	19.42
50 % K through MOP + 50 % K through CKFD	636.67	20.25	70.71	23.46
CD (0.05)	5.80	2.65	1.15	2.12

The studies on fertigation in papaya cv. Co 7 revealed that application of 10 litres water/day + 50 g each in N, P and K in bimonthly intervals resulted in significant changes in physiological characters and higher fruit yield. Fertigation improved the plant nutrient status (N&K) and resulted in higher chlorophyll fluorescence (Fv/Fm), net photosynthesis (Pn), water use efficiency (WUE) and relative water content (RWC) (Jeyakumar *et al*. 2001). The alterations in the physiological characters of the plant due to fertigation resulted in more number of fruits (Table 5).

Table 5. Effect of fertigation on physiological characters. nutrient status and fruit yield in papaya

Physiological characters	Soil application (50g in each of N, P & K)	Fertigation (50g in each of N, P & K)
Chlorophyll Fluorescence (Fv/Fm)	0.71	0.87
Net Photosynthesis (μmol m^{-2} s^{-1})	12.45	18.66
Stomatal conductance (mmol m^{-2} s^{-1})	262	375
Water use efficiency (Pn/E)	3.47	4.72
Relative water content (%)	70.45	79.64
Leaf Nitrogen (%)	1.26	1.54
Leaf Potassium (%)	2.23	2.67
Number of fruits	76.40	94.73

Nalina (2002) reported that application of 150% of recommended dose (*i.e.* 165:52.5:495 g NPK) in 4 splits enhanced the physiological activities and resulted in higher bunch weight in tissue cultured banana cv. Robusta. The improvement in bunch weight might be due to efficient photosynthesis as evidenced by soluble protein, specific leaf weight (SLW), NRase and crop growth rate (CGR) (Table 6).

Apart from the maintenance of plant water status, K has significant role in quality improvement of fruits and vegetables. The studies on nitrogen and potassic fertilizers on tomato revealed that application of 125 kg N & 75 kg K_2O/ha resulted in improved physiological efficiency as evidenced by higher ascorbic acid, lycopene content, total soluble solids (TSS) and fruit yield (Table 7) as reported by Ingole (2005).

Table 6. Physiological characters and fruit yield of tissue cultured banana cv. Robusta due to fertilizer application

Treatments	Soluble protein (mg g^{-1})	NRase (µg NO_2 $g^{-1}h^{-1}$)	SLW (g cm^{-2})	CGR (g m^{-2} day^{-1})	Bunch weight (kg)
110: 35: 330 g NPK in 3 splits	44.7	827.25	87.27	11.47	26.87
165:52.5:495 g NPK in 4 splits	60.05	863.30	98.82	21.79	35.18
CD (0.05)	1.01	2.19	1.23	0.74	1.09

Table 7. Influence of N and K on fruit quality and yield in tomato

Treatments	Ascorbic acid (mg $100g^{-1}$)	Lycopene (mg $100g^{-1}$)	TSS (°brix)	Yield (ton/ha)
75kg N & 50kg K/ha	40.92	3.46	5.33	28.65
125 kg N & 75 kg K/ ha	45.99	3.88	6.06	31.14
CD (0.05)	0.43	0.01	0.02	0.45

Being a perennial fruit crop, mango exhausts the available soil nutrients continuously and hence, nutrient supplementation is very much essential to get sustained yield. Vijayalakshmi (1997) reported that foliar spray of KNO_3 1 % in addition to the recommended fertiliser dose as soil application resulted in more number of fruits by improving the physiological efficiency of the plant through alterations in photosynthetic characteristics, carbohydrate levels, C/N ratio and enzymatic activities (Table 8). KNO_3 1% also favoured for higher activities of enzymes such as catalase (CAT), peroxidase (POX) and NRase aiding in abiotic stress tolerance and enhanced fruit yield (Table 9).

Table 8. Physiological characters of mango influenced by KNO_3 spray

Treatments	SLA (gcm^{-2})	Chl. ($mg\ g^{-1}$)	g_s ($mmol\ m^{-2}\ s^{-1}$)	Pn ($\mu mol\ m^{-2}\ s^{-1}$)	Leaf N (%)	Sol.protein ($mg\ g^{-1}$)
1 kg in each of N, P and K/tree	2.72	0.463	45.67	4.27	1.12	14.05
KNO_3 1 %*	3.47	0.715	68.0	6.43	1.36	18.09
CD (0.05)	2.85	0.007	5.25	0.37	0.01	0.91

* in addition to soil application of 1 kg in each of N, P and K/tree

Micronutrients

Kumar and Jeyakumar (2001) assessed the importance of micronutrients in banana and 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 fertilizer dose of NPK@ 110:35:330g $plant^{-1}$ $year^{-1}$ improved the leaf micronutrient status, chlorophyll content and resulted in higher bunch weight besides better fruit quality (Table 10). The higher accumulation of chlorophyll associated with the micronutrients which act as coenzymes in major metabolic pathways. The combined spray of micronutrients was able to increase the pseudostem girth and number of leaves possibly helping in synthesis and translocation of greater quantities of photosynthates necessary for enhanced bunch yield.

Table 9. Physiological characters and fruit yield of mango influenced by KNO_3 spray

Treatments	C/N	CAT (μmol 100g^{-1} min^{-1})	POX (μg g^{-1}hr^{-1})	NRase (μg NO_2 g^{-1}h^{-1})	IAA (μg g^{-1}h^{-1})	Fruit yield (kg tree^{-1})	Fruit no. tree^{-1}
1 kg in each of N, P and K/tree	5.19	5.31	2.33	0.66	298.17	13.0	82
KNO_3 1%*	7.32	16.25	4.76	1.32	421.97	26.92	197
CD(0.05)	0.11	0.1	0.06	0.03	19.40	1.86	5.15

* in addition to soil application of 1 kg in each of N, P and K/tree

Table 10. Effect of micronutrients on physiological characters in banana cv. Robusta

Treatments	Chl. (mg g^{-1})	Zn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Bunch weight	TSS (°brix)
110:35:330g NPK	1.67	29.0	74.0	10.1	17.2	18.3	17.0
$ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $CuSO_4$ (0.2%) + H_3BO_3 (0.1%) spray *	2.03	37.2	93.0	18.2	23.1	23.1	19.1
CD (0.05)	0.22	3.40	7.0	2.6	5.1	2.26	1.1

***** in addition to soil application of 110:35: 330g NPK plant^{-1} year^{-1}

Jeyakumar *et al* (2001) observed significant physiological changes due to foliar spray of Zn (0.5%) + H_3BO_3 (0.1%) during fourth and eighth month after planting in papaya cv. Co 5 (Table 11). The higher number of fruits (80.63) could be due to better fruit set owing to Zn mediated protein and IAA synthesis and, B mediated stimulation of pollen germination, pollen tube growth, fertilization process and higher metabolite synthesis. The higher TSS could be due to efficient translocation of photosynthates to fruit pulp promoted by Zn and hydrolysis of complex polysaccarides into simple sugars aided by B.

Table 11. Effect of micronutrients on physiological characters and fruit yield in papaya

Treatments	Chl. (mg g^{-1})	Pn (µmol m^{-2} s^{-1})	Zn (ppm)	B (ppm)	No. of fruits	Fruit weight	TSS (°brix)
50g in each of N, P and K	1.43	9.04	44.62	33.35	70.44	1.78	12.30
$ZnSO_4$(0.5%)+ H_3BO_3(0.1%) spray *	1.87	12.46	63.44	39.89	80.63	2.22	14.80
CD (0.05)	0.25	0.49	1.23	1.17	1.86	0.12	0.40

***** In addition to soil application of 50g in each of N, P and K at bimonthly intervals.

Sujatha (1997) reported that combined spray of Zn (0.2%), B (0.1%), $CaNO_3$ (0.1%) and $CaCl_2$ (0.1%) prior to flowering caused significant changes in chlorophyll content, soluble protein and activities of enzymes such as NRase, IAA oxidase, peroxidase and catalase (Table 12a). The changes in the physiology and biochemistry of the plant resulted in higher dry matter accumulation (DMA) and more number of fruits in tomato cv. PKM 1 (Table 12b).

Table 12a. Effect of micro nutrients on physiological characters in tomato

Treatments	Chl. (mg g^{-1})	Sol. Protein (mg g^{-1})	NR (µg NO_2 $g^{-1}h^{-1}$)	IAA oxidase (µg auxin $g^{-1}h^{-1}$)
75: 100: 50 kg NPK/ha	2.098	19.71	2.97	27.43
Zn (0.2%), B (0.1), $CaNO_3$ (0.1%) and $CaCl_2$ (0.1%) *	3.24	28.34	3.11	10.813
CD (0.05)	0.10	3.5	0.006	0.14

* in addition to soil application of 75: 100: 50 kg NPK/ha

Table 12b. Influence of micro nutrients on biochemical traits and yield characters of tomato

Treatments	POX (μg $g^{-1}hr^{-1}$)	CAT (μmol H_2O_2 $100g^{-1}min^{-1}$)	TDMA (g)	No. of fruits $plant^{-1}$	Yield (g $plant^{-1}$)
75: 100: 50 kg NPK/ha	0.02	0.394	120.37	26.17	1387.9
Zn (0.2%), B (0.1%), $CaNO_3$ (0.1%) and $CaCl_2$ (0.1%)*	0.03	0.426	175.66	40.66	2440.3
CD (0.05)	0.001	0.004	10.9	5.443	297.78

* in addition to soil application of 75: 100: 50 kg NPK/ha

Plant growth regulators and nutrient use efficiency

Cavendish group of bananas are known to be very vigorous and foliar spray of plant growth regulators play a significant role in improving the yield through increased fertilizer use efficiency. Foliar spray of chlormequat chloride @1000 ppm during 4th and 6th month after planting in addition to soil application of NPK@ 110:35:330g/plant/year resulted in improved physiological efficiency, nutrient status and fruit yield as given in Table 13a (Jeyakumar *et al*., 2003). Higher photo chemical efficiency (Fv/Fm), net photosynthesis (Pn) and better water/nutrient use efficiency y registering enhanced chlorophyll fluororescence. the higher nutrient and water use efficiency might have helped for improved fruit yield (Table 13b).

Table 13a. Influence of chlormequat chloride application on banana

Treatment	Pn (μmol m^{-2} s^{-1})	Fv/Fm	E (μmol m^{-2} s^{-1})	RWC (%)	WUE
110:35:330g NPK	19.40	0.71	5.04	80.20	3.84
Chlormequat chloride 1000 ppm *	25.30	0.86	4.24	87.70	5.96
CD(0.05)	3.12	0.05	1.82	4.26	1.32

***** in addition to soil application of 110:35: 330g NPK $plant^{-1}$ $year^{-1}$

Table 13b. Influence of chlormequat chloride application on banana

Treatment	N (%)	P (%)	K (%)	CEC (me g^{-1})	Bunch weight (kg)
110:35:330g NPK	1.51	0.505	2.01	9.25	24.80
Chlormequat chloride 1000 ppm*	1.94	0.745	2.98	16.43	33.62
CD(0.05)	0.04	0.03	0.07	1.42	1.76

***** in addition to soil application of 110:35: 330g NPK $plant^{-1}$ $year^{-1}$

Sea weed based bioregulators are widely used in the recent years to increase the nutrient use efficiency in various agricultural and horticultural crops. Foliar spray of 0.2 % plantozyme during fourth and sixth month after planting, in addition to the fertiliser dose of 200:40: 200 g N: P_2O_5 : K_2O per plant per year revealed the influence of nutrients and amino acids in plantozyme on higher cell wall plasticity and dry matter accumulation resulting in better yield besides improving the leaf nutrients status in banana cv. Dwarf Cavendish (Jeyakumar and Kumar, 2002).The higher LAI due to plantozyme enabled the plant to make more effective use of solar energy during photosynthesis. The increase in leaf area could be due to the osmotic uptake of water facilitated by K (Table 14a). The higher N and K status in plants due to plantozyme favoured the plants to have more dry matter production by influencing net photosynthesis, transpiration and activities of enzymes such as NRase and IAA oxidase (Table 14b).

Table 14a. Effect of bio regulator on physiological and bio chemical characters of banana

Treatments	LAI	LTR	E (μmol m^{-2} s^{-1})	IAA Oxidase (μg auxin $g^{-1}h^{-1}$)	NRase (μg NO_2 $g^{-1}h^{-1}$)
110:35:330g NPK	2.34	50.10	4.89	0.56	7.52
Plantozyme 0.2% *	3.37	34.50	7.62	0.77	9.63
CD(0.05)	0.49	6.28	0.54	0.02	1.18

***** in addition to soil application of 110:35: 330g NPK $plant^{-1}$ $year^{-1}$

Table 14b. Effect of bio regulator on leaf nutrient status and fruit yield of banana

Treatments	N (%)	K (%)	Bunch weight (kg)	Total sugars (%)	TSS (%)
110:35:330g NPK	1.72	3.11	18.0	14.0	19.7
Plantozyme 0.2% *	2.07	3.92	26.3	16.6	25.7
CD(0.05)	0.038	0.064	1.56	0.54	1.22

***** in addition to soil application of 110:35: 330g NPK plant^{-1} year^{-1}

Conclusion

The studies on balanced fertilization in different horticultural crops revealed the significance of nutrients on improvement in physiological efficiency of the crops by influencing photosynthesis, water use efficiency, nutrient use efficiency, enzyme activities, hormonal balance, crop growth rate and dry matter production. Irrespective of the crops, balanced fertilization with macro nutrients, micronutrients and plant growth regulators helped the crops to give more yield and improved quality of the produce. Scientific trials clearly demonstrate that if any plant nutrient is deficient, crop growth will be affected. A true balanced fertilization requires supplying of adequate amounts of nitrogen, phosphorus and potassium, plus other nutrients such as magnesium, sulphur and micronutrients, as determined by soil tests and crop requirements. Acid and sodic soils must undergo remediation for effective fertilizer use. Applying lime to acid soils and gypsum to sodic soils is critical to effective nutrient management.

To finalize a balanced nutrition programme, a farmer has to choose the nutrient sources, the appropriate way to apply fertilizers (e.g. soil broadcasted or foliar application) and when to apply them. This is important since the timing of application of each nutrient may vary for optimal efficiency. While nitrogen is more required during the vegetative stages of plant development to support new shoot growth, calcium is important during the early development and potassium during the rapid expansion of fruits and tubers. The same is true for micronutrients (e.g. boron is often required for good pollination and fruit setting). A balanced fertilization strategy is the only way to ensure a sustainable agriculture that can provide the world population with high quality food while minimizing the impact on the environment.

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