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Integrated Nutrient Management in Major Spices

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India has been a traditional producer, consumer and exporter of spices. Almost all states in the country produce one or other spices. Spices exports have registered substantial growth during the last one-decade. However, the current productivity levels show a disturbing downward trend. Besides pests and diseases afflicting these crops, another important factor contributing to reduced yields in spices is poor soil quality; a reflection of low carbon sequestration coupled with alarmingly higher nutrient mining from these soils. Poor nutrient management strategies have resulted in depletion of C reserves, reduced nutrient levels, and decreased nutrient cycling processes due to decreased biological activity. Low pH and lower levels of organic carbon, K, Ca, Mg and Zn are the major constraints in spice growing soils. This coupled with high soil erosion and associated nutrient losses in high rainfall areas growing spices have further compounded the problem. Long-term trials on integrated nutrient management (INM) indicate that fertiliser input efficiency can be increased through scientific management practices, rational use of costly inputs and a combination of both inputs and management practices. Adoption of INM techniques will not only enhance productivity but will also increase the total productivity and the efficiency of fertiliser use in these spices crops. While doing so there is an urgent need to augment supplies of organic manures, fortified, coated and customised fertilisers supplying secondary and micronutrients, biofertilisers and soil amendments to sufficiently support INM use in spice production.

The green revolution caused by increased yields of irrigated rice and wheat was possible due to fertile soils and intensive use of fertilisers. However, the gains in agricultural production could not be sustained due to scarce or imbalanced input use, declining soil fertility and severe soil degradation. Thus sustainable and enhanced crop production to feed the ever growing population is once again a matter of grave concern. The degradation of hitherto fertile soils due to depletion of soil organic matter (SOM) and associated plant nutrient losses has assumed ominous proportions. While there is little scope for an increase in arable area, the major cause of concern is the decrease in arable area due to urbanization and soil degradation. Thus, a logical alternative for increasing food production is to develop, fine tune, and implement smart soil/crop management practices, which enhance and maintain the SOM content and plant nutrient reserves at appropriate levels. Adopting a strategy of INM can increase nutrient use efficiencies, strengthen nutrient cycling, and increase and sustain food production. The INM strategy involves meeting a crop's nutritional requirement to achieve the desired yield through judicious use of fertilisers, biofertilisers, biosolids, biological nitrogen fixation, and other nutrient cycling mechanisms that enhance nutrient use efficiency, and optimize the use of the most limited or nonrenewable resources (1). In this paper we bring together an array of information related to nutrient management in major spice crops with emphasis on INM strategies in black pepper, ginger, turmeric and cardamom.

Table 1 - Area, production and productivity of major spice crops in India

Year	Black pepper			Ginger			Turmeric			Small cardamom		
	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg ha^{-1})	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg ha^{-1})	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg ha^{-1})	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg ha^{-1})
2000-01	213.87	63.67	298	86.200	288.000	3341	191.70	714.30	3726	66.00	9.10	138
2001-02	219.38	62.44	285	90.500	317.900	3513	142.90	658.40	4607	65.20	9.90	152
2002-03	225.33	72.46	322	88.216	276.965	3140	150.10	522.24	3479	65.89	10.27	156
2003-04	233.41	73.22	314	85.900	303.350	3531	150.33	564.28	3754	66.01	10.46	158
2004-05	256.29	79.45	310	98.530	382.276	3880	157.79	712.59	4516	65.74	10.20	155
2005-06	260.23	92.94	357	113.551	408.788	3600	172.01	851.70	4951	66.07	11.37	172
2006-07	245.97	69.00	281	105.900	370.300	3497	186.00	837.20	4501	69.60	9.90	142

(Source: http://dacnet.nic.in/spices/publications/Area_and_Pro.pdf)

Area and Production

India has been a traditional producer, consumer and exporter of spices. Almost all states in the country produce one or other spices. Spices exports have registered substantial growth during the last one-decade, registering an annual average growth rate of 13.1% in value and 9% in volume. During the year 2009-10, spices export from India has registered an all time high both in terms of quantity and value. In 2009-10 the export of spices from India has been 502,750 tonnes valued ` 5560.50 crores (MLN US $ 1173.75 million) as against 470,520 tonnes valued ` 5300.25 crores (MLN US $ 1168.40) in 2008-09, registering an increase of 7% in volume and 5% in rupee value. India commands a formidable position in the World Spice Trade with 48% share in volume and 44% in value.

Black Pepper

Black pepper (*Piper nigrum* L.) originated in the tropical evergreen forests of Western Ghats of South India and is cultivated in twenty six countries located in the humid tropical belt of the globe with adequate rainfall and humidity. The crop tolerates the temperature range of 10ºC to 40ºC and an altitude from sea level to 1500 m above MSL in a wide range of soils. Major cropped area is in India (245970 ha), Indonesia (171000 ha), Brazil (45000 ha), Vietnam (50000 ha) and Malaysia (13000 ha) with a production of 62, 30, 39, 90 and 16.5 thousand tonnes in 2004, respectively. Among the major spice crops, the area under black pepper in India during 2000-01 was 213870 ha with a production of 63670 tonnes and productivity of 298 kg ha^{-1}. Statistics available up to 2006-07 reveal that the area increased to 245970 ha, with a production of 69000 tonnes and productivity of 281 kg ha^{-1}. Peak production of 92940 tonnes was recorded in 2005-06, from an area of 260230 ha and productivity of 357 kg ha^{-1} **(Table 1)**. Inter annual variations for area (CV=29.30 %), production (CV=39.91%) and yield (CV=14.58%) was noticed over the years (1961 to 2004). The fluctuation was insignificant before 1985 and there was a steady increase in area and production after 1985. The productivity increase was minimum. Cultivation is mainly confined to Kerala, Karnataka and Tamil Nadu. However, it is cultivated to a lesser extent in Andaman and Nicobar Islands, Pondichery, Maharashtra, Andhra Pradesh, Orissa, Goa, West Bengal and North Eastern States. The quantity exported varies over the year, during 2007-08, our export estimate was 35000 tonnes with a value of Rs. 519.5 crore and we export to more than fifty countries.

Ginger

Ginger (*Zingiber officinale* Rosc.) is a perennial herb, but cultivated as an annual for its underground rhizome which is used as a spice. The crop is

Table 2- Estimated production target for spices in India (Qty. = tonnes)

Year	All Spices	Black pepper[1]	Cardamom (s[2])	Ginger[3]	Turmeric[1]
2011-12	4268221	92658	36159	500558	776905
2016-17	4810895	103733	67535	640934	897816
2021-22	5416858	115362	126330	819999	1037830
2026-27	6103366	128570	236580	1051128	1200210

Note: 1-With 80% import reduction; 2-With 0% import; 3-With 60% import reduction
Source: (132)

originated as a native of tropical South-East Asia, got introduced into the West Indies, African countries and other tropical countries of the world. It is sold as fresh ginger or, more frequently, in a peeled and split dried form. Ginger is widely used in pickles, candies and such other preparations and as a medicinal herb. Dry ginger is used for preparing ginger powder, extracting ginger oil, oleoresin etc. India has the enviable position of being the World's largest producer and consumer of ginger. The major ginger producing countries are India, China, Nigeria, Indonesia, Bangladesh, Thailand, Philippines, Jamaica etc. United Kingdom, United States and Saudi Arabia import large quantities of ginger. Nigeria ranks first with respect to area under ginger covering about 56.23 percent of total world area followed by India (23.60%), China (4.47%), Indonesia (3.37%) and Bangladesh (2.32%). India ranks first with respect to ginger production contributing about 32.75 percent of world's production followed by China (21.41%), Nigeria (12.54%) and Bangladesh (10.80%). In 2000-01, the area under ginger in our country was 86200 ha with a production of 288000 tonnes and productivity of 3341 kg ha^{-1} **(Table 1)**. The production registered a marked 42% increase (408788 tonnes) in 2005-06 from an area of 113551 ha and a productivity of 3600 kg ha^{-1}. However, in the subsequent year, the production declined marginally by 9.0% to 370300 tonnes from an area of 105900 ha and productivity of 3497 kg ha^{-1}. High global demand for Indian ginger is due to its lemony flavour. India has capabilities to meet the quality and quantity demands of importing countries matching to international standards. India earned a foreign exchange of around Rs.40 crores during 2005-06 through ginger export. The crop exhibited an annual growth rate of 4.6 per cent in area, 7.4 % in production and 2.7 % in productivity.

Turmeric

Turmeric (*Curcuma longa* L.) is one of the most important spices used extensively by all classes of people in India. Besides, it is one of the most ancient and traditional spices of export for our country. India is the biggest producer of turmeric, supplying 94% of the world's demand. It is cultivated on a commercial scale and enters the market usually in the form of dried rhizomes which are then prepared according to their end use. It is widely used in South Asia as a spice. The main producing countries of turmeric include India, Pakistan and Bangladesh. Other producers include Sri Lanka, Taiwan, China, Myanmar, Indonesia, Jamaica, Haiti, Costa Rica, Peru, Brazil, Malaysia, Vietnam, Thailand, Philippines, Japan and Korea. These countries contribute to the production of around 8,00,000 tonnes of turmeric annually. India wholly dominates the world production scenario contributing to approximately 75% of the world's total production producing 6,00,000 tonnes of turmeric annually. The production of turmeric is concentrated in the southern part of the country mainly in the peninsular area. The warm climatic conditions and consistent rainfall in these areas support the growth of turmeric and many other spices also. Andhra Pradesh is the leading turmeric producing state in India followed by Tamil Nadu. Andhra Pradesh also dominates the area under production of turmeric. In India, the area under the crop was 191700 ha with a production of 714300 tonnes and productivity of 3726 kg ha^{-1} in the year 2000-01 (Table 1). A 25% reduction in area (142900) was observed in the subsequent year (2001-02). This possibly led to decreased production of 658400 tonnes, albeit an increase in productivity to 4607 kg ha^{-1}. An increasing trend in area under production from 2003-04 to 2006-07 led to greater production of turmeric with peak production of 851700 tonnes during 2005-06 and productivity of 4951 kg ha^{-1}.

Small Cardamom

Small cardamom (*Elettaria cardamomum* M.) production is concentrated mainly in India and Guatemala. In India, cardamom cultivation in located in three states viz., Kerala, Karnataka and Tamil Nadu. Kerala has 59% of area and contributes 70% of production; Karnataka 34% of area and 23% of production and Tamil Nadu has 7% of area as well as production. Cardamom continued to show positive trends in production and productivity, while the area under the crop showed very little increase **(Table 1)**. In 2000-01, the area under the crop was 66000 ha, with a production of 9100 tonnes and productivity of 138 kg ha^{-1}. In 2006-07, the area increased marginally to 696000 ha. Similarly, the production also increased marginally to 9900 tonnes with a productivity of 142 kg ha^{-1}.

Future Projections

Over the years, India's share in world spices market has not appreciated much and its monopoly as a supplier of spices is threatened by countries like China, Brazil, Vietnam, Pakistan, Egypt, Turkey and other African and Caribbean countries. India also faces shortage of exportable surplus because of increasing domestic demand. Sharp fluctuations in the quantum and value of exports and in the unit value realization have characterized the spices trade in recent years. The forecasted production level **(Table 2)** highlights the targeted task to be achieved for major spice crops. These estimates were made taking into account the present level of production, export, import, per capita consumption, expected level of increase in export and population growth etc. There is an urgent need to take stock of the present level of production and export and prospects of increasing the production with available technologies to meet the future demand. Another factor that needs to be considered is that in spices like black pepper majority of the vines in households supply the requirement for the family and only the surplus reach the market. Besides, the consumption of spices within the country has increased due changing food pattern and other alternate uses showing increased trend in per capita consumption of spices. For meeting the total demand, the productivity should be increased to 0.49, 1.45, 9.4 and 6.9 t/ha in black pepper, cardamom, ginger and turmeric, respectively by 2020.

Soil Suitability

Black Pepper

Black pepper requires a friable soil rich in humus and essential plant nutrients, with good drainage and adequate water holding capacity. Black pepper plantations are established on a wide variety of soils with varying texture from sandy loam to clayey loam. In Kerala state, Pepper is grown mainly as a monocrop in forest loam soils that are rich in organic matter, N and K and medium in phosphorus and base status and as a homestead mixed crop in coconut and arecanut gardens in red loam and lateritic soils that are acidic (pH 5.0-6.2) and in coastal sandy soils (2). Pepper is also grown as a mixed crop trailed on arecanut in alluviums that are deep with sandy or loamy in texture, moderately rich in plant nutrients and varying physico-chemical properties that respond well to management practices. Hamza et al. (3) reported that soils of high yielding black pepper gardens are sandy to loam textured with near neutral pH, high in exchangeable bases, organic carbon and micronutrients especially zinc. The major pepper growing soils of India can be broadly classified into four major orders *viz.,* Oxisols (6%), Alfisols (70%), Mollisols (10%) and Entisols (4%) (4).

Ginger

Ginger adapts widely to different soils. Higher yield requires well drained and deep friable soils. Shallow soil can also be used satisfactorily by proper bedding and mulching. In India, ginger is gown on sandy loams, clay loams and laterite soil but virgin forest soils rich in fertility are ideal. Generally large scale cultivation of ginger is practised in high range laterites of Kerala and North East states. Maximum ginger yield was realized in soils with bulk desnity 1.2 g cm^{-3}, moderate acidity (pH 5.7) and high organic matter (1.1%)

Turmeric

Turmeric can be cultivated in most areas of the tropics and subtropics provided the rainfall is adequate or facilities for irrigation are available. It requires a hot and moist climate. It is usually grown in regions with an annual rainfall of 1000 to 2000 mm; if the rainfall is below 1,000 mm, irrigation is required. Cultivation has been extended into wetter areas with over 2000 mm of rain per annum. It can be grown up to an altitude of 1,220 m in the Himalayan foothills. Turmeric thrives best on loamy or alluvial, loose, friable, fertile soils and cannot stand water logging. Well-drained sandy or clayey loam or red loamy soils having acidic to slightly alkaline soil is ideal for its cultivation Gravelly, stony and heavy clay soils are unsuitable for the development of the rhizomes.

Cardamom

The major soils of cardamom growing tracts come under the order alfisols, formed under alternate wet and dry conditions, and the suborder ustalfs derived from schists, granite and gneiss and are lateritic. Soils most suited for cardamom are red lateritic loam with layers of organic debris present in evergreen forests, although it grows on a variety of soils with only a shallow zone of humus accumulation. In general, cardamom-growing soils are fairly deep having good drainage. The clay fraction is predominantly kaolinitic and hence there is some fixation of potassium in these soils. The cardamom-growing soils of Karnataka are mostly clay loam (5). In Guatemala, cardamom growing areas have rich forest soils. Towards the northern region, it is grown in the newly cleared forestlands, the soil having dolomitic limestones, underlined with typical tropical clay. In the southern regions, soils are sandy clay loam with volcanic ash deposits. Soils in the south are more fertile than those of the north because of the presence of volcanic ash.

Soil Related Constraints

The main constraints faced in the potential zones for spices are steep sloping landform leading to excessive erosion, risk of water logging in valleys during heavy monsoon periods and acidic soils due to heavy leaching of bases from soil leading to low soil fertility status. The extent of soil erosion in spice growing tracts i.e. Western Ghats, Coastal and NEH region ranges from 20-80 t ha^{-1} yr^{-1}, rated to be very severe, affecting approximately 2.4 lakh km^2 area in this region. Adopting soil and water conservation measures like terracing and bunding to reduce the degree and length of the slope and to reduce erosion is the primary measure. Experiments were conducted at Cardamom Research Centre, IISR with soil and water conservation measures like contour staggered trenches (CST) in alternate rows, CST with cover crops viz. pineapple, ginger, french bean etc. in cardamom plantations. Average runoff and soil loss ranged from 2219.74 kg per hectare to 495.56 kg per hectare with a minimum runoff (31.82 mm) and soil loss (495.56 kg/ha) in CST with pine apple treatment. Small quantity of nutrients was removed through runoff water and addition of vegetative barrier like pine apple, french bean and ginger leads to better soil cover and additional income.

The major reasons for low productivity of spices are low soil pH, high clay and low sand content, low CEC, base saturation, low status of organic carbon, K, Ca, Mg and Zn. Use of low level of inputs like manures and fertilisers, crop protection materials and crop loss due to diseases ad to the farmers woes. Another crucial factor is the tree species used for trailing black pepper vines. A better understanding of the mechanisms by which they influence soil properties, will improve our ability to predict the effect of tree species on the ecosystem. An enhanced predictive capacity has many applications, including restoration of degraded black pepper plantations, designing of sustainable black pepper-tree support systems and nutrient management strategies, selection of tree species for enhanced C sequestration and improvement of soil quality in the tropics (6). This is more important for black pepper, because, unlike most other crops, pepper is a perennial crop and the utilization pattern of nutrients over several years, could be uniquely different.

Soil erosion and associated nutrient losses is a serious issue in the humid tropics, more so in ginger and turmeric as the soil is constantly disturbed for inter cultivation operations without any conservation measures. The introduction of contour staggered trenches (CST) could reduce the soil loss and runoff to a marked extent. In cardamom also, introduction of CST with cover crops like pine apple or french bean, reduces runoff and soil loss due to reduced rainfall erosivity and obstruction to overland flow by contour terrace as well as the barrier effect of crops. The use of plant covers on steep slopes is advisable for the recycling nutrients, and consequently for an efficient regulation of the flow of nutrients by runoff and sediments. Vegetation cover makes a nutrient pool available while moderating surface runoff and sediment movement, both of which are major nutrient carriers. In addition having inter or cover crops improves the soil fertility that benefits the both the main and component crops. Live mulches like sun hemp, green gram, horse gram, black gram, niger, sesbania, cluster bean, French bean, soybean, cowpea, daincha and red gram can also be grown as intercrop in ginger or turmeric and mulched *in situ* between 45-60 days after planting will reduce weed growth and increase the yield. Green manure crops like daincha (*Sesbania aculeata*) can be raised successfully in inter-spaces of ginger beds in a row, which adds to 50% of the green leaves required for mulching, suppresses weed growth and reduces cost of production.

Adopting optimum spacing, nutrient and water requirements for black pepper, cardamom, ginger and turmeric that are standardized for different soils will ensure profitable productivity. Also, proper land use with appropriate crop planning with perennial crops and recommended package of practices has to be followed to prevent soil degradation, to improve productivity and the environment. Except for turmeric and minor seed spices, growing in wide range of pH (5.0 to 7.5), all the other major spices are grown in slightly acidic soils which are being grouped under red loams or laterites. These soils are generally deficient in available P, Ca, and Mg and possess low CEC. Intensive survey in spice growing areas of Kerala showed that 57% of the samples collected were low in P and judicious application of P is vital in these soils for sustainable production. Among micronutrients, deficiency of Zn is more predominant in acid soils of India with highest deficiency rate of 57% in acid soils of Meghalaya followed by Jharkhand, Orissa and West Bengal (23-54 %). Fifty per cent of turmeric growing soils in Andhra Pradesh are Zn deficient, more than 80% are deficient in Fe and 80 % of them are calcareous (with > 50% of $CaCO_3$) (7). Deficiency of micro nutrients in soil like boron (B) results in reduced accumulation of sugars, amino acids, and organic acids at all leaf positions and overall reduction in yield. Hence technologies to alleviate macro and micro nutrient deficiencies in location specific soil-crop systems have to be given priority. Fertigation

Table 3- Nutrient removal by an adult (8 years) pepper vine (kg ha^{-1})

Variety	Panniyur-1				Karimunda			
Parts	Dry matter	N	P_2O_5	K_2O	Dry matter	N	P_2O_5	K_2O
Stem	6.0	43.8	13.7	100.8	4.4	35.6	8.1	68.6
Leaf	6.0	151.8	28.9	195.6	5.8	98.6	30.5	22.1
Root	2.5	72.3	9.2	76.0	2.2	26.4	5.5	55.4
Berry	1.0	24.2	4.6	32.3	1.0	22.0	5.0	30.2
Total	15.5	292	56	405	13.4	183	49	376

(Spacing 3x3 m accommodating 1100 vines ha^{-1}); Source: (4)

is adopted under precision farming project of Tamil Nadu for augmenting turmeric yield (8). Identification of efficient location specific strains of bio fertilisers and developing INM through conjoint use of organics, to meet the plant nutrient requirement may be thought of.

Nutrient Requirement and Removal

Black Pepper

Major nutrients (nitrogen, phosphorus, potassium), secondary nutrients (calcium, magnesium and sulphur) and micronutrients especially Zn are the most important nutrients essential for black pepper growth, development and yield. Studies on nutrient removal by black pepper plants showed that three months old cuttings with four to five leaves removed 64.8, 3.3, 54.8, 24.5, 11.2, 8.1 mg of N, P, K, Ca, Mg and S respectively. Among the major nutrients studied, uptake of N was highest followed by K and Ca and among micro nutrients iron uptake was the highest. The magnitude of the nutrients removed was in the order: N>K>Ca>Mg>P>S.

Azmil and Yau (9) reported that the nutrient removal by black pepper plants was N - 255, P - 22.8, K - 208.2, Ca - 54.5 and Mg - 36.4 kg ha^{-1}. Sadanandan (10) reported a higher uptake of N and K up to the magnitude of 183-292 kg ha^{-1} and 313-337 kg ha^{-1}, respectively by eight year old yielding vines of pepper with a population of 1000 vines ha^{-1}. The magnitude of removal by Indian varieties is almost comparable to that of Malaysian varieties **(Table 3)**. Sadanandan (4) found that varieties like Panniyur-1 and Karimunda removed 292 and 183 kg ha^{-1} $year^{-1}$ of N respectively. Azmil and Yau (9) quantified the P removal by various plant parts (g $vine^{-1}$) as: leaves-3.64, branches-2.58, stem-3.96, fruit spikes-0.08 and flowers-0.18 with a total of 22.8 kg ha^{-1}. Similarly, Sadanandan (10) reported a removal of 24.6 and 21.4 kg P ha^{-1} by Panniyur-1 and Karimunda varieties of which 50-62% of removal was constituted by the leaves followed by stem (16-24%), root (11-16%) and berries (8-10%). Among the sources of P, bone meal and mussoorie rock phosphate were found to be better P sources in an acid soil for the pepper varieties Panniyur-1 and Karimunda than super phosphate with higher cumulative yield and relative agronomic efficiency (11). As plant density increased from 1100 to 5000 ha^{-1}, depletion of organic matter, K, Ca, Mg and micronutrients like Zn, Fe, Cu and Mn was more in soils (12).

Pepper requires large quantities of K for growth and fruiting and K requirement is related to the content of other nutrients in the plant, mainly nitrogen. A soil fertility survey carried out in the major pepper growing tracts in the states of Kerala and Karnataka in India indicated that 10% of the gardens surveyed were low (< 120 kg ha^{-1}), 31% medium (120-280 kg ha^{-1}) and 59% high (> 280 kg ha^{-1}) in available K status. The amount of K removed by various parts of the black pepper plant has been quantified (g $vine^{-1}$) as leaves 28.73, branches 28.7, stem 19.6, fruit spikes 0.05, and flowers 1.4 with a total uptake of 203.2 kg ha^{-1} (9). However, higher removal to the extent of 313-337 kg K ha^{-1} by Indian varieties has been reported by Sadanandan (10). Even though the varieties Panniyur-I and Karimunda have shown comparable amount of total K removed, K removal by leaf was higher in Karimunda (58.9%) in spite of less dry matter compared to Panniyur-1 which recorded higher removal by stem. Among the K sources, potassium sulphate was found to have a positive influence on quality (oleoresin 13.5% and piperine 6.1%) of black pepper (13).

Calcium is removed to an extent of 54.5 kg ha^{-1} and the total Mg removal is 36.4 kg ha^{-1} (9) by different plant parts of pepper. The removal by stem

Table4 - Nutrient uptake by black pepper and fertiliser recommendations

Sl. No	Country	Nutrients removed (kg ha^{-1})	Dose recommendation (kg ha^{-1})	Source
1	Malaysia (Sarawak)	cv. Kuching N 252, P_2O_5 32, K_2O 224	N: P_2O_5 : K_2O: MgO 240: 120:340:100 and 28g trace elements	(117)
2	Sarawak	N 233, P_2O_5 39, K_2O 207		(118)
3	Sarawak	-	N 340g (Urea)*, P 113g (S. Super)*, K 454 g (MOP)*	(10)
4	Malaysia (Johore)	-	N 250, P_2O_5 100, K_2O 250 (+400 gm magnesium lime stone/ plant)	(9)
5	India	N 34, P_2O_5 3.5, K_2O 32 (g $vine^{-1}$)	N 50, P_2O_5 50, K_2O 200	(119)
6	India	N 137, P_2O_5 61, K_2O 330	N 140, P_2O_5 55, K_2O 270	(4)

* per vine

and branches was maximum with 30 and 34.3% followed by leaves (12.5 and 15.2%), respectively in Mg and Ca. Sadanandan (14) reported the positive effects of Ca and Mg application at 50 kg each ha^{-1} levels. Yield response can be expected for pepper when sulphur content in the soil is less than the threshold value of 6 mg kg^{-1}. Hardly any response was seen as sulphur gets supplemented through super phosphate source which makes up the crop requirement (10). Among micronutrients, zinc, molybdenum and boron are likely to become deficient in acid soils by leaching or precipitation. Studies on nutrient removal by black pepper plants showed that about three months old cuttings with four to five leaves removed 981, 19, 128 and 451 mg of Fe, Mn, Zn and Cu respectively. The magnitude of the nutrients removed was in the order: Fe>Cu>Mn>Zn.

Ginger

Ginger rhizomes are mainly N and K exhausting, intermediary in P and Mg removal and the least in Ca removal (15). The uptake of N, P and K in leaf and pseudostem increases up to 180 days and then decreases, whereas that of rhizome uptake steadily increases till the harvest (16). Xu et al. (17) observed that ginger shoots and leaves were growth centers at the seedling stage, and 80.7 % of the carbon (C) assimilation was transferred to these parts. About 48.41 % of the N absorbed from fertiliser applied at seedling stage was distributed to the shoots and leaves. While 65.43 % of the N derived from fertiliser applied at vigorous growth of rhizome was distributed into rhizomes, only 32.04 % was distributed into shoots and leaves. The results indicated that the rate of fertiliser-N utilisation increased with delay of application. An average dry yield of 4.0 t ha^{-1} dry ginger rhizomes removes 70 kg N, 17 kg P_2O_5, 117 kg K_2O, 8.6 kg Ca, 9.1 kg Mg, 1.8 kg Fe, 500 g Mn, 130 g Zn and 40 g Cu ha^{-1}. For healthy growth of ginger, very low external Ca is required. A heavy ginger crop removes 35-50 kg P ha^{-1}. The leaves of healthy plants contained 1.1 to 1.3% of Ca and concentrations as low as 2 ppm is sufficient to achieve 90 per cent of maximum yield. In order to calculate nutrient requirement of the crop, Johnson (16) recommended 5^{th} pair of leaf in a period between 90 and 120 DAP for foliar diagnosis of N, P and K.

Turmeric

In turmeric the maximum uptake was observed in active vegetative growth phase. Higher uptake of K up to third, N up to fourth and P up to fifth months of development was observed with subsequent decrease in their uptake. Planting mother rhizomes enhances the uptake of N, P and K as compared to primary or secondary rhizomes. The uptake of nutrients by turmeric was in the order of K > N > Mg > Ca **(Table 5)** (15). An average dry yield of 5.5 t ha^{-1} rhizome removes 91 kg N, 16.9 kg P_2O_5, 245 kg K_2O (18). According to Kumar et al. (19) approximately 9% of the turmeric growing area in Tamil Nadu is severely limited by mineral nutrition and about 20% of samples were identified as having deficiencies. They worked out optimum levels for 12 nutrients (N, P, K, Ca, Mg, Na, S, B, Zn, Cu, Fe and Mn) in the leaves of turmeric using Diagnosis and Recommendation Integrated System (DRIS)/Modified Diagnosis and Recommendation Integrated System (MDRIS) and Compositional Nutrient Diagnosis (CND) approaches. The reference norms for optimum concentration in leaves of turmeric in Erode district of Tamil Nadu ranged as 1.22-2.75% for N, 0.36-1.27% for P, 3.66-6.6% for K, 0.18-0.33% for Ca, 0.61-1.25% for Mg, 0.16-0.31% for Na, 0.13-0.29% for S, 14.3-26.3 mg kg^{-1} for B, 41.1-93.2 mg kg^{-1} for Zn, 15.2-40.3 mg kg^{-1} for Cu, 143-1568 mg kg^{-1} for Fe and 66-219 mg kg^{-1} for Mn. The order of nutrient imbalance was in the order S > B > Mg > Cu > P > Na > Ca > K > Zn > N > Fe > Mn based on DRIS, S > B > Cu > Ca > Na > Zn > Mg > P > Fe > Mn > K > N based on MDRIS, and S

Table 5 - Removal of nutrients by turmeric at harvest (kg ha^{-1})

Location/soil type	Nutrients					Source
	N	P_2O_5	K_2O	Ca	Mg	
Kasaragod-Laterite	124	30	236	73	84	(15)
Vellanikkara-Laterite	72-115	14-17	141-233	--	--	(120)
Bhavanisagar-Sandy loam	166	37	285	--	--	(120)
Coimbatore-Clayey loam	187	39	327	--	--	(120)
Calicut – Laterite	86	31	194			(18)

> Ca > Na > Mg > Cu > Zn > K > B > Mn > P > N > Fe based on CND. Among the various approaches, CND projected the nutrient imbalances better than DRIS. Among the micronutrients, deficiency of B in turmeric results in reduced accumulation of sugars, amino acids, and organic acids at all leaf positions. Translocation of the metabolites towards rhizome and roots and photoassimilate partitioning to essential oil in leaf and to curcumin in rhizome decreases. The overall rhizome yield and curcumin yield also decreases due to B deficiency (20).

Dixit and Srivastava (21) observed decrease in plant growth, fresh weight, rhizome size, photosynthetic rate and chlorophyll content and significant increase in curcumin content in all the genotypes due to Fe deficiency. N, Mn and Zn contents of rhizomes had a positive significant correlation with curcumin content, whereas P, Ca, Mg, S, Cu and Fe contents had no correlations (22). Total Zn concentration in the third leaf was considered for delineation of deficiency that varied from 10 to 51.3 mg kg^{-1}. Zinc concentration was significantly and positively correlated with leaf weight and rhizome yield and negatively with Fe: Zn and P: Zn concentration ratios. P: Zn ratio in the absence of added Zn proved as a good indicator of efficiency of response to added Zn (23). Leaf P: Zn ratio had a positive correlation and soil P: Zn ratio had negative correlation with rhizome yield (24).

Small Cardamom

Cardamom is generally grown in the rich fertile soils of the forest eco-system. The nutrient analysis data obtained from cardamom-growing tracts in south India revealed that the limiting leaf nutrients were in the order Zn > K > P > Ca > Mg > Cu > Mo > Fe > Mn > N (25). Being a perennial crop, sucker production is throughout the year. Initiation of panicles and development of capsules are spread over a period of eight to nine months in a year. A steady absorption and utilization of plant nutrients take place throughout the life cycle of cardamom and hence a regular application of nutrients should be followed for higher yields. Good plant growth, yield and capsule quality depends on an adequate supply of all the nutrients through the growth period. A deficiency of any one of them will affect the cardamom yields detrimentally (27).

Deficiency symptoms of N, P, K, Ca and Mg have been observed and were found to be expressed when their contents in leaf were 0.84, 0.32, 2.16, 0.65 and 0.11% respectively. Nutrient uptake studies in cardamom have indicated the uptake of N, P, K, Ca and Mg to be in the ratio of 6:12:3:0:8 respectively and for the production of one kg of cardamom capsules, 0.122 kg N, 0.014 kg P and 0.2 kg K are removed by the plant (5). Korikanthimath et al (27) reported that N, P and K uptake by cardamom increased with increase in dry matter production. Of the various nutrients, the total K uptake was more followed by N and P in both stages of crop suggesting that the crop requires more of K than N and P. Among the different plant parts, highest contribution to the total N uptake was by green leaves (44.69%) and tillers (29.6%) in one-year-old and prepotents respectively. The highest P and K uptake was by roots and grown up tillers in one-year-old plants and green leaves and tillers in prepotent plants respectively. The broad nutrient uptake ratio per plant was 9N:1P:17K. Among secondary nutrients, the highest uptake of Ca was observed in shoots at both the stages, whereas, for Mg it was the leaves which showed highest values. Uptake of Ca by shoots at harvest stage was more than that of pre-bearing stage. The reverse was the trend in case of Mg (28).

Soil Test Based Nutrient Recommendations

Black Pepper

Long-term studies (18 yrs) on NPK fertilisation of black pepper in a laterite soil of Kerala, India revealed that the economical optimum was at 140-55-270 kg ha^{-1} N, P_2O_5 and K_2O respectively with 15 tonnes green leaf ha^{-1} yr^{-1} (29). However, the quantity of fertilisers required to get high yield varied largely among locations **(Table 4)**. A yield increase of 22% was recorded by Sarawak workers when nine sprays of 0.7%

urea at weekly intervals were given (30). Experiments conducted on bush pepper showed that nutrient availability increased significantly due to increasing dose of NPK application. Among the treatments, NPK at the rate of 0.5, 1.0 and 2.0 g $plant^{-1}$ was superior for optimum yield realization (18).

The application of 400-600 g $plant^{-1}$ NPK and Mg (12:12:17:2) three times a year, with 500 g $plant^{-1}$ dolomite applied two times a year is reported to be the best fertiliser dose for productive black pepper plantations in Bangka (31). For the Johore area in Malaysia the recommendation is 120 kg N, 80 kg P_2O_5 and 50 kg K_2O ha^{-1} for the first year; 200 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1} for the second year and 250 kg N, 100 kg P_2O_5 and 250 kg K_2O ha^{-1} for mature plants to give sustainable high yield (9). Veloso et al. (32) reported increased yield of black pepper due to fertiliser application at 72-98 kg ha^{-1} N, 60 kg ha^{-1} P and 13 to 42 kg ha^{-1} K. Muthumanickam (33) reported increased yield (9.2 kg $vine^{-1}$) and oleoresin content (12.34%) of black pepper in acid soils of Yercaud, India due to soil application of 40g P_2O_5 as rock phosphate and spraying of 0.5% $ZnSO_4$. Studies carried out at IISR showed that application of NPK at 150:60:270 kg ha^{-1} with micronutrients Zn, B and Mo at 5:2:1 kg ha^{-1} recorded highest yield in varieties Subhakara and Sreekara. Application of 2.5 mg kg^{-1} of Zn for potted bush pepper and 2.5 kg ha^{-1} Zn for field planted pepper as Zn- EDTA was found to increase soil Zn availability, berry yield, oleoresin and piperine. Among sources of Zn and methods of application, soil application of 2.5 kg ha^{-1} of Zn as $ZnSO_4$ gave the highest benefit: cost ratio of 5.27 followed by foliar spray of $ZnSO_4$(34).

Molybdenum is found to increase with the application of organic matter, as it forms a complex which makes Mo more available to the plants for absorption. Liming also increases the available Mo content in the soil. Boron deficiency can be expected in coarse textured soils low in organic matter, especially in high rainfall areas. Hamza and Sadanandan (35) reported that application of Zn at 5 mg kg^{-1} for potted bush pepper and Zn at 6.2 kg ha^{-1} for field condition was optimum for increasing yield and improving the quality of black pepper. They also reported that under Mo deficient conditions, black pepper responds up to 0.9 kg ha^{-1} of Mo and application of Mo at 0.25 mg kg^{-1} soil or foliar spray of 0.1% sodium molybdate is economical in increasing the yield and quality of bush pepper (36). In Brazilian soils with low levels of micronutrients, application of 25g $ZnSO_4$, 2.0g $CuSO_4$, 5.0 g H_3BO_3, 8.0 g $FeSO_4$ and 6.0 g $MnSO_4$ $plant^{-1}$ is recommended (37). Economic analysis of experimental results using appropriate tools enabled identification of risk-free rational technology wherein application of ½ prevailing package of practices + Zn is a risk free rational technology for better returns from black pepper (38).

Liming is critical in acid soils under black pepper. Studies showed that liming enhances yield and quality of pepper (36). They observed increased quality of pepper in terms of its piperine content in potted bush pepper with application of lime at 20g pot^{-1} and significant yield increase under field condition with high benefit cost ratio (4.58) at an application rate of 0.5 t ha^{-1}. They also reported an increased soil Mo availability with the application of 0.5 tonnes ha^{-1} lime alone or 0.5 kg ha^{-1} Mo + 0.5 t ha^{-1} lime.

Ginger

Response of fertiliser varies with variety, soil type and climate. A fertiliser dose of 36-225: 20-115: 48-200 N, P_2O_5, K_2O kg ha^{-1} has been adopted in different states in India. Maximum yield was obtained with the application of 125 kg N ha^{-1} in Orissa (39), with 100 kg N ha^{-1} in Himachal Pradesh (40) and with 150 kg N ha^{-1} in Maharashtra, India (41). However, higher dose of N has been found to decrease the yield (42). The ginger growth and yield is highly influenced by the N levels and yield increase was observed with optimum levels. The application of N beyond optimum results in disturbing the balance between N and carbohydrate compounds within the plants and plants developing under such metabolic conditions showed lower growth (43). Lee and Asher (44) rated the cost effectiveness of N fertilisers in the order: urea > ammonium nitrate > ammonium sulphate.

A heavy crop removes 35 to 50 kg ha^{-1} of P and it is mostly applied as a basal dose at the time of planting. Plant height, number of leaves per clump, number of tillers per clump, leaf length, fresh and dry yield, crude protein and fibre, and volatile oil content were highest when ginger was sown in flat beds followed by earthing up and application of 50 kg P ha^{-1} (45). K is one of the most important limiting factors for ginger production, since the crop removes a large amount of soil K (up to 500 kg ha^{-1}). The main practices to obtain high rhizome yield include top dressing K fertiliser at growth stages with peak demand and applying enough K to balance the appropriate N and P application rates (46). In the lower range of replaceable K (0.3 me %), a positive field response was observed with application of up to 325 kg K_2O ha^{-1}, while above 0.3 me % no response was recorded with rates above 60 kg K_2O ha^{-1}. Even though, K increased the yield, a higher dose of K_2O reduced the height of plants and yield (47). Besides sole application of K, an obvious response of ginger growth and quality was observed due to the combined application of N and K (48). They observed that a suitable rate and ratio of K and N combined application markedly promoted ginger growth, increased rhizome yield, improved nutrition qualities

Table 6 - Manures and fertilisers recommended for ginger in various locations of India

State	Recommendation
Kerala	FYM 30 t ha^{-1}; NPK 70:50:50 kg ha^{-1}. Full dose of P and 50% K may be applied as basal dose. Half the quantity of N applied at 60 DAS. The remaining quantity of N and K applied at 60 DAS.
Karnataka	FYM/compost 25 t ha^{-1}; NPK 100:50:50 kg ha^{-1}. Apply the entire dose of P and K at planting. Half quantity of N to be applied at 30-40 DAS and other half at 60-70 DAS.
Orissa	FYM 25 t ha^{-1}; NPK 125:100:100 kg ha^{-1}. Full P and half K applied as basal dose in furrows before planting and N and K in 2 splits at 45 and 90 DAS.
Himachal Pradesh	FYM 20-30 t ha^{-1}; CAN @ 400 kg ha^{-1}, NPK 100:50:60 kg ha^{-1}. Apply P and K at the time of planting and N in 3 equal splits, first at the time of planting and subsequent 2 doses at monthly interval. K_2O also can be applied in two splits, half at sowing and other half at rhizome initiation.
Bihar	FYM 20-30 t ha^{-1}; NPK @ 60:60:120 kg ha^{-1}
Andhra Pradesh	FYM 20-30 t ha^{-1}; NPK @ 75:50:50 kg ha^{-1}
Chattisgarh	FYM 20-30 t ha^{-1}; NPK @ 150:125:125 kg ha^{-1}
Sikkim	Manures 40-50 t ha^{-1}; Few farmers apply fertilizers*
Meghalaya	FYM 10 t ha^{-1}; NPK @ 60:90:60 kg ha^{-1}**

Source: (61) * (121); ** (122)

and enhanced K recovery efficiency. Besides, the maximum rhizomatous yield was attained by the application of 450 kg ha^{-1} each of N and K. They also observed that 2 ppm Ca concentration was sufficient to achieve 90% of maximum yield.

In Kerala, India three N and K combinations *viz*., 150 kg N + 50 kg K, 150 kg N + 100 kg K and 75 kg N + 150 kg K ha^{-1} were found to be superior for yield. However, the optimum dose was found to be 144 kg N and 109 kg ha^{-1} K (50). Under low shade, 150 per cent (112.5: 75: 75 kg NPK ha^{-1}) of the recommended dose (75:50:50 kg ha^{-1}) enhanced the yield (51, 52). Gowda et al. (53) obtained higher yield (15.62-22.53 t ha^{-1}) with the combined applications of 150 kg N + 75 kg P ha^{-1}; 150 kg N + 50 kg K ha^{-1}; and 25 kg P + 50 kg K ha^{-1}. However, the yield of variety 'Rio-de-Janiero' could be increased by the application of 150 Kg N, 75 kg P_2O_5 and 50 kg K_2O ha^{-1} in Bangalore. In Orissa, maximum yield of 10.16 t ha^{-1} was obtained by planting 1.8 tonnes of seed rhizomes and application of 125 kg N, 70 kg P and 150 kg K ha^{-1} (39). In China, 260-300 kg ha^{-1} of K_2O and approximately 300 kg ha^{-1} of N is recommended to improve the inherent and external quality of ginger and to increase the content of vitamin C (ascorbic acid) and soluble sugar and markedly decrease the content of nitrate in ginger rhizomes (54). Further, they registered the highest rhizome weight in ginger with 375 kg N + 90 kg P + 450 kg K ha^{-1} (55).

Studies by Haque et al. (56) revealed that the effects of combined application of N and K was found more pronounced than the single effect of N and K and also the effect of N was more distinct than K. The combined effect of N and K up to 180 and 160 kg ha^{-1} respectively had significantly increased the yield and other yield contributing characters like plant height, number of leaves, finger numbers, weight and rhizome yield. The highest mean yield (26.95 t ha^{-1}) was also recorded by N and K application at 180 and 160 kg ha^{-1} respectively. Paliyal et al. (57) obtained highest rhizome yield of 16 t ha^{-1} due to balanced nutrient application of FYM at 20 t ha^{-1} and 100-75-40-5-1 kg ha^{-1} of N-K-S-Zn-B fertilisers. Application S, Zn and B along with NPK increased the uptake of N, P, K, Ca and S. Soil availability of organic carbon, available N, P, S, Ca, S, Cu, Mn, Fe and Zn increased after the harvest of the crop. The fertiliser requirement of ginger in different states of India was studied and the recommendations are provided in **Table 6**.

Micronutrient deficiency is common in ginger-growing soils and application of micronutrients has markedly improved growth and yield. Soil and plant analysis of samples across the country revealed 49% mean deficiency of zinc (Zn) with acid soils of Meghalaya having the highest deficiency rate of 57% (58). Roy et al. (59) obtained maximum yield with a combined spraying of Zn (0.3%) + Fe (0.2%) +

Table 7 - Optimum levels of N, P and K (kg ha^{-1}) recommended for turmeric in different locations

NPK	Recommended Location	Source
150:125:250 kg ha^{-1}	Central Karnataka Plateau, Hot Semiarid eco region	(124)
120: 60:120 kg ha^{-1}	Hill zone of Karnataka	(125)
60: 50: 120 kg ha^{-1}	Western Ghats and Coastal Plains of Kerala, Hot humid eco region	(123)
130: 90: 70 kg ha^{-1}	Subdued Eastern Himalayas (Arunachal Pradesh), warm to hot per humid region	(126)
200: 60: 200 kg ha^{-1}	Alluvial plains of West Bengal	(127)
75: 60: 150 kg ha^{-1}	Middle Gangetic plain, hot moist semi dry eco region (Allahabad)	(128)
100: 50: 50 kg ha^{-1}	Western Himalayas, hot moist subhumid transition eco region (Shimla hills)	(129)
200: 100: 100 kg ha^{-1}	Eastern Plateau, hot dry subhumid eco region (Maharashtra)	(130)
100: 100: 100 kg ha^{-1}	Middle Gangetic plains of Uttar Pradesh	(131)

B (0.2%), twice at 45 and 75 days after planting. Foliar application of Zn at 0.25% (twice-May-June and August-September) increased the rhizome yield (16.2 kg/3m^2 bed), as compared to soil application (14.4 kg) (60). Studies conducted at Solan on the effect of micronutrients namely, Zn (20 kg ha^{-1}), B (10 kg ha^{-1}), Mo (1 kg ha^{-1}), Mg (10 kg ha^{-1}) and Jagromin (chelated form of micronutrients) along with recommended dose of NPK (100:50:50 kg ha^{-1}) showed significant increase in the yield with NPK along with two sprays of Jagromin (0.7%), once at rhizome initiation and again one month after the first spray (61). In an Ustic Humitropept soil of Kerala, highest rhizome yield (13.78 kg bed^{-1} of 3 m^2) was obtained in plots where Zn (zinc sulfate) at 5 kg ha^{-1} was applied. The optimum fertiliser rate for obtaining maximum rhizome yield was determined as 6 kg Zn ha^{-1}. The maximum limit of soil DTPA-extractable zinc for obtaining higher rhizome yield was 3.4 mg kg^{-1} (58). An appropriate critical limit of 2.1-3.74 mg Zn kg^{-1} for soil and 27.0-53.8 mg Zn kg^{-1} for leaf was fixed for getting maximum ginger yield (62). Application of Cu (0.05% spray) or combined spray of Cu and Mn (0.05%) has resulted in higher carotenoid and chlorophyll accumulation in ginger resulting in increased photosynthate production, there by increased crop yield (63). Sole application of Zn or combined application with B significantly influenced rhizome yield and yield attributes of ginger (64, 65), in micronutrient deficient soils of Bangladesh. The integrated effect of B and Zn was found to be highly significant. They observed about 125 and 143% yield increase in Zn and B combined application at the maximum level (B-3.0, Zn-4.5 kg ha^{-1}) over the control (B-0, Zn-0) with highest economic return and marginal rate of return (484 and 548%) in two successive years.

Turmeric

Being an exhaustive crop, turmeric responds well to judicious application of fertilisers and yield increases to the tune of 81 to 282% have been observed due to fertiliser application compared to non-fertilized control. Location specific fertiliser recommendations have been made based on agro climatic situations **(Table 7)**. Studies indicate that turmeric responded economically up to 300 kg N ha^{-1}. In Tamil Nadu increased N levels up to 120 kg N ha^{-1} significantly increased the fresh rhizome yield (41 t ha^{-1}) and the yield increase was up to 62 %. The yield of fresh rhizomes increased as a result of N application from 0 to 130 kg ha^{-1} and P application up to 177 kg P_2O_5 ha^{-1} and split application of N did not affect the rhizome yield (66). Contrarily, in the Trans Gangetic plains of Punjab, application of 60 kg N ha^{-1} in three equal splits produced the maximum fresh rhizome yield than basal application of whole N (67). In Maharashtra, yield response to application of N up to 120 kg ha^{-1} was observed (68), while, application of 80 kg N ha^{-1} was the optimum dose for increasing productivity of turmeric in Nagaland (69).

The response to applied P is reported up to 175 kg ha^{-1} with the combination of other nutrients. Application of rock phosphate (RP) and single super phosphate (SSP) in ratios of 1:3, 1:1, 3:1 combinations also increased the yield of turmeric in comparison to the control. The highest yield was obtained following the application of 90 kg N and 60 kg P ha^{-1} in an intercropping system with poplar on sodic soils (70). Under North eastern plain, hot semi arid regions of Haryana conditions, split application of K at 25 kg K_2O ha^{-1}, half at planting and half at earthing up resulted in higher rhizome yield (25.7 t ha^{-1}) as compared to basal application alone (71). A study by Yamgar et al. (72) revealed that application of K_2O at 175 kg ha^{-1} registered significantly the highest turmeric yield. Among the K sources, increased yield was obtained with K_2O in the form of sulfate of potash. Significantly higher yield was obtained with K_2O in split (50% at planting and 50% at the time of earthing up) than that with basal dose.

Optimum levels of N, P and K, and method of application vary with locations. In Karnataka, maximum yield and cost-benefit returns were recorded with the application of 150:125:250 kg NPK ha^{-1}, irrespective of cultivars (123). Similarly, in Maharashtra state application of N:P:K at 200:100:100 kg ha^{-1} resulted in the maximum plant height, fresh rhizome yield the highest net return with a benefit cost ratio (129) and split application of N was better compared to one time application. N applied in 3 splits recorded the highest rhizome yield, maximum net returns and benefit: cost ratio. Swain et al. (72) recorded the highest fresh yield with 120:60:120 kg N: P: K_2O ha^{-1}, but the highest benefit cost ratio was obtained with 100:50:110 kg N: P: K_2O ha^{-1}.

Combined application of N and K (NK) or N, P and K (NPK) provided 4 to 6 times greater shoot biomass and 8 to 9 times higher yield (73) and Jagadeeswaran et al. (74) found that fresh rhizome yield increased significantly up to 125% of recommended NPK level applied in the form of tablets. Micronutrient application positively influenced turmeric growth and yield and up to 24% increase in rhizome yield with the application of $FeSO_4$ at 30 kg ha^{-1} was observed in Fe deficient soils of Tamil Nadu. Application of $ZnSO_4$ at 15 kg ha^{-1} increased the rhizome yield by 15%. Combined application of 50 kg ha^{-1} each of $FeSO_4$ and $ZnSO_4$ increased yield up to 21.4 t ha^{-1}. Foliar application at 0.25% $ZnSO_4$ twice has given higher rhizome yield on par to soil application of 7.5 kg Zn ha^{-1} (74). Turmeric cultivars (Krishna, Suvern, Salem and Waigaon) registered the greatest plant height, number of leaves per plant, leaf area index, total dry matter per plant, highest average and total yield of fresh and dry rhizomes at recommended fertiliser rates in Akola, Maharashtra (RFR, 120 kg N + 60 kg P_2O_5 + 60 kg K_2O) + 30 kg Zn ha^{-1} (75). Halder et al. (64) found that the highest rhizome yield was recorded with the combination of Zn and B applied at the rate of 4.5 and 3.0 kg ha^{-1}, respectively.

Small Cardamom

The present recommendation of nutrients for cardamom is NPK at 75:75:150 kg ha^{-1}. For rapid multiplication of suckers, application of 32.5 g of N, 25 g of P_2O_5 and 50 g of K_2O plant was found desirable. A fertiliser dose of 37.5:37.5:75 kg of NPK ha^{-1} for one year old crop during September and 75:75:150 kg of NPK ha^{-1} from second year onwards in two - split doses (during May and September) were found to be optimum. Numerous studies exist on the optimum NPK levels for maximum capsule yields in cardamom. A fertiliser dose of 45: 45: 45 kg N, P_2O_5 and K_2O ha^{-1} for Kerala, 67: 34: 100 kg N, P_2O_5 and K_2O ha^{-1} for Karnataka with half N in organic form and 45: 34: 45 kg N, P_2O_5 and K_2O ha^{-1} for Tamil Nadu. Considering the low nutrient requirement and the high status of N and K in cardamom-growing soils, a maintenance dose of 30:60:30 kg N, P_2O_5 and K_2O ha^{-1} was recommended (75). For a crop yielding 100 kg dry capsules ha^{-1} under rainfed conditions, the present fertiliser dose of 75:75:150 kg N, P_2O_5 and K_2O ha^{-1} was recommended. But when plant population is increased to 5000 ha^{-1} under trench method of planting, a fertiliser dose of 120:120:240 kg N, P_2O_5 and K_2O ha^{-1} is recommended (77). Under low rainfall situations prevailing in the lower Palni tracts of Tamil Nadu, a fertiliser dose of 40:80:40 kg N, P_2O_5 and K_2O ha^{-1} was found to be optimum (78). Kumar et al (79) reported that highest application of 150:150:225 kg NPK ha^{-1} recorded highest green capsule yield. Contrarily, Murugan et al. (80) reported that increasing the levels of N, P and K increased the yields of cardamom up to 125:125:200 kg ha^{-1}. Under irrigated conditions, tiller initiation and panicle initiation are continuous processes and hence more split applications are beneficial (28).

Significant yield increase and savings in fertiliser requirements would be possible by way of soil-cum-foliar application. The findings of Srinivasan et al. (81) suggested that in Karnataka state (India) , N, P_2O_5 and K_2O ha^{-1} at 37.5: 37.5: 75 kg ha^{-1} through soil application and 2.5 % urea + 0.75% single super phosphate + 1.0% muriate of potash through foliar spray gave 64 kg yield increase ha^{-1} over no fertiliser application. The yield increase recorded in Tamil Nadu state (India) was 43 kg ha^{-1} when a fertiliser dose of 20: 40: 20 kg N, P_2O_5 and K_2O ha^{-1} through soil and 3% urea + 1% single super phosphate + 2% muriate of potash as foliar spray was given. Under irrigated conditions, the general fertiliser recommendation is 125:125:250 kg N, P_2O_5 and K_2O ha^{-1} applied in three splits.

Among the N forms, ammoniacal forms of N were found to be the best for acidic soils to enhance nutrient use efficiency (26). Hence, complex fertilisers 20:20:15 or 10:26:26 or 18:18:18 or DAP are much useful. In case of P source, acid soluble form of P either as rock phosphate or bone meal is better for acid soils. A mixture containing N: P: S association in the form of ammonium phosphate sulphate enhances the efficiency of applied nutrients. Spray of water soluble form of P *viz.*, polyfeed (13: 40: 13 NPK), mono ammonium phosphate (0: 52: 53 NPK) is helpful for profuse flowering and yield. Similarly, water soluble form of K viz., K nitrate (13: 0: 45 NPK), sulphate of potash (0:0:50:20-NPKS) polyfeed (13:40:13-NPK) and mono potassium phosphate (0:52:34 NPK) would help in getting bold capsules with high oil content (26).

Micronutrient survey conducted by Indian Cardamom Research Institute, Myladumpara, Idukki, Kerala showed that zinc deficiency is widespread in cardamom soils and B deficiency is observed in certain areas. Hence, it is recommended that Zn may be applied as a foliar spray as zinc sulphate at 250 grams 100 $liters^{-1}$ of water during April-May and September-October. Besides, Zn, application of B seems to be imperative in soils deficient in B. In such cases, soil application of B in the commercial grade borax at the rate of 7.5 kg ha^{-1} is recommended in B deficient areas. It is applied in two doses along with NPK fertilisers.

Integrated Nutrient Management

Black Pepper

Integrated nutrient management with annual application of NPK at the rate of 100:40:140 kg ha^{-1} and organic manure like FYM at the rate of 5.0 kg $vine^{-1}$ enhanced the fertility of soils under black pepper. Application of castor and cotton cakes at 1-2 kg per plant or poultry waste at 1-2 kg or cattle manure at 3-5 kg, 200 to 300g NPK (12:12:17) mixture, 500g of lime and 300g thermo phosphate per plant per year in addition to foliar sprays of micro nutrients are the general practice followed by the growers (83). From a four year study conducted in 162 locations, Sadanandan et al. (29) reported an increase in almost all the nutrients and yield due to the adoption of INM involving recycling of FYM. A five year study on optimizing fertiliser nutrient use in black pepper involved substitution of 50% of the recommended fertiliser dose with FYM on equivalent N basis and the remaining 50% of the dose was met either through fertiliser N and P, fertiliser N + Phosphobacterium (PB) + Vesicular Arbuscular Mycorrhiza (VAM) or fertiliser P + Azospirillum. The study revealed that fertiliser nitrogen and phosphorus dose could be reduced by 50% in black pepper by substituting with FYM (84).In addition, cattle manure or chicken manure at the rate of 1-2 kg $plant^{-1}$ for the first and second year and 3-4 kg $plant^{-1}$ in subsequent years are also applied. Kanthaswamy et al. (85) reported highest yield of black pepper due to application of Azospirillum and fertilisers in addition to FYM. A study by Stephen and Nybe (86) indicated that treatments involving complete organic (FYM, ash) and biofertiliser (Azospirillum, AMF, phosphobacteria) + organic + fertiliser combinations exhibited higher values of soil nutrients (N, P, K, Ca, Mg). Nybe et al. (87) suggested manuring @ 10 kg cattle manure/ compost/ green leaves with NPK 50:50:150 g $vine^{-1}$ $year^{-1}$ and limi @ 500g $vine^{-1}$ in alternate yea during April-May in plant basins 50-75 cm radius for higher yiel Hamza et al. (88) reported that IN by combined application of FY leaf litter and fertilisers are good f maintenance of soil fertilit Srinivasan et al. (89) recommende application of coir pith compost 1.25 t ha^{-1} integrated with half t recommended fertiliser dose a *Azospirillum* sp. @ 20 g $vine^{-1}$ f higher yield and fertility build up black pepper gardens. Mathew a Nybe (90) observed that combin application of 50% N as FYM Azospirillum + 50% P as fertiliser Phosphobacteria + 100% K fertiliser resulted in highest ber yield comparable with 50% N and as fertiliser + biofertilisers + 100% as fertiliser and recommended do of fertilisers. The foliar and so NPK contents also showed high status with 50% N and P as fertiliser biofertilisers + 100% K as fertiliser.

Ginger

Ginger performs well with goo supply of humus and organic matt which has positive correlation wi yield. Farm Yard Manure (FYM poultry manure, green leaf, compo press mud, oil cakes, biofertiliser night soil and urine are used sources of organics. The quantity organics applied may vary wi availability of material and general it varies between 5-30 t ha However, farmers of Maharasht apply heavy doses of FYM, about 4 to 50 t ha^{-1}. Organic manures a mostly applied as basal doses and certain places it is also applied aft the emergence of crop as mulch. Kerala the recommended dose organic manure is 25-30 t ha^{-1} FYM and 30 t ha^{-1} of green leaf mul applied in three splits.

Application of organic cak increased nutrient availabilit improved physical condition of th soil, increased the yield and oleores production. Neem cake application significantly increased the N availability and the highest available N was recorded in soils that received half the dose of N as urea along with neem cake at 2 t ha^{-1}. In addition to neem cake, phosphobacteria and P as rock phosphate increased the availability of P, Ca, Mg, Zn and Mn (91). Under Kerala conditions, in an Ustic Humitropept, Bray available P increased with the application of rock phosphate mixed with FYM and among the P sources, Raj phos was superior. Rhizome P concentration was higher when superphosphate and FYM incubated rock phosphates were applied. Significantly higher dry yield in ginger was registered with Raj phos and Gafsa phos application with FYM, and it was significantly higher than other sources of P applied. Not much variation was observed in oleoresin content of ginger due to application of different sources of P. Among all the sources, apparent phosphate recovery, agronomic efficiency of the applied P and percentage yield response was higher for Gafsa phos, followed by Raj phos incubated with FYM in ginger (92).

Incorporation of fertiliser N combined with neem cake (50% N), poultry manure (25% N), and groundnut cake (50% N) were found to be best for getting higher yield of up to 29 t ha^{-1} of ginger. Also, application of neem cake at 2t ha^{-1} along with NPK at 75:50:50 kg ha^{-1} increased yield of ginger and reduced the rhizome rot incidence under Kerala conditions (93). Among other organic sources, application of coir compost (Terracare) at 2.5 t ha^{-1} increased the yield by 37.5% over control (94). Gradual availability of nutrients through decomposition of organics throughout the growth phase may be the probable cause for better growth and development of plant and ultimate yield when fertiliser were substituted with organics at different levels (95). Similarly, Pawar and Patil (96) recorded higher yield when fertilisers were applied in both organic and fertiliser sources (20t FYM + 225 kg N, 50 kg P and 180 kg K ha^{-1}). In an acidic Alfisol of Meghalaya, India, rhizome yield, N, P and K uptake and crude protein and oleoresin contents of ginger increased significantly with the application of N at 100 kg ha^{-1} and FYM at 5 t ha^{-1} (97).

The trials on different management systems on ginger at Indian Institute of Spices Research (IISR), Calicut, India showed that higher soil nutrient buildup with highest organic carbon content (2.33%) in organic system on par with INM system. A 15-20% reduction in yield was observed under organic system as compared to INM system (98). Trials conducted through All India Coordinated Research Project on Spices (AICRPS) at various locations in India revealed that, combined application of different organic sources like FYM + pongamia oil cake + neem oil cake + stera meal + rock phosphate + wood ash has yielded on par to the conventional practice in addition with high quality. Lime application is practised in acidic soils to correct the pH and nutrient imbalance. Under Kerala conditions where the soils are lateritic with high P fixing capacity, available P increased with the application of rock phosphate incubated with FYM and among the P sources, Rajphos was found to be superior. The apparent phosphate recovery, agronomic efficiency of the applied P and percentage yield response was higher for Gafsaphos, followed by Rajphos incubated with FYM in ginger (92). Both the nature and level of the organic manures markedly influence the growth and yield attributes of ginger. Roy and Hore (95) reported that the maximum values for plant height, tiller number, leaf number, clump weight and length and plot yield (13.76 kg 3 m^{-2}) and projected yield (29.72 t ha^{-1}) were recorded when 1/4 N was incorporated through poultry manure and 3/4 N as urea. Field studies on ginger cv. Nadia conducted at Umiam, Meghalaya, India in a sandy loam soil revealed that N at 100 kg ha^{-1} + FYM was the best treatment for obtaining the highest yield and good crop quality (97).

Turmeric

Many experimental evidences show the beneficial effects of organic matter alone or in combination with fertilisers in turmeric. Compost or FYM at 40 t ha^{-1} is applied by broadcasting and ploughing at the time of preparation of land or as basal dressing by spreading over the beds to cover the seed after planting. The fresh yield increase was over 37%. Kerala Agricultural University (KAU) recommends 40 t ha^{-1} compost or cattle manure as basal dressing, for Western Ghats and Coastal Plains of Kerala; whereas in Orissa 15 kg has been applied in 5m^2 bed area in three splits along with fertilisers. Organic manures like groundnut cake, vermicompost and neem cake can also be applied. In such cases the dosage of FYM can be reduced. Farmyard manure + 90 kg N ha^{-1} is optimum for turmeric production in acidic alfisols of Meghalaya, with considerable N use efficiency (34.3%) and nutrient build up in the soil (99). In turmeric, application of cowdung (50 t ha^{-1}) followed by 90, 60 and 90 kg N, P_2O_5, K_2O ha^{-1} yielded the highest with maximum profit in Mizoram. In Wayanad (Kerala, India), application of 100 kg N per ha along with FYM (15 t ha^{-1}) and green leaf mulch (50 t) produced maximum yield. Contrarily, no significant differences in dry yield and curcumin content of turmeric rhizomes was observed with the combination of chicken manure and fertiliser under Chinese conditions (100). Among P sources superphosphate and FYM incubated rock phosphate increased the rhizome P concentration. Significantly higher dry yield was obtained with Gafsa phos followed by Raj phos applications when incubated with FYM. Not much variation was observed in curcumin content due to application of different sources of P. Among all the sources, apparent phosphate recovery, agronomic efficiency of the applied P and percentage yield response were higher for Gafsa phos followed by Raj phos incubated with FYM (92). N and P uptake, curcumin content and P use efficiency increased with the application of 1:3 RP + SSP + FYM in Meghalaya state, India.

Application of 50% RDF (175 kg N, 60 kg P_2O_5 and 125 kg K_2O ha^{-1}) + 10 t ha^{-1} vermicompost improved soil porosity, reduced soil bulk density and increased organic carbon content (from 0.44 to 0.72%) under Madhya Pradesh (Central Plateau and hill regions), with the highest yield, net returns and benefit: cost ratio. Application of vermicompost at 5 t ha^{-1} + 100% RDF (125:60:60 kg NPK ha^{-1}) along with humic acid at 0.2% showed significant increase in fresh rhizome yield per plant, number, length, girth and weight of mother, primary and secondary rhizomes per plant in Erode local cultivar (99).

Turmeric shows good response to the application of organics and biofertilisers. Integrated application of coir compost (2.5 t ha^{-1}) combined with FYM, Azospirillum and half the recommended NPK significantly increased yield and quality of turmeric (94). Similarly, application of FYM (5 t ha^{-1}) with 50% fertiliser N and *Azospirillum* (5 kg ha^{-1}) produced higher yield of mother, primary and secondary rhizomes with a cost benefit ratio of 1:2.28 (101). Up to 16% increase in yield by the application of 25 kg Azospirillum with 50% of the recommended dose of inorganic N and 5 t FYM ha^{-1} over the recommended dose of fertiliser application was observed by Selvarajan and Chezhiyan (102). Jena et al. (103) noted that the rhizome yield and nutrient uptake by turmeric were significantly higher in both individual and combined inoculation of *Azotobacter* and *Azospirillum* and the percentage increase in yield due to inoculation integrated with fertiliser N ranged from 15.2 to 30.5% with enhanced N-use efficiency. The soil was left with a positive N-balance in the INM treatments indicating a build up of soil fertility. Rao et al. (104) reported that the highest dry yield was recorded in the crop applied with neem cake 1.25 t ha^{-1} + FYM 12.5 t ha^{-1} + recommended fertiliser dose (RFD), followed by FYM 25 t ha^{-1} + RFD over RFD. Among the quality characters, curcumin content was more with neem cake 1.25 t ha^{-1} + FYM 12.5 t ha^{-1} + RFD, whereas, essential oils and oleoresins were more in vermicompost 1.0 t ha^{-1} alone over RFD.

The use of FYM and lime in laterite soils is crucial for greater turmeric yield and enhanced soil fertility. This was apparent from the results of Senapati et al. (105), who found that 50% recommended dose of fertiliser in combination with FYM (20 t ha^{-1}) + lime (500 kg ha^{-1}) recorded the highest mean yield of 8.78 t ha^{-1}, which was 65% greater than control. Kamble et al. (106) also reported highest turmeric dry yield with the recommended fertiliser dose applied in combination with FYM (25 t ha^{-1}). Similarly, field trials conducted to evaluate the application of composted coir pith (CCP) for growth and yield of turmeric cv. Sudarsana revealed that CCP combined with 3/4 of the recommended dose of leaf mulch under limed condition recorded the highest benefit: cost ratio and net income.

Besides, organic manures and lime, application of biofertilisers has been found to benefit soil quality as well as yield of turmeric. Results on the effects of *Azospirillum*, *Azotobacter*, phosphate solubilizing bacteria (PSB) and AMF coupled with three levels (100, 75 and 50% of recommended rate) of NPK fertilisers on growth and yield of turmeric cv. Suguna grown as intercrop in six year old arecanut plantation revealed that maximum projected yield was obtained in the treatment. NP (75%) + *Azospirillum* + AM followed by NPK (75%) *Azotobacter* + AMF (31.531 ha^{-1}) compared to 100% fertiliser NP alone (107). The study b Thenmozhi, and Paulraj (10 further indicated that the highe rhizome yield was recorded with th application of poultry manur enriched microbia inoculant/*Trichoderma viride* banan pseudostem compost at 750 kg ha applied along with 75 per cent of th recommended dose of fertilise Findings also revealed tha application of organic manure (FYM, vermicompost, neem cak ash) and biofertilisers (*Azosprillu brasilense* and phosphobacteria) t turmeric either singly or i combination with fertiliser positively influenced microbia biomass C, N mineralisation, so respiration and enzymes activitie while, in soils with exclusive use o fertilisers the microbial communit was stressed sue to reduced supply o organic substrates (109). Mohan et a (110) recorded a linear response o turmeric growth, yield and quality o turmeric with inoculation o *Azospirillum* in combination with levels compared to that o *Azotobacter* in Karnataka stat India. Poinkar et al. (111) reporte that application of NPK 120:60:60 k ha^{-1} followed by FYM (10 t ha^{-1}) *Azotobacter* + Phosphat Solubilizing Bacteria (PSB) (250 per 10 kg of seed) increased plan height, number of leaves, size an surface area of leaves, girth o pseudo-stem, number of tillers pe plant and fresh yield per h significantly in Maharashtra and C B ratio was the highest (2.17) i treatment FYM + *Azotobacter* PSB.

Cardamom

Organic manures are considere essential for improving physica characteristics of soil, apart fron their nutritional values, and they ar indispensable for cardamon irrespective of whether fertilisers are applied or not (28). The limited literature available indicated that application of organic manures such as neem cake at 1-2 kg plant^{-1} or poultry manure/ FYM/ compost/ vermicompost at 5 kg plant^{-1} may be done once in a year during May-June. If necessary application of rock phosphate or bone meal may be done based on soil analysis. Nevertheless, application of compost or FYM at one kg plant^{-1} year^{-1} in May-June is recommended. Application of 3-4 t of well rotten cattle or sheep manure apart from 75 kg each of N, P_2O_5 and 100 kg K_2O ha^{-1} was found to greatly enhance the yield of cardamom (112). Nearly 70% of cardamom roots were confined to shallow depth of 5 - 40 cm and 30 - 50 cm radius. Therefore, for the maximum efficiency of applied manures it would be necessary to apply at a radius within 50 cm and being a surface feeder, deep placement of manures are not advisable.

Studies on integrated use of organic and fertiliser sources of nutrients in cardamom are many. Thimmarayappa et al (113) reported that INM with 25% organic manure + 75 % fertilisers and 50 % organic manure + 50 % fertilisers recorded yields at par with 75 % organic manure + 25 % fertilisers. Field studies in cardamom have shown that application of recommended NPK nutrients as organic manures (50 per cent each as FYM and neem cake + 50 per cent P each as bone meal and rock phosphate + 50 per cent K as wood ash) was effective in increasing the yield and quality of cardamom (114).

Three species of vesicular arbuscular mycorrhizal (VAM) fungi (*Glomus macrocarpum*, *G. fasciculatum* and *Gigaspora coralloidea)* were recorded in the roots of cardamom plants. Per cent colonization in roots varied from 40 – 100 per cent in pre monsoon samples and 63 - 94 per cent in post monsoon samples. Seedlings inoculated with the VAM fungi grew taller, had more leaves and tillers, and greater seedling biomass and uptake of nutrients than control seedlings. Among the various mycorrhizal fungi tested, seedlings inoculated with *Gigaspora margarita* and *Glomus monosporum* exhibited significantly greater growth with increased uptake of nutrients. Results revealed that application of 100% organic manure in the form of FYM enhanced capsule yield by 34.1 per cent over control (115). They also found that as the proportion of fertiliser nutrient application increased, the response of yield also increased. Application of 100% recommended dose of fertiliser yielded 188.81 kg ha^{-1} followed by 75% inorganic RDF+25% FYM (144.14 kg ha^{-1}). Field experiments conducted for seven years (2000 to 2007) revealed that application of FYM at 5 or 10 kg plant^{-1} with or without *Azospirillum* did not influence the yield components as well as yield levels appreciably. However, application of FYM at 5 kg plant^{-1} + 50% recommended N + *Azospirillum* yielded 141.20 kg ha^{-1} similar to that of FYM at 5 kg plant^{-1} + 75% recommended N (146.34 kg ha^{-1}), thereby providing 25% saving in fertiliser N (116).

FUTURE RESEARCH NEEDS

* Since these crops are grown in a wide range of soils, it is essential to develop location-specific fertiliser recommendations based on soil fertility levels. The need is to develop soil test kits and decision support aids on the one hand and farmers' capacity to adopt and utilize these in field fertility management on the other. Hence, development of decision support software, which imbibes an INM program based on soil series and soil testing will be imperative

* It is vital to evolve smarter techniques and technologies that integrate native and synthetic inputs with natural resources. The need is to broaden the scope and depth of INM systems. Research involving generation of conservation agricultural practices and harnessing the power of a vast array of QTLs for designing plant types with tolerance to biotic and abiotic constraints and exploiting the power of soil biodiversity is necessary to derive maximum advantage from INM systems.

* Identifying cheaper and efficient sources of nutrients and low input technologies to alleviate macro and micro nutrient deficiencies in location specific soil-crop systems.

* Investigating the effect of rhizosphere organisms on mobilising the insoluble sources of plant nutrients leading to development of efficient nutrient utilization systems.

* Identifying efficient location specific strains of biofertilisers and developing INM systems through conjoint use of organics, at least to meet one third to half of the plant nutrient requirement.

CONCLUSIONS

Black pepper, ginger, turmeric and cardamom require a friable soil rich in humus and essential plant nutrients, with good drainage. In addition to major (nitrogen, phosphorus, potassium) and secondary (calcium and magnesium) nutrients, micro nutrients especially Zn is most important for better growth, development and yield of these crops. In soils with low pH, liming based on lime requirement could enhance the yield. It is therefore necessary to develop sound soil fertility management programme that encompasses nutrient recommendations based on sound soil tests. Sound crop management programmes that are location specific should form the basis for manure and fertiliser management that optimizes economic return while protecting water quality and the environment. Overall, it is apparent that in majority of the soils the reasons for low productivity of these crops are low pH, high clay content, low CEC, low levels of organic carbon, K, Ca, Mg and Zn. Fertiliser schedules for different agro-ecological locations exits for these crops. Similarly organic nutrition schedules have also been devised for these crops. However, among the different nutrient management strategies, INM through judicious use of fertilisers, biofertilisers, biosolids, biological nitrogen fixation, and other nutrient cycling mechanisms that enhance nutrient use efficiency appears to be the best bet.

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