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Nutrition of Black Pepper

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1. INTRODUCTION

Black pepper (*Piper nigrum* L.), a native of Western Ghats of India, is cultivated in 1.74 lakh ha in India with a production of 48,000 tonnes. This accounts for more than 50 per cent of the world's area but contributes only 23 per cent of the global pepper production. Though India occupied a pre-eminent position during 1950s by meeting 80 per cent of the world's supply of black pepper, the export has now dwindled to less than 33 per cent in four decades as a result of stiff competition from newly emerged pepper producing countries like Indonesia, Malaysia and Brazil, who entered pepper cultivation and trade by the middle of the 19th century. Black pepper productivity in Indonesia is about three tonnes per hectare, whereas the productivity in India is only 245 kg. Kerala state accounts for 96 per cent of the area of cultivation as well as production of black pepper in India. And the balance is contributed by neighbouring states of Karnataka and Tamil Nadu. In order to meet increasing international market and internal demand, an annual growth rate of eight per cent per annum has been envisaged. There is, therefore, an urgent need to augment production and productivity to meet the demands.

Poor production and low productivity of pepper in India is attributed to the negligent soil conservation measures, existence of unproductive vines, inadequate manuring, improper management of pests and diseases and poor adoption of cultural practices. Many workers in the field of black pepper nutrition are of the view that production and productivity of pepper in India can be increased considerably through an integrated approach in which nutrition can play a major role (Waard, 1964; Sim, 1971; Pillai *et al.*, 1979; and Sadanandan, 1992). This chapter reviews the nutrition and management work carried in black pepper.

2. SOILS

Black pepper is grown in a wide variety of soils, though (in its natural habit, in the forest) the vines thrive well in well drained mollisols. Several workers have attempted to give a picture of the ideal conditions for black pepper cultivation.

The major black pepper growing tracts of the West Coast of India is grouped into four categories (Sadanandan, 1986). They are as follows :

a) The plains adjacent to the coast where pepper is grown in the backyard and homestead gardens which accounts for about 70 per cent of the cultivated area of pepper.

b) The valley of hill and midland slope tracts where vines are cultivated as monocrop on plantation scale.

c) The upland hills in coffee, cardamom and tea plantations between an altitude of 750 to 1500 m MSL where the vines are grown as mixed crop and trailed on shade trees in the plantations in Kerala, Karnataka and Tamil Nadu.

d) In the valleys as a mixed crop in arecanut gardens in northern parts of Calicut, Cannanore and Kasaragod districts of Kerala, and also Dakshina Kannada and Uttara Kannada districts of Karnataka state.

2.1 Soil Types

According to Krishnamoorthy (1969), pepper thrives best on virgin well drained red, lateritic or alluvial soils, rich in humus. The ideal soil for growing pepper in Sarawak (Malaysia) is an alluvium, that is well drained and having a high humus content (Waard, 1969). Each of these soils represent extensive tracts of land, under both permanent and shifting cultivation. Though different in parent materials and in some cases in physical characteristics, the one common feature of all those soils is their inherently low fertility status. According to Sadanandan (1992), the degree of success in pepper cultivation depends on good surface and subsurface drainage, adequate waterholding capacity, friable structure, near neutral in reaction, rich in organic matter with good nutrient reserves. Pepper is grown in India, on variety of soils, varying in texture such as red-loams, sandy-loams, clay-loams and red lateritic sandy clay loam soils; but the best plantations are raised in humus-rich virgin soils of the hill slopes of the Western Ghats (Paulose, 1973). In Andamans, pepper is raised in virgin mollisols, clayey loam in texture, rich in humus (Sadanandan and Nair, 1973). In Kerala, much of the pepper cultivation is on lateritic soils of hill slopes or sandy clay loams adjacent to coastal tracts. Sadanandan (1993) reported that the pepper growing soils broadly come under the order mollisols, alfisols and ultisols distributed in Kerala, Karnataka and Tamil Nadu. In ultisols, laterite is the predominant soil type, while in mollisols forest loam is the predominant soil type. However, in alfisols, both red loam and laterite soil type occurs (Table 1). Amongst these soils, pepper is grown largely in the lateritic soils, generally poor in native fertility and nutrient retention capacity, where the clay is kaolinitic. The mollisols are restricted to Western Ghats originated from gneiss which are shallow in depth, well drained and has high organic matter status. These soils are low to medium in phosphorus (P) and potassium (K) status. They receive high rainfall and are best suitable for growing pepper.

In Kerala, pepper is grown largely as a mixed crop in coconut and arecanut gardens in the lateritic, loam and alluvial soils. Pepper prefers well drained soil and will not thrive in waterlogged soils. Low bulk density of the soil though an important factor

Table 1 : Distribution of major pepper growing soils and their taxonomic classification

Soil type	Order	Sub-order	States
Forest loam	Mollisols	Udolls Ustolls	Kerala, Karnataka and Tamil Nadu
Laterite	Alfisols Ultisols	Ustalfs	Kerala, Karnataka and Tamil Nadu
Red loam	Alfisols	Ustalfs Ustults	Kerala and Karanataka

favouring pepper growth and development no systematic studies have been made regarding the requirement of physical characters (Sadanandan, 1987).

2.2 Soil Fertility and Nutrient Availability

Soil fertility refers to the inherent capacity of the soil to provide nutrients in adequate amounts for growth of plant. To maintain soil fertility, nutrients removed by crops must be restored by the application of manures and fertilizers. Even a highly fertile soil gets exhausted of reserve nutrients. If black pepper is grown and harvested continuously, the soil, needs replenishment (Waard, 1964). In a survey conducted in major pepper growing tracts of Kerala and Karnataka in 296 locations, Sadanandan (1993) reported that though level of nitrogen is generally satisfactory, but are poor with respect to P and K, secondary nutrients like Ca and Mg, and micronutrients like Zn (Table 2). It was also recorded that the soils are acidic and as the elevation increases the organic matter increases and also as the acidity increases the organic matter status increases. The selection of the right kind of nutrient to be replenished and proper quantity to be applied depend on nutrient exhausted by pepper. It also depends on nutrient-supplying ability of the soil. In order to achieve maximum productivity, there should be enough nutrient available in the soil. Even to maintain soil productivity at the existing levels, it is necessary to restore to the soil the nutrients removed by the crops and also those lost through

Table 2 : Nutrient status of soils of major pepper growing tracts*

Nutrient	Minimum	Maximum	Mean	CV (%)
Soil pH	4.5	7	5.5	8.8
O.C $g100g^{-1}$	0.3	4	1.7	43.7
Bray P mg kg^{-1}	1.0	94	31.6	45.5
Exch. K "	40.0	550	180.0	51.8
" Ca "	216.0	986	454.5	30.9
" Mg "	19.0	92	42.4	35.3
DTPA Fe "	9.3	74	16.2	17.9
Mn "	2.0	23	14.1	41.9
Zn "	0.6	8	0.9	38.9
Cu "	0.4	27	5.2	76.3

*196 locations.

leaching and erosion. Therefore, continued maintenance of high levels of soil fertility is indispensable for profitable land use and sustainable pepper production.

In the soil, there are a number of competitive reactions in which the microorganisms play a dominant role as soil may contain many substances not directly connected with plant nutrition. The availability of a nutrient will depend upon conditions prevailing in the soil solution. Each nutrient contributes to the solution phase ions depending on its potential. The interaction in the soil solution depends upon the chemical forms of the nutrients. The amount of nutrients taken up by a plant during its entire span (or up to the desired stages of growth) gives the correct measures of nutrient availability. Soil reaction has a great influence on the availability of plant nutrients. The nutrient availability in pepper growing soil is highest between pH 5.5 and 6.5 (Sadanandan, 1993). In acid soils, iron and aluminium are more soluble and make phosphorus less available by precipitating it. Therefore, it is essential to maintain the reaction of the soil pH around 6.5 so that the chemical and biological conditions become optimum for pepper growth. Sadanandan *et al.* (1991) in a study in laterite soil in farmers field for four years in 162 locations reported that an increase in almost all the nutrients due to the adoption of integrated nutrient management in which farm yard manure, bone meal and fertilizers have been applied (Table 3).

Table 3 : Build up of soil nutrients due to integrated nutrient management in farmers fields (1986-90)*

Nutrients	Farmers' practice	Experimental plots	Increase over farmers practice (%)
Soil org. matter (%)	1.8	2.7	50
" Bray-P mg kg^{-1}	17.0	32.0	88
" Exch.K	108.0	154.0	43
" " Ca	454.0	691.0	52
" " Mg	42.0	62.0	48
" DTPA Extr. Fe	16.2	18.7	15
" " Mn	3.9	6.0	54
" " Zn	0.9	1.4	52
" " Cu	2.2	4.1	86

*102 locations.

2.3 Nutrient Mobility and Fixation

Nutrients are taken up by plants through roots which are in contact with the soil. In soils, the nutrients, already present as well as those freshly added are subject to a number of transformations—chemical, physical and biological—before they become available to the plant roots. Soil may contain many substances not directly connected with plant nutrition. The plant has to survive by choosing the required nutrients. The transformation brought about in the soil may result in either release or fixation of nutrients, and the manner in which they take place is quite complex. When fertilizers (organic and inorganic) are added to the soil, they interact with the soil components leading to

their immobilisation or fixation. Fixed ammonium may be partly transformed by microorganism into nitrate which is taken up by crops. Potassium may either remain in soil solution or in exchangeable form on the clay minerals.

Water soluble phosphatic fertilizers interact strongly with iron and aluminium in the soil to form sparingly soluble products known as P fixation. The soil factors that influence phosphate fixation are pH, nature and amount of clay, free oxides of iron and aluminium. An experiment carried out at National Research Centre for Spices (NRCS) farm with a lateritic soil using Mussoorie rock phosphate at different levels showed that irrespective of the source of P addition of P increased saloid P, Fe-P, Al-P and Ca-P; significantly over no P application (the other sources of P were single super phosphate and bone meal) (Sadanandan, 1986). This indicates that fertilizer P is transformed into these inorganic forms. Similar results are reported by Koshi *et al.* (1961).

Waard (1969) stated that the possible way of the entry of nutrients in pepper roots are :

a) contact with plant roots and dissolved nutrients,

b) movement by water flow and

c) supply by diffusion.

The root system of a plant is able to come into direct contact with approximately three per cent of the available nutrient in the nutrient pool (Waard, 1969). It was found that for pepper cultivated in a fertile soil, this contact ratio is sufficient only for the requirement of calcium and magnesium. Further, since the pepper soils have low exchange capacity, root contact with cations on the exchange complex would be reduced. The passive mode of transport would supply most of the calcium, magnesium and also anions. Accumulation and back diffusion of the base elements and sulphate takes place at the root surface. It was found that even in fertile soil only a small portion of phosphate and potassium can be supplied to the soil/root interface in this manner. Soil solution concentration will affect the movement of nutrients by water flow. Apparently, neither phosphorus nor potassium are supplied in sufficient quantities by the above mentioned mechanism. It was suggested that the less mobile ions are removed only from the immediate vicinity of the root surface, concentration gradient is established providing a driving force for ionic diffusion, the velocity of which depends on their respective coefficients of diffusion and concentration gradients between medium and root sink. The phase geometry and the fixation power of soil influence the magnitude of diffusion rate. In soil, where fixation is mild, mobility of added phosphate is likely to be higher and replenishment would extend from beyond the volume explored by the root hairs. Ion uptake was found to increase directly with concentration of nutrients in soil solution. The physical characteristics of the soil might be considered as more significant in pepper nutrition than the inherent presence of chemical fertility.

3. NUTRIENT REQUIREMENT

From a limited number of chemical element drawn from soil and air, black pepper vines build up a vast array of dry matter, essential oils, oleoresins, etc. For this, 16 elements are recognised at present as being essential to all plants for their normal growth and development. Each of these essential nutrients has a definite and specific function to perform in the growth of vines. The quantity of requirement vary from variety to variety. For example, in a study conducted at NRCS using 12 major pepper varieties, it was found that Panniyur-1 leaf contained maximum nitrogen, Karimunda contained maximum phosphorus, Kottanadan leaf contained maximum potassium, Balankotta contained maximum calcium, Panniyur-1 contained maximum magnesium, Kalluvally contained maximum iron, Karimunda maximum copper and Valiyankaniyakadan maximum molybdenum (Table 4) in the leaf of these varieties. From the above experiment, it is clear that nutrient requirement of pepper varieties may vary (Sadanandan, unpublished). Some varieties may be resistant and some varieties may be susceptible to the deficiency/toxicity of a particular nutrient. This stresses the need for location specific variety and variety specific recommendation. Investigations on nutritional requirement of hybrid Panniyur-1 pepper in ultisol, poor in major nutrients showed that application of 140 g N, 55 g P_2O_5 and 270 g K_2O vine^{-1} year^{-1} was optimum (Sivaraman *et al.*, 1987). In another study to find out the nutrient requirement of bush pepper, it was found that bimonthly application of NPK at the rate of 1, 0.5, 2.0 g bush^{-1} grown in (10 kg soil) pot was found to be optimum (Anon., 1992).

Table 4 : Leaf nutrient status of some pepper varieties

Variety	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Al	Mo
	(g/100 g)					(mg/kg)					
Arakulam	2.31	0.15	2.77	1.56	0.19	78	161	30	631	68	1.24
Balankotta	2.42	0.13	3.15	2.37	0.24	125	227	19	248	87	4.54
Karimunda	2.64	0.16	2.92	2.30	0.24	129	542	27	800	85	3.40
Kottanadan	2.12	0.13	3.55	1.40	0.15	94	293	26	425	60	2.34
Kutching	2.40	0.14	3.13	1.48	0.20	91	298	26	390	59	3.24
Kuthiravally	2.32	0.14	3.00	1.93	0,27	127	327	27	501	68	4.00
Kalluvally	2.18	0.14	3.14	1.61	0.20	139	446	28	608	86	3.10
Neelamundi	1.75	0.15	2.79	1.51	0.22	111	310	25	317	92	3.26
Panniyur-1	3.12	0.13	2.70	2.13	0.25	94	285	19	405	82	3.40
Thommankudi	3.02	0.14	2.94	2.02	0.17	92	199	29	627	78	3.28
Valiyakaniyakadan	1.93	0.12	2.61	2.33	0.23	92	311	29	335	71	4.73
Thevanmudi	2.54	0.12	3.52	1.69	0.20	84	273	24	356	53	1.77
CD 5%	0.24	0.02	0.33	0.23	0.04	14.6	89	5.2	127	13	0.70

4. UPTAKE OF NUTRIENTS

The nutrition of pepper cannot be considered in isolation from other aspects of its agronomy, because pepper yields vary greatly as the vines are trailed on different

standards under a wide range of environment, agronomic practices and economy. The nutrient elements required are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B) and molybdenum (Mo). The reported results of research on nutrition of pepper in India are scarce and concern mainly with NPK and to a lesser extent with secondary and micronutrients. Information about nutrients removed by pepper, their uptake, translocation and effect on plant growth is very meagre. What little is available relates to the findings of Malaysian and Indonesian workers. Work in India pertaining to inorganic nutrition of pepper is of recent origin and has not progressed much even though manurial experiments were conducted in Kerala as early as 1920 by the Department of Agriculture, Madras (Nambiar *et al.*, 1965). Pepper vines grown on living standards gave lower yields compared to those which had non-living standards as support (Menon *et al.*, 1982). This obviously is due to competitive absorption of nutrients from the soil by living standards. The advantages of using organic sources as plant food for pepper nutrition has been advocated for a long time. Reports from Malaysia showed that the application of burnt earth improved soil texture, increased soil potassium uptake and sterilised the soil. The supermacy of prawn dust as plant food for pepper vines has also been recognised.

Waard (1969) reports about the investigations carried out in Indonesia prior to 1942 (Hardon and Neuteboom, 1934; Hardon and White, 1934; Huitema, 1941). These mainly concerned the effect of burnt earth on the production of black pepper, application of fertilizers of mineral origin, effects of soil conditions on the development of yellow disease and some aspects of soil fertility in the island of Bangka. Comprehensive treatment about traditional methods of fertilization and uptake of nutrients were contained in a publication by Bregman (1940).

Data on trials conducted in India, involving NPK and Ca have been reported by Marinet (1953). These results indicated the necessity of liming acid soil for proper pepper cultivation; however, no definite pH limits have been given. Little work on liming of pepper soils and the release of K seems to have been carried out in India.

Fearnside (1980) formulated a multiple regression equation, correlating pepper yield of vines with soil fertility growing in the Trans Amazon highway of the Altamira colonisation areas in Brazil. This contains information on soil quality, effects of fertilization, and other factors on soil fertility, probability of colonists using fertilizers, etc., and favoured the construction of a computer model for higher pepper yields in Brazil.

The essentiality of phosphatic sources of nutrient for black pepper growth has long been recognised. Garry (1963) showed that in Cambodia balanced manuring of black pepper could quadruple the yield. According to Purseglove *et al.* (1981), organic manures are extensively used in Sarawak for growing black pepper and these included guano, prawn and fish refuse and soybean cake for better growth and uptake of nutrients by vine. More recently "steramеal", a potassium-fortified, sterilized animal meal and bone meal have become popular.

Sadanandan and Hamza (1990), after studying the effect of slow release nitrogenous fertilizers for pepper in laterite soil, reported that application of one per cent neem seed extract (Nimin) oil-coated urea increases the efficiency and uptake of nitrogen compared to urea (Fig. 1). No information is available on the patten of N and K uptake due to different forms of N and K application for black pepper. Farmers use ammonium sulphate, urea, calcium ammonium nitrate, diammonium phosphate, etc., for black pepper. The K fertilization is normally done as muriate of potash, being the only source freely available in the market. Similarly, published information regarding the effect of placement of fertilizer below the soil surface on growth, uptake of nutrients and yield of pepper is also lacking. Phosphorus deficiency has been observed in some of the pepper growing soils where iron and aluminium are predominent. The form of P applied to pepper seemed to affect the yield. Sadanandan (1986) compared the response of pepper to equivalent rates of the different forms of P fertilizers at different levels and obtained higher pepper yield and high relative agronomic effectiveness (RAE), when P was applied at 80 kg P_2O_5 ha^{-1} $year^{-1}$ as Mussoorie rock phosphate.

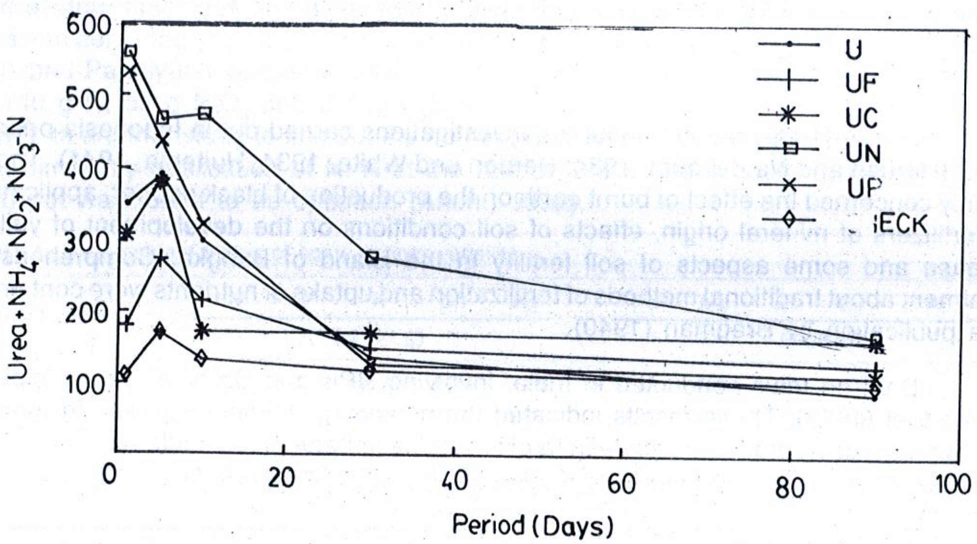

Fig. 1 : Effect of slow release N fertilizers on the release pattern of N in soil.

Black pepper is responsive to K fertilizers. Application of potash at 270 kg K_2O ha^{-1} $year^{-1}$ as muriate of potash gave significant yield increase. The response of K fertilization is not uncommon in all the soils as most of the pepper growing soils in Kerala are deficient in K (Sadanandan, 1993). There is good probability that pepper will respond to application of K fertilizer, if the ammonium acetate extractable K is less than 70 mg kg^{-1} of soil (Sadanandan, 1992) and the response of Panniyur-1 pepper to applied K was up to 270 kg K_2O ha^{-1} $year^{-1}$.

Wahid (1987), while studying the seasonal variation in foliar nutrient concentration, reported that the concentration of N and K increased up to June and then decreased. With the application of NPK fertilizers in August-September, the leaf concentration again increased and dropped thereafter in October. In case of P, the increase was seen up to June which decreased thereafter in spite of P application. The foliar levels of Ca decreased up to May and increased with the onset of monsoon, while the level of Mg tends to increase up to July, beyond which it decreased. Slight improvement in Mg level was seen beyond October. Almost similar trend was noticed in the case of sulphur.

4.1 Nutrient Uptake by Nursery Plants

Pepper is propagated by planting rooted cuttings in potting mixtures containing soil, sand and farm yard manure (FYM) in equal proportion. The selected runner shoots, emerging from the base of high yielding vines, are mainly used for propagation of pepper. It is estimated that the annual requirement of rooted plants for rejuvenation of the existing gardens by replacing disease and senile vines, extension of new area for growing pepper is about 17.5 million plants annually. The improved varieties emerging from the breeding need large scale multiplication for distribution among the growers.

The exact requirement of the nutrients for proper growth and development of the pepper plants has not been work out. Studies on nutrients removed by pepper plant (Table 5) showed that rooted pepper plants of about 3 months with 4 to 5 leaves weighing approximately 2 g removed 64.8, 3.3, 54.8, 24.5, 11.2, 8.1 mg of N, P, K, Ca, Mg and S respectively.The micronutrients utilised were 981, 191, 128, 451 and 4 micrograms of Fe, Mn, Cu and Mo. Among the nutrients utilised by pepper plants, maximum absorbed nutrients were N, K, Ca and Mg. Regarding the micronutrients, maximum utilised was iron followed by copper. The preferential absorption of nutrients by pepper varieties point to the need for the study of pattern of absorption selectively.

Significant differences were observed between cultivars with regard to utilization of nutrients. Aimpiriyan utilised N and K the maximum compared to other varieties for the growth and development. The data further showed that nutrients removed are considerable within a short period of three months, warranting judicious application of these nutrients for healthy nursery plants of black pepper (Sadanandan, 1992, unpublished).

5. ROLE OF LIME

Survey of a major pepper growing soils showed that (Sadanandan, 1993) the soils are acidic, porous, friable with good drainage and adequate water holding capacity, and rich in humus. The principal of liming a soil is to apply a nutrient which will react with soil, removing hydrogenous and replacing them with calcium and magnesium. Liming of pepper growing soil benefits by reducing acidity and increasing availability of nutrients like P, K, Ca, Mg and Mo and also increase the efficiency of fertilizers used in acid soils. It also decreases concentration of micro elements like Fe, Mn, Zn, Cu and Al,

Table 5 : Uptake of nutrients by some important cultivars of black pepper

Variety	Dry matter (g)	Root length (cm)	Shoot length (cm)	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Mo (µg/ Plant)
				(mg/plant)										
Panniyur-I	1.724	25.0	23.8	53.33	3.55	51.30	15.86	5.56	6.05	1.54	0.185	0.098	0.207	5.24
Kottanadan	2.470	12.0	26.0	58.65	3.00	59.25	30.11	12.84	8.88	0.75	0.195	0.184	0.832	3.38
Karimunda	1.657	90.8	29.8	59.13	3.36	40.51	16.05	6.85	6.08	0.75	0.140	0.074	0.241	3.63
Aimpiriyan	2.834	7.0	23.0	88.13	3.47	68.08	35.77	19.62	11.57	0.87	0.243	0.157	0.524	4.70
CD 5%	0.590	8.7	10.5	6.73	0.99	15.09	10.46	4.94	3.77	0.18	0.061	0.040	0.189	1.17

which may be present in toxic quantities. It also encourages the growth and action of beneficial micro organism and improves soil structure.

Quantity of lime to be applied depends on soil reaction, its structure, type of clay minerals present, soil organic matter content, etc. Soils with low clay content will require less lime compared to those with heavier texture. Soils with higher organic matter need more lime. The common practice is to apply to soil burnt shell lime. It is more economical not to completely neutralise an acid soil for crop production as a pH of 6.5 is more than sufficient for proper plant growth. A number of experiments have been conducted to study beneficial effect of liming in pepper soils. These experiments showed that application of lime as such can increase crop yield from 25 to as high as 400 per cent (Roy and Seetahraman, 1977). Pillai *et al.* (1979) studied the effect of Panniyur-1 black pepper to application of lime in a laterite soil but could not establish the response to liming perhaps no consideration was given to lime requirement and an addition of lime without affecting the change in soil pH will not give any worthwhile result.

Experiments conducted at NRCS have shown that application of Ca and Mg increases the exchangeable Ca and Mg in the soil as well as in the plant indicating the necessity of these elements in balanced nutrition of black pepper (Table 6) (Anon., 1990). Therefore, application of lime at 600 g per vine during April-May in alternative year is recommended (Anon., 1990).

Table 6 : 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⁻¹)	Leaf Ca (g kg⁻¹)	Soil Mg (mg kg⁻¹)	Leaf Mg (g kg⁻¹)
Check	2.75	268	27.0	64	2.8
N_{50} P_{60} K_{140}	3.35	986	22.0	46	3.0
N_{50} P_{60} K_{140} Ca_{50} Mg_0	3.01	1278	34.0	45	2.9
N_{50} P_{60} K_{140} Ca_0 Mg_{50}	3.18	742	22.0	65	3.5
N_{50} P_{60} K_{140} Ca_{50} Mg_{50}	3.35	1368	24.0	79	2.8

6. ROLE OF ORGANIC MANURES

The cultivation of pepper in the olden days was done by manuring with organics. The essential differences in manuring pepper with organic matter and inorganic nutrients is mainly the release of organic ions in the soil when organic manures are used. These organic ions released by the decomposition of organic matter chelates the P-fixing agents like Fe and Al which results in the release of nutrients slowly in a more freely available form. Organic ions also combine with free oxides of iron and aluminium thus making them harmless and minimising the fixation of phosphorus in the soil. It is essential to find out the kind of organic matter, the mode of organic matter decomposition and the stability constants of chelates for assessing the proper kind of organic matter to be used for growing pepper. Several kinds of organic manures like FYM, compost, poultry manure and organic cakes like neem cake and groundnut cake are used by pepper farmers in India. But no specific information is available on the exact quantity of organic manure to be used for pepper, rate of decomposition, release of nutrients, etc.

The advantage of using organic sources of plant food for pepper nutrition has been recognised for a long time in India and other pepper growing countries. The supermacy of prawn dust as plant food for pepper has been advocated in Malaysia. Guano application is very popular in Sarawak. This is usually placed in holes about 20 cm from the main stem, in quantities of about 85 g for every two months. Some farmers use prawn refuse and fish manure, puting them in considerable quantities in shallow trenches around the vine every two months. According to Pursoglove *et al.* (1981), organic manures are extensively used in Sarawak for growing pepper and these included guano, prawn and fish refuse and soybean cake. More recently, 'steramеal', a potassium-fortified sterilised animal meal and bone meal has become popular.

6.1 Manuring with Burnt Earth

The jungle land which was cleared for pepper planting provided the raw material for the preparation of 'burnt earth' in Malaysia (Hardon and White, 1934; Bregman, 1940). After felling the vegetation, a portion of the top soil was stripped from the vacant land. This soil was then used to cover a pile of wood. Slow roasting was then restored to for a period of one to three weeks, followed by thorough mixing of the sterile soil. The wood ash and the soil provided the 'burnt earth' which serves as fertilizer. The 'burnt earth' has a pH of 7-8 as compared to a pH of 4-5 for fresh soil. The content of CaO in the 'burnt earth' was 0.3 per cent. Application of this 'burnt earth' was made at 18 kg vine^{-1} year^{-1}. The addition had three-fold effect as follows :

a) it altered the physical characteristics of the rooting medium,

b) it increased the pH value, and

c) it supplied nutrients.

The actual quantities of nutrients added to the soil by following these processes are small, but these are offered in a form ideally suited for uptake of nutrients by the roots (Waard, 1978). It is worthwhile to conduct detailed studies to explore the possibilities of using 'burnt earth' for augmenting pepper productivity.

7. ROLE OF INORGANIC NUTRIENTS

There are only a few reports in India of positive yield response by pepper varieties to application of N, P and K fertilizers. The results of yield trials are sometimes inconsistent, especially with nitrogen in the hybrid variety Panniyur-1. Much of this variation in response is probably due to the inherent soil fertility and nutrient interaction effects on yield. The interaction between initial nutrient status of the soil, seasonal factors and soil moisture availability are also of vital importance.

7.1 Fertilizer Experiments

Nitrogen, phosphorus and potassium are the most important nutrient for growth, development and yield of pepper vines and their influence depend on the ratios of these nutrients in the soil as well as in the plant system. Sadanandan (1993) reviewed an exhaustive series of fertilizer trials with pepper in major pepper growing countries in the world and reported that the levels of fertilizer used in India is much low and is perhaps one of the reasons for poor yield in India. Studies conducted in farmers field over a period of four years (1979-84) showed that there was 250 per cent increase in the pepper yield due to the application of NPK fertilizers at 100 kg N, 40 kg P_2O_5, 140 kg K_2O together with one kg neem cake and half kg bone meal vine year^{-1} and adoption of plant protection measures (Table 7). The response to fertilization was more frequent and larger when soil status of N, P and K were low. In situations where N, P and K fertilizers are required, the rates applied to achieve maximum yields vary largely depending on soil status of different locations (Sadanandan *et al.*, 1991). Location specific fertilizer recommendations for pepper advocated by the Kerala Agricultural University is given below (Anon., 1989).

Table 7 : Response functions, optimum dose, optimum yield for N, P and K on pepper

Nutrients	Response functions	R^2 (%)	Optimum dose (kg ha^{-1})	Optimum yield (kg ha^{-1})
N	$884.18 + 31.0182N - 0.105564N^2$	99.00	147	3163
P	$88.974 + 83.2164P - 0.756818P^2$	98.72	55	3177
K	$895.06 + 17.8095K - 0.033585K^2$	99.35	265	3256

a) General recommendation of NPK: 100:40:140 g vine^{-1} year^{-1},

b) For Panniyur, northern most part of Kerala and similar agroclimatic regions NPK at 50:50:200 g vine^{-1} year^{-1}, and

c) Calicut region and similar agroclimatic areas : NPK at 140:55:270 g vine^{-1} year^{-1}.

Pillai *et al.* (1979) studied the response of Panniyur-I variety of pepper to application of nitrogen and lime and pointed out that higher levels of N adversely affected the yield. According to them, it is not necessary to increase N dose to Panniyur-I pepper beyond certain specific level. Investigations on the mineral nutrition requirement of hybrid Panniyur-I pepper in laterite soil, poor in major nutrients, showed that application of 140 g N, 55 g P_2O_5 and 270 g K_2O vine^{-1} year^{-1} resulted in significant increase in the availability of N, P and K in the soil and resulted in higher uptake of nutrients by the pepper vine (Sivaraman *et al.*, 1987). The response curve fitted for NPK application is presented in Fig. 2 to 4.

The response functions worked out revealed that an optimum yield 3163, 3177 and 3256 kg h^{-1} from an optimum dose of 147, 55 and 265 kg of NPK ha^{-1} respectively

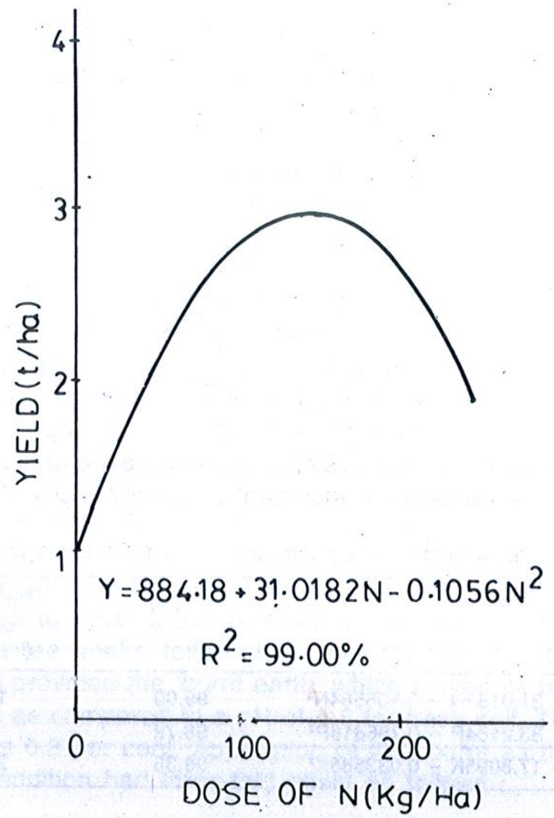

Fig. 2 : Yield response curve for N application in black pepper.

(Table 7). The optimum level obtained were 140 kg N, 55 kg P_2O_5 and 270 kg K_2O per hectare per year. The N and K fertilizers are to be applied in two equal split doses in soil, first half in June and the second half in September, while the entire P is to be applied in one dose in shallow basins of 30 cm radius made around the base of the adult vine. Sadanandan (1993) reviewed the nutrient uptake and fertilizer recommendations followed in different countries (Table 8). The nutrient removal of the variety Kuching in Malaysia was 252 kg N, 32 kg P_2O_5 and 224 kg K_2O ha^{-1} $year^{-1}$ (Waard and Sutton, 1960). Sim (1971) and Sadanandan (1993) observed more or less similar results. From Table 8, it is seen that there is a broad similarity in the quantity and proportion of nutrients absorbed as seen in the serial number 1, 2 and 7. This information provides useful guidelines for approximating the quantity of nutrients and the proportion in which they are to be applied to pepper vine. Similar work has been reported by Raj (1973).

It could be noticed that uptake of nutrients by pepper is appreciably higher, wherever high amounts of NPK fertilizers are added as input to the pepper plant. For example, according to the fertilization schedule of Waard and Sutton (1960), the fertilizers

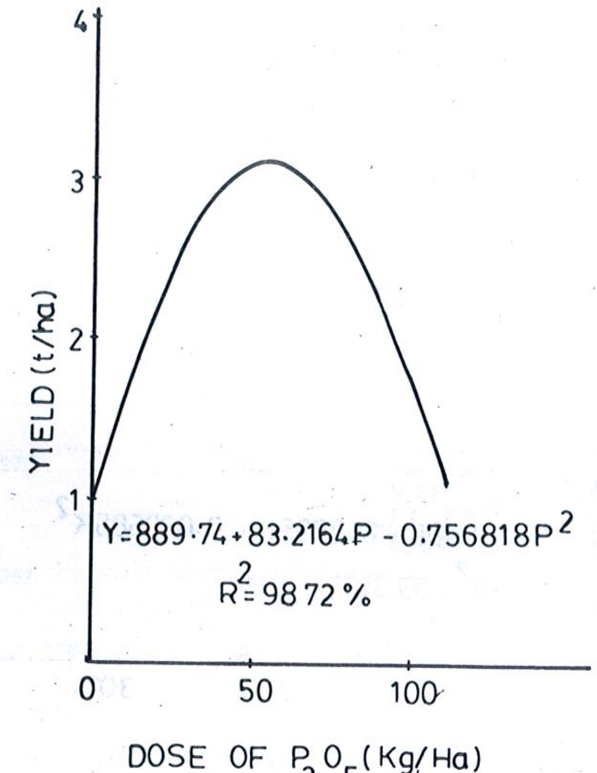

Fig. 3 : Yield response curve for P application in black pepper.

added are 240 kg N, 120 kg P_2O_5 and 340 kg K_2O, and the uptake by the plant is 252 kg N, 32 kg P_2O_5 and 240 kg K_2O ha^{-1} respectively while, according to the schedule advocated by Pillai *et al.* (1976), the doses applied at 100 kg N, 40 kg P_2O_5 and 140 kg K_2O which resulted in an uptake of 34 kg N, 3.5 kg P_2O_5 and 32 kg K_2O ha^{-1}. According to Sadanandan (1993), when the fertilizers were added at 140 N, 55 P_2O_5 and 270 K_2O kg^{-1} ha^{-1}, the uptake were 137 N, 61 P_2O_5 and 330 K_2O kg/ha^{-1} respectively. It has been reported that the yield of pepper as per the fertilizer schedule of Sadanandan (1993) was higher than that of Pillai *et al.* (1976), while the schedule of Waard (1964) resulted in the highest yield in Malaysia. This clearly shows that fertilization of pepper in India has been very inadequate.

7.2 Fertilizer Experiments and Yield Response to Nutrients

7.2.1 *Nitrogen Nutrition*

Some studies have been made regarding the nitrogen status of pepper soils, the dose of nitrogen to be applied to pepper vines and its uptake for getting maximum yields (Waard, 1964; Sim, 1971; Pillai and Sasikumaran, 1976; Pillai *et al.*, 1987;

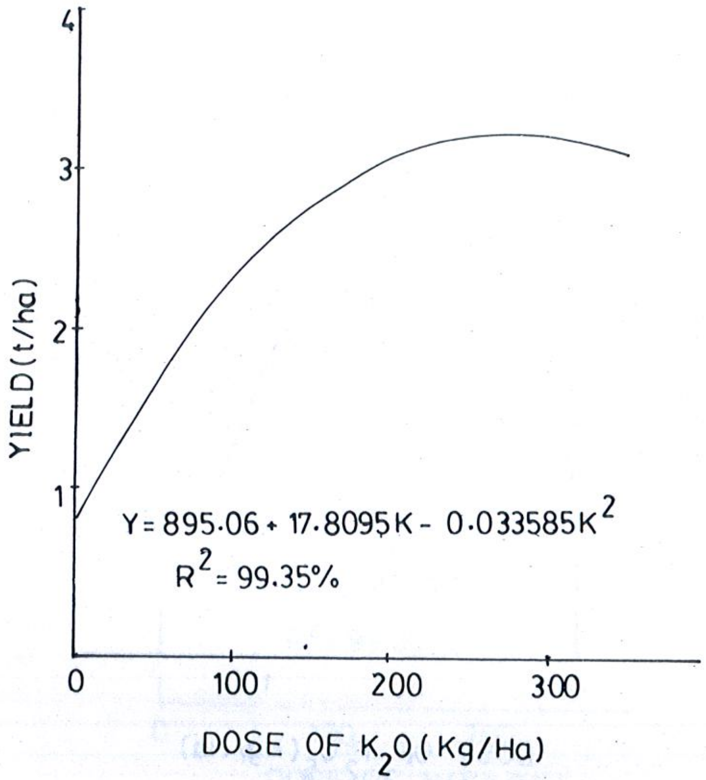

Fig. 4 : Yield response curve for K application in black pepper.

Sadanandan, 1993). Studies on single element in isolation do not project the real nature of nutrient requirement. It is only when all nutrients are taken in combination in varying proportions with their interaction effects, that better picture of nutritional requirements would emerge. In this connection, nutrient ratios, both in the soil and in the plant (included in the different parts of the plant have a significant role to play in the plant nutrition. Waard (1969) worked out a number of ratios in the pepper leaves and showed their relevance in determining nutrient deficiencies. Studies by Pillai *et al.* (1987) revealed that the dose of N at 50 kg along with 100 kg of P_2O_5 and 200 kg of K_2O for Panniyur-1 pepper is optimum. However, Sadanandan (1993) found that 140 kg N, 55 kg P_2O_5 and 270 kg K_2O per $year^{-1}$ ha^{-1} was the best dose of nutrients for adult vines for producing maximum yields in laterite soil deficient in major nutrients after arriving at response. The response function for the nutrients fitted for N is given in Fig. 2. Effect of nitrogen application as urea on the status of organic carbon in the soil, leaf and berry status of nitrogen in pepper vines are given in Table 9 and 10. The data revealed that N application increased the leaf and berry status of N significantly. The pepper yield obtained by addition of 140 g N, a supplementary yield was obtained over others. Sadanandan and Hamza (1992), after studying the effect of slow release N fertilizers for pepper in

Table 8 : NPK utilisation by black pepper and fertilizer recommendations

Sl No.	Author/year	Country	Nutrients removed ($kg\ ha^{-1}$)	Dose recommended ($kg\ ha^{-1}\ year^{-1}$)
1.	Waard and Sutton, 1960	Malaysia	Kuching N 252 P_2O_5 32 K_2O_5 224	N:P_2O_5 : K_2O : Mgo 240 : 120 : 340 : 100 and 28 g trace elements
2.	Sim, 1971	-do-	N 233 P_2O_5 39 K_2O 207	
3.	Raj, 1972	-do-	—	N 340 g (Urea)* P 113 g (S. super)* K 454 g (MOP)
4.	Pillai *et al.*, 1976	India	Panniyur-1 N 34 P_2O_5 3.5 K_2O 32	N 100 P_2O_5 40 K_2O 140
5.	Pillai *et al.*, 1987	-do-	-do-	N 50 P_2O_5 50 K_2O 200
6.	Sivaraman *et al.*, 1987	-do-	Panniyur-1	N 140 P_2O_5 55 K_2O 270
7.	Sadanandan, 1993	-do-	N 137 P_2O_5 61 K_2O 330	-do-

*Per plant.

Table 9 : Response function of N, P and K dose on the nutrient status in the leaf

Nutrients	Response functions	R^2 (%)	Dose required for maximum status in leaf	Attainable maximum leaf status
N	$1.99 + 0.01064N - 0.0004N^2$	99.93	133	2.69
P	$0.121 + 0.000894P - 0.000008P^2$	97.40	56	0.14
K	$1.85 + 0.005681K - 0.00001K^2$	98.19	284	2.65

Table 10 : Response functions of dose of K in soil on berry status of N, P and K

Nutrients	Response functions	R^2 (%)	Dose required for maximum status in berry (kg/ha^{-1})	Attainable maximum berry status (%)
N	$1.24 + 0.0136N - 0.000052N^2$	99.79	131	2.12
P	$0.092 + 0.0018P - 0.000017P^2$	98.70	53	0.14
K	$0.48 + 0.0038K - 0.000007K^2$	99.94	271	0.99

laterite soil, found that application of 'nimin' coated urea increased the yield of pepper by 47 per cent compared to urea alone. The increased release of urea N, ammoniacal N and also total N in the soil was noticed and these must have contributed to the increased yield (Table 11). Laboratory incubation studies gave more or less similar results. Similar trend was reported by Bopaiah *et al.* (1987).

Table 11 : Effect of slow release N fertilizer on organic matter, available and total nitrogen in soil, yield, uptake and recovery of nitrogen, agronomic efficiency and B.C. ratio

Urea Source	Soil			Yield kg ha^{-1}	Uptake kg N ha^{-1}	Recovery of N(%)	Agro-nomic efficiency	B.C. ratio
	Org. matter g kg^{-1}	Avail N mg kg^{-1}	Total N g kg^{-1}					
CK	20.6c	224b	1.01b	480c	10c	—	4.8c	0.7
U	27.5b	232b	1.11b	1710b	39b	29	17.1b	2.6
UF	31.0a	299a	1.17a	1905b	44aab	34	19.1ab	2.9
UC	36.1a	309a	1.23a	2310a	53ab	43	23.1ab	3.5
UN	36.1a	319a	1.20a	2580a	59a	49	25.8a	3.9
UP	32.7a	293a	1.08a	1765b	41b	31	17.7b	2.6
Mean	30.7	278	1.13	1892	41	31	17.9	2.7
CD (5%)	5.1	38.6	0.15	380	18	—	7.8	—

Figures with the same superscript are not significantly different at 5% level.

Studies on placement of N fertilizers in the rhizosphere of pepper vine at different depths has been neglected and emphasis must be laid on such studies in future. Jayasankar *et al.* (1988) reported that over 90 per cent of the pepper vines root activity was within an area of 30 cm radius around the vine. Another important aspect of nutrition requiring investigation is the foliar application of N fertilizers. Though the cost of application may be high, it is a more efficient method of fertilizer application involving very little dose of nitrogen. Administering of N in conjunction with fungicide is yet another area of study, which is important from the view point of the needs of the farmer. This may be profitably done alongwith compatible pesticides. In this connection, it may be said that the determination of N requirements for pepper in all its aspects, in a regular and systematic manner, will be easily possible through mass spectroscopy in conjunction with chromatography.

7.2.2 *Phosphatic Nutrition*

Phosphorus is a key element in nutrition of pepper vines. Its importance stems from the fact that it is required not only in the buildup of tissues, but also in supplying the plant with enzymes that figure in the energy relationships connected with the multifarious metabolic process taking place in the plant. In the soil, the availability of phosphorus is a vital necessity and it depends on the dynamics of phosphorus fixation in the soil and uptake by the plant. Hence, the pH and organic matter of the soil play vital role. Most of the experiments done on pepper soils in India have largely ignored these aspects and hence the results obtained are scarcely comparable for drawing definite

conclusions on the optimum level of requirements (Sadanandan, 1986). The experiments conducted on N, P, K fertilization in black pepper revealed that phosphorus dose of 55 kg ha^{-1} along with 140 kg N^{-1} and 270 kg K_2O ha^{-1} year^{-1} was ideal for the proper nutrition of the vine as revealed by the response function (Fig. 3). The effect of application of P as superphosphate in the soil availability of P, leaf and berry status of P in pepper vines are given in Table 9 and 10. The data revealed that P application resulted in increased leaf and berry P status significantly. The pepper yield obtained by the addition of P at 40 g gave supplementary yield over other levels of P.

In another study, with the pepper varieties Panniyur-1 and Karimunda involving different P sources at different levels alongwith N and K at 100 and 140 kg ha^{-1}, Sadanandan (1986) found that both the bone meal and Mussoorie rock phosphate were comparable to superphosphate in an acid soil. The cumulative yield of pepper for two years and Relative Agronomic Effectiveness (RAE) were high in the case of Mussoorie rock phosphate (Fig. 5). This study shows that availability of phosphorus to the proper

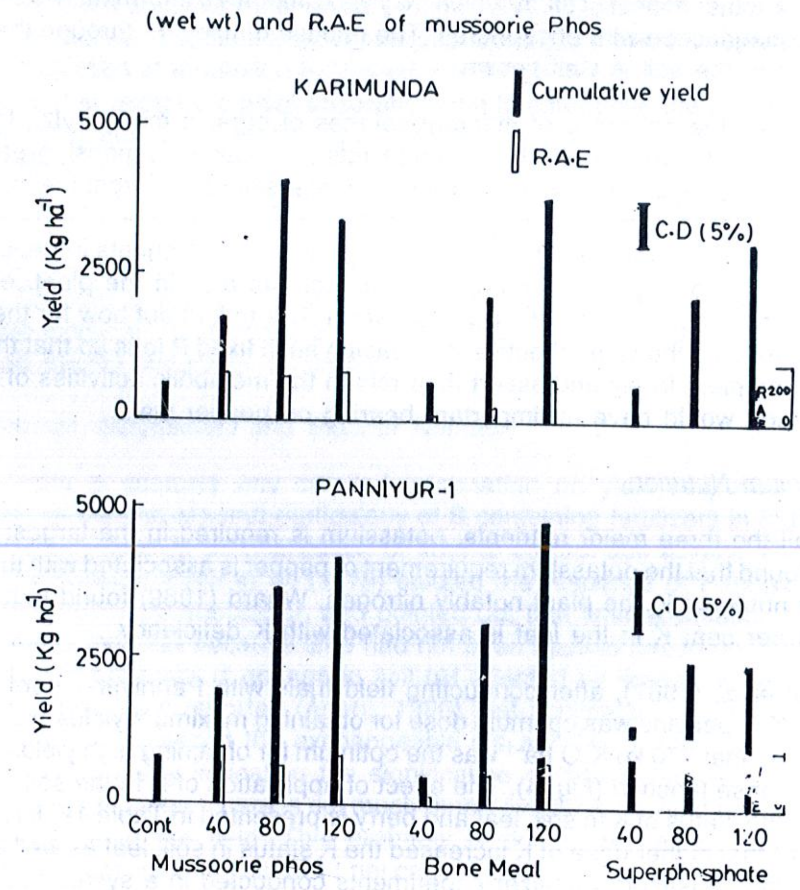

Fig. 5 : Effect of phosphatic sources on the cumulative yield.

vine cannot be assessed by finding out the water soluble or citrate soluble phosphorus in the fertilizer s quantum of P fixed is different in the case of water soluble and water insoluble fertilizers. The micro-environment in the rhizosphere obtained, when different kinds of fertilizers are used, is a vital and determining factor in these studies.

An important aspect of plant nutrition is the influence of nutrient ratios in determining the nutrition need of pepper. This aspect is a sphere of investigation demanding urgent attention for widening our knowledge on nutrient responses to fertilizer application. In the case of pepper, several nutrient ratios were worked out for getting a meaningful relationship between the status of nutrients in the plant and its yield (Sadanandan and Rajagopal, 1989). An index was worked out by finding the ratio of P in the plant to the sum of ratios of nutrients (termed as P index) and pepper yield. The significant correlation obtained between leaf P index of the youngest mature leaf (P/N+P+K+Ca) and yield of pepper (r = 0.81**) indicate the importance of phosphorus nutrition of pepper. In future, such studies will be quite useful in assessing nutrients requirement. Another aspect of study which may yield important information is on nutrient interaction in conjunction with phosphorus. The release of fixed 'P' through the agency of organic ion in the soil is well known.

However, the efficiency of different sources of organic matter, viz., farm yard manure (FYM), poultry manure (PM), different kinds of oil cakes, compost, green leaves from different plant origin, etc., on the efficiency of releasing P ions from the fixed states has to be investigated in order to understand the effect of application of organic source in the uptake of organic ions and translocation of P and other nutrients in pepper vines. It is known that P ions get fixed not only in the soil but also in the plant, especially in the root, leaf-nodes, petioles, etc. It will be worthwhile to find out how far the organic ions are absorbed by the vine, effective in releasing such fixed P ions so that they could move within the plant freely and assert their role in the metabolic activities of the vine. This information would have an important bearing on pepper yield.

7.2.3 *Potassium Nutrition*

Of all the three major nutrients, potassium is required in the largest quantity. It has been found that the potassium requirement of pepper is associated with the content of the other nutrients in the plant notably nitrogen. Waard (1969) found that a critical level of two per cent K in the leaf is associated with K deficiency.

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. Sadanandan (1993) reported that 270 kg K_2O ha^{-1} was the optimum for obtaining high yields in pepper by fitting response function (Fig. 4). The effect of application of K in the soil as muriate of potash on the status of K in soil, leaf and berry is presented in Table 12. It is apparent from Table 12 that higher dose of K increased the K status in soil, leaf as well as berries indicating better utilisation. Fertilizer experiments conducted in a systematic way with K has not been done in the country. Systematically planned experiments with the object

Table 12 : Effect of applied K on soil leaf and berry K

K levels (g vine^{-1})	Soil K			Leaf K (%)	Berry K (%)
	1984	1986	Pooled		
70	84	94	81	2.26	0.72
140	93	134	102	2.40	0.81
280	104	172	125	2.64	1.00
Control	58	76	67	1.83	0.48
CD 5%	7.7	10.8	5.6	0.08	0.04

of finding critical levels of K in the plant in combination with different levels of other nutrients and at various stages of plant growth in different seasons are worthwhile in order to find out the proper nutrient response by pepper vines. Investigations carried out so far in Kerala showed that K status is 'low to medium' (Sadanandan, 1990). The different fractions of K, like water soluble, citrate soluble, acid soluble, nitric acid soluble, ammonium acetate extractable, etc., have to be found out, and their respective importance in plant absorption of K nutrition evaluated. It will then be possible by analysing different fractions of K in relation to plant absorption and to categorise the pepper growing soils as to their K status (Sadanandan *et al.*, 1993). It will also be necessary to find out the critical limits of K in relation to the needs of pepper varieties in the different categories of K fraction. Another important study is with regard to the organic ions released by decomposition of organic matter in the soil and K availability. Soil organic matter releases K when it decomposes. It also releases organic ions which chelates K ions present in the soil. The role of different organic ions in mobilising native K present in the soil and that made available by decomposition of organic matter will have to be assessed for getting an overall picture of K nutrition.

7.2.4 *Calcium, Magnesium and Sulphur Nutrition*

There is scarcely any detailed information on yield response of pepper to application of Ca and Mg and particularly of S containing fertilizers in India. What little work has been done is on application of lime to correct soil acidity. This has little to do with Ca nutrition. Pillai *et al.* (1979) studied the response of Panniyur-1 variety of pepper to N and lime application and pointed out that lime application had no effect. Most probably this was because lime had not been applied based on lime requirement of the soil. Unless there is change in soil pH affected by liming, no response can be expected. It has been reported (Anon., 1990) that application of Ca and Mg at 50 kg each ha^{-1} $year^{-1}$ increased the exchangeable Ca and Mg in the soil and their status in pepper leaf thereby indicating the significance of these elements in the balanced nutrition of pepper vines. There is not much report available on yield response by pepper to S application in the field. This probably is due to the extensive use of single superphosphate (containing about 11 per cent S) used for pepper as a phosphate source, which indirectly correct any inherent deficiency of sulphur in soil (Sadanandan *et al.*, 1991a). Yield response can be expected for pepper when sulphur content in the soil is less than the threshold value of 6 mg kg^{-1}. Nybe (1986) reported profound response due to sulphur application for pepper yield.

The practice of application of NPK fertilizers for pepper are often done in combination, and N:P:K ratio varies considerably. Pillai *et al.* (1979) obtained highest yield with NPK ratio of 5:5:10, whereas Sadanandan (1993) suggested an N:K ratio of 1:2 for pepper. This calls for urgent need for investigations in different locations for determining the correct ratio for important pepper varieties for augmenting productivity.

7.2.5 *Micronutrients*

The studies on micronutrient nutrition of pepper vine are of comparatively recent origin. Of the various micronutrients available in the soil, most important for pepper vine are Zn, Mo and B as these are likely to become deficient in acid soils due to leaching or precipitation (Waard, 1969). The effect of organic matter on the availability of micronutrients is an important area to be investigated. Field studies on the micronutrient nutrition of pepper showed high correlation between soil Zn and leaf Zn (r = 0.89**), and soil copper and leaf copper (r = 0.77**) emphasising the significance of these elements in pepper nutrition (Rajagopal and Sadanandan, 1984). Investigation on pepper nutrition with micronutrients is available. Molybdenum is found to increase with the application of organic matter as it forms a complex which makes Mo available to the plants for absorption. Zinc and boron are micronutrients which get depleted due to leaching in acid soils. Boron deficiency can be expected in coarse textured soils low in organic matter especially in high rainfall area. One of the methods of counteracting the deficiency of micronutrients in pepper is to resort to foliar nutrition.

7.3 Nutrient Interactions

The inter-relation of P content in the leaf and yield of pepper in a laterite soil was studied by Sadanandan and Rajagopal (1989) who found significant correlation between leaf P index (P/N+P+K+Ca) of the youngest matured leaf with the yield of pepper (r = 0.81**) underlining the importance of phosphorus nutrition for pepper.

Interaction studies between elements in pepper vines by Sadanandan *et al.* (1992) showed that there are significant and negative correlation between plant P *vs* Zn (r = –0.56*), P *vs* Cu (r = –0.72*) and P *vs* Mo (r = 0.76**). Similarly, significant and negative correlation was obtained between soil K and leaf Mg (r = –0.30**). Wahid (1987) obtained negative correlation between leaf K and Mg (r = –0.63**) showing the antagonistic effect of K on magnesium. Among the microelements, significant positive correlation was obtained between iron and manganese (r = 0.77**); negative correlation between Cu and Mo (r = –0.77**), and positive correlation between zinc and molybdenum (r = 0.43**) (Sadanandan *et al.*, 1992).

Waard (1969) states that the vegetative health of pepper with respect to each of the five nutrient elements may be characterised by specific values for absolute levels of N, P, K, Ca and Mg for several ratios between the elements and by specific locations in triangular diagrams for N, P, K and K, Ca, Mg. This stresses the point that leaf concentrations of the elements are mutually inter-related and not dependent on the supply of a single element.

Poor performance of pepper vines was found to be associated with elevated leaf concentrations of Ca and P, and lowered concentrations of N, K and Mg. Maintenance of leaf nutrients above the normal level by promoting consumption of nutrients prior to fruiting so that the vegetative portion of the plant is used as a temporary buffer stock for supplying nutrients. Thus, physiological exhaustion and instability of yield may be prevented by adequate quantitative nutrition (Waard, 1969).

Foliar diagnosis can be employed as a suitable guide for detection of nutritional aberrations in pepper. Waard (1969) indicated that throughout the season the balance of base nutrients should be carefully controlled. The concentration and ratio must be maintained in appropriate relation to yield. The level of productivity can be manipulated by varying the value for log N/P, but simultaneously leaf K concentrations and related Mg and Ca must be adjusted in relation to induce the yield. It is, therefore, appropriate to control the foliar concentrations and ratios within the range of fair to normal concentrations for achieving the maximum yield.

If an abundant yield is desired by the farmer, a value of log N/P of at least 1.0 in July should be arrived at by suitable modes of fertilizing. This should be followed by a relatively high removal of leaves (80-90 per cent). In the period from September-January, the application of fertilizers should be manipulated in such a way as to increase the log N/P to a final value of 1.26 (in January).

Waard's (1969) work on fixing the critical levels for major nutrients revealed the values of 2.7, 0.1, 3.0, 1.0 and 0.2 per cent as the critical limits of N, P, K, Ca and Mg respectively in the leaves of pepper, lower than the above, indicate deficiency of these nutrients.

7.4 Fertilizer-Irrigation

Black pepper is grown mainly as rainfed crop with a mean annul rainfall of about 3000 mm received in 120 rainy days. About 70 per cent of the total rainfall is received during the south-west monsoon (June-September) and the balance in October to November. Summer months are practically dry. Studies on the water balance in pepper growing tracts showed that there is a distinct soil moisture stress period of about five months (December to May) and consequent death of vines (Sadanandan, 1991). To overcome the moisture stress, there should be sufficient moisture in the soil. Moist condition of the soil enhances the entry of water in the plant system and better translocation of nutrients for the metabolic activity of the plant.

Studies on either the effect of irrigation requirement on black pepper or fertilizer *vs* irrigation interaction studies are scarce. Irrigation studies at Pepper Research Station, Panniyur showed that irrigation of hybrid Panniyur-1 and Karimunda about 100 l of water at IW/CPE ratio of 0.25 during December to March has increased the yield of pepper by 90 per cent (Anon., 1993).

7.5 Fertilizer *vs* Varietal Experiments

Investigations on nutritional requirement of hybrid Panniyur-1 showed that application of N at 140 g as urea applied in two half (June and September), P_2O_5 at 55 g as single superphosphate in June and K_2O as muriate of potash at 270 g per vine per year in two half (June and September) resulted in a significant increase in availability of N, P and K in the soil (Sivaraman *et al.*, 1987). Studies conducted at the Pepper Research Station, Panniyur in a laterite soil where N status is medium showed that for Panniyur-1 pepper, the application of N levels may be scaled down to 50 g N (as urea) and may be applied in two splits (June and September), and P_2O_5 at 50 g as single superphosphate one dose in June and K_2O as muriate of potash at 200 g per vine per year in two split doses (Pillai *et al.*, 1979).

Field experiment conducted to find out the relative efficiency of indigenous Mussoorie phos in comparison with single superphosphate and bone meal each at three levels in a light textured ultisol for two varieties of pepper, viz., hybrid Panniyur-1 and Karimunda showed that Mussoorie phos at 80 g P_2O_5 per vine per year was as effective as single superphosphate for both the varieties of pepper in respect of soil availability of P, yield response and relative agronomic efficiency (RAE) and economics.

Studies on the evaluation of complex fertilizers for black pepper, Karimunda in a field experiment using ammonium polyphosphate (APP) and diammonium phosphate (DAP), it was found that APP and DAP were equally effective with regard to P availability and yield of pepper (Sadanandan *et al.*, 1991).

7.6 Fertilizer *vs* Pests-Disease Incidence

Malnutrition most often results in incidence of disease in pepper vines. Deficiencies of nutrients like P and K as causes of disease in plants have been known (Harper, 1974; Waard, 1969). Waard (1969) refers to the key role plyed by nutrients, especially K, in the control of 'yellow leaf' diseases and states that a fertilizer mixture having 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg applied to one hectare with appropriate mulching will control the disease and yield 2.0-2.5 kg dry berry per vine. Slow decline of pepper first reported by Krishna Menon (1949), in Wayanad, causes at least 10 per cent loss of yield. Slow decline of pepper is identified by the general appearance of wilting symptoms beginning with pale yellow leaves. Nambiar *et al.* (1965) worked out tentative ratios of K_2O (total)/N, K_2O (available)/N and $CaO+K_2O+MgO/N$ in soil, and found that slow decline of pepper occurred when these ratios were below 14.1, 0.05 and 3.8 respectively. The etiology of the disease is not clear (Nambiar *et al.*, 1978).

Involvement of fungi, soil moisture stress and deficiency of K and P (Nambiar and Sarma, 1977); nematode (Ramana and Mohandas, 1987) were attributed to slow decline. Wahid and Kamalam (1982) analysed leaf samples from 'slow decline' affected plants and found that K levels of the leaves of healthy vines were considerably higher than those of disease-affected ones. The pot culture studies conducted by them indicated K deficiency as a cause for the slow decline of pepper vines.

Survey was carried out in major pepper growing areas of Kerala and Karnataka states to study the relationship of nutrients with yield and slow decline of pepper. The pepper yield was correlated with DTPA extractable Fe (r=0.56*) and Cu (r=0.41**) in healthy gardens (Table 13). The yield was also correlated with leaf iron (r=0.56**) in a healthy and also diseased gardens (r=0.63**) with leaf manganese (r=0.27*) and leaf Cu (r=0.37**) in diseased gardens, indicating the importance of these elements in pepper nutrition (Table 14). Thus, micronutrients like F, Zn and Cu play vital role in superscribing

Table 13 : Simple correlation (r) among micronutrients and yield of black pepper

	r values	
	Healthy gardens	Diseased gardens
DPA Fe *vs* Yield	0.55**	—
DTPA Cu *vs* Yield	0.41**	
Leaf Fe *vs* Yield	0.56**	0.62**
Leaf Mn *vs* Yield	0.46**	—
Leaf Zn *vs* Yield	—	0.27*
Leaf Cu *vs* Yield	—	0.37**

*Significant at 1% level.
**Significant at 5% level.

Table 14 : Simple correlation (r) among nutrients

	r values	
	Healthy gardens	Diseased gardens
Soil Fe *vs* Soil K	−0.39**	—
Soil Fe *vs* Soil Ca	0.36**	—
Soil Fe *vs* Soil Mn	0.45**	—
Soil Mn *vs* Leaf Fe	0.34*	—
Soil Mn *vs* Root Zn	−0.37**	—
Soil Mn *vs* Leaf Zn	—	0.23*
Soil Zn *vs* Soil K	0.47**	—
Leaf Zn *vs* Leaf Mg	−0.36*	—
Root Fe *vs* Root K	0.30*	0.39**
Root Zn *vs* Root Mg	−0.36*	—
Root Cu *vs* Root K	0.39**	—

*Significant at 1% level.
**Significant at 5% level.

disease incidence and enhancing production of pepper (Sadanandan and Hamza, 1992). Wahid *et al.* (1982) reported that foliar yellowing and necrosis of distal ends of laminar in slow wilt affected gardens were due to N and K deficiencies respectively. The adoption of integrated nutrient management together with adoption of disease and pest management brought down the incidence of *Phytophthora* foot rot from 6.1 to 1.9 per cent and slow decline from 6.4 to 2.2 per cent (Fig. 6). An integrated approach for sustainable

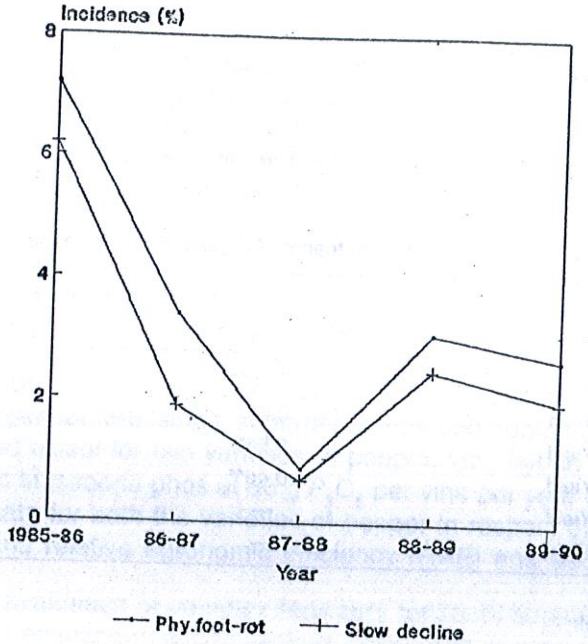

Fig. 6 : Disease incidence in mono-cropping of pepper.

management of pepper garden by the integration of chemical, agronomic and physical factors are depicted in Fig. 7.

8. FERTILIZER MANAGEMENT

Improving soil quality for better plant growth has long been primary objective of soil science. Loss of soil quality can result from the mismanagement of soil resources. A soil management strategy for sustainable pepper production must be based on maintaining soil quality in long term. Soil fertility and agricultural production can be maintained only by efficient and judicious management of nutrient addition to the soil from external sources. Organic and inorganic fertilizers are the two major external sources, proper management depends upon dose recommended, sources, time and method of application, basin management and fertilizer management for cropping systems.

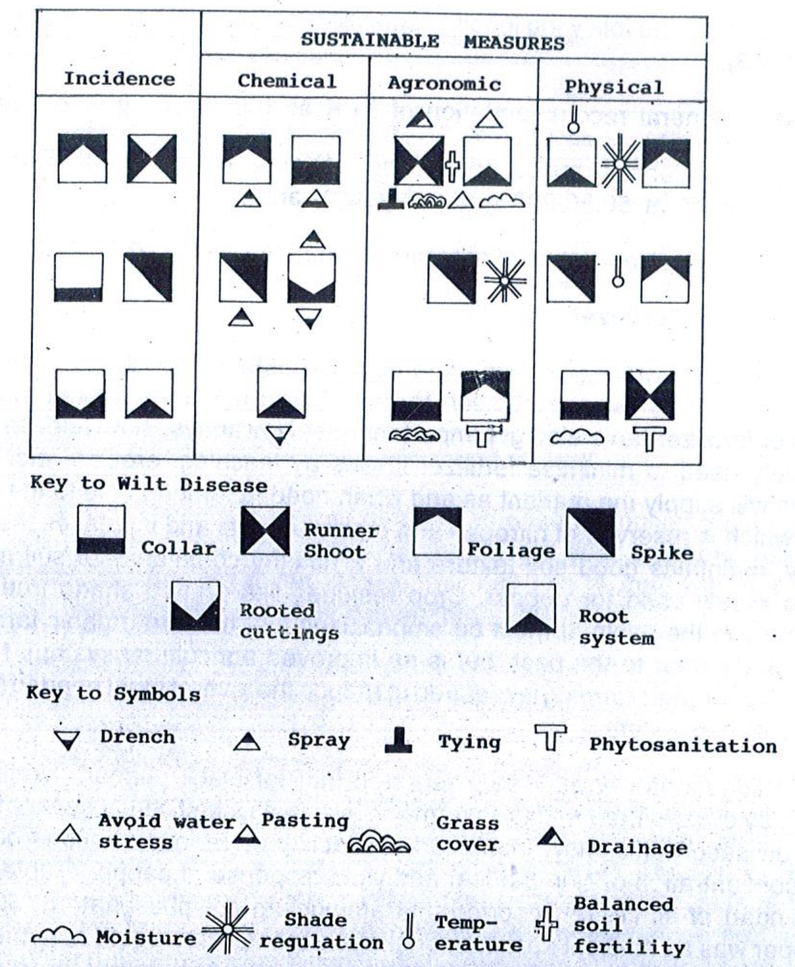

Fig. 7 : Sustainable management of pepper garden.

8.1 Doses

Fertilizer doses can be recommended based on soil tests and field trials. Since nutrients requirement vary from variety to variety, it should be variety specific also. New high yielding varieties are continuously being released. In black pepper, nine improved varieties have been released. The nutrient requirement may differ for these varieties. Higher crop yield need application of higher levels of fertilizers including micronutrients so that soil may not become deficient. The changes in soil fertility levels with continued fertilization also necessitate the reassessment of the rate of fertilizer application. Fertilizer recommendation may also need revision when established research results are available. Fertilization based on cropping system rather than for one single crop is justifiable. Location specific recommendations are meaningful as native nutrient levels vary in different location. The following location specific recommendations have been suggested (Anon., 1989).

a) General recommendation of NPK at 100:40:140 g vine^{-1} year^{-1};

b) For Panniyur region, northern part of Kerala and similar agroclimatic conditions, NPK at 50:50:200 g vine^{-1} year^{-1}; and

c) Calicut and similar agroclimatic region, NPK 140:55:270 g vine^{-1} year^{-1}.

8.2 Sources of Fertilizer

In India, a number of nitrogenous, phosphatic, potassium, mixed and complex fertilizers are being used in addition to the organic manures. To get maximum profit, sources of fertilizer have also got important role. Nowadays, slow release fertilizers are also widely used to minimise fertilizer losses by leaching, erosion, etc. Slow release fertilizers will supply the nutrient as and when needed for long time to the crop. Organic matter, which is reservoir of nitrogen and other nutrients and increases the soil buffering capacity, maintains good soil texture and a healthy community of soil microorganism are also widely used for pepper. Crop residues like pruned shade trees should also be supplied to the basin. It must be emphasized that modern organic farming does not represent a retreat to the past, but is an improved agricultural system. More research on the role of organic farming is required to reduce the level of input needed for sustainable agricultural ecosystem.

Sadanandan *et al.* (1992) reported that for black pepper, 'nimin' coated urea followed by cyclo-diurea and urea formaldehyde was significantly superior as evidenced by the utilisation efficiency, increased availability of various fractions of N in the soil, tissue concentration of N in the leaf and yield response of pepper (Table 11). Similarly, Sadanandan *et al.* (1992) reported that ammonium polyphosphate at 50 kg P_2O_5 ha^{-1} for pepper was as efficient as diammonium phosphate with regard to nutrient availability, yield response and uptake of P (Table 15). In another study, it was found that Mussoorie phos at 80 kg P_2O_5 per vine per year was as efficient as superphosphate for both Panniyur-1 and Karimunda pepper varieties with respect to soil availability of P, yield response, relative agronomic efficiency (RAE) and economics (Sadanandan, 1986).

8.3 Time and Method of Application

Time and method of fertilizer application may considerably influence crop response to fertilizer. A number of factors like growth stages, nutrient requirement, soil moisture conditions, nature of the fertilizer, etc., should be taken into consideration. Some phosphate fertilizer like rock phosphate, basic slag, etc., should be applied well before requirement to obtain maximum effect, whereas better utilisation of applied nitrogen is affected by supplying it at a time when crop need it. Potassium uptake is more or less continuous throughout the different stages of growth. In order to avoid leaching loss, split application is generally recommended as black pepper is raised as a rainfed crop

Table 15 : Effect of of P sources on soil availability of nutrients and yield

	Yield (kg vine^{-1})	1990-91						
		o.m (%)	Bray P	K	Ca	Mg	Fe	Zn
Check	2.46^{d}	3.06^{d}	17.0^{e}	212	919	83	15^{c}	1.0^{d}
APP 25	4.92^{c}	2.76^{b}	34.0^{d}	190	901	91	17^{b}	1.2^{bc}
APP 50	5.56^{b}	3.92^{ab}	56.2^{c}	241	772	81	20^{a}	1.4^{ab}
APP 75	6.30^{a}	4.10^{a}	84.6^{a}	251	926	96	18^{ab}	1.5^{a}
DAP 25	4.30^{c}	3.46^{c}	36.2^{d}	232	901	95	20^{a}	1.3^{ab}
DAP 50	5.60^{b}	3.84^{ab}	53.8^{c}	283	891	97	20^{a}	1.4^{ab}
DAP 75	6.48^{a}	4.06^{ab}	72.8^{b}	248	703	95	18^{ab}	1.2^{bc}
CD (5%)	0.59	0.34	7.1	NS	NS	NS	3	0.2

Figures with the name superscript are not significantly different at 5% level.

in heavy rainfall areas. One third of the recommended dose is applied during first year which is increased to two-thirds in the second year. Third year onwards, full dose is given. The fertilizers are applied in two doses. The first half in April with the onset of monsoon and the second half in August-September.

For one year old vines 1/3 and two-year old 2/3 quantity of recommended dose is applied. From third year onwards, first dressing should be given early during south-west monsoon (June) followed by one, two or three more dressings at intervals of 40 days. Approximately 10-20 days after dressing, the buds develop and new leaves and flower spikes appear. In the course of 2 or 3 months, the vines develop a dense canopy. Banding of fertilizer in 3/4 circle around the vine or in alternating parallel band on either side of the vine underneath the edge of the canopy is common practice in Sarawak (Waard, 1964). The apparent discrepancy between nutrient distribution by broadcasting and the condition required to ensure an adequate supply of nutrients at low root densities may be overcome in part by calculated placement of fertilizer close to extreme tips of the rootlets.

Foliar application is more effective for the application of trace elements. As very small quantities of these elements are required, they can be more effectively and economically applied as sprays along with insecticide and pesticides. Studies need to be taken in these lines in view of the recent hike in fertilizer costs.

8.4 Basin Management

Basin management has got important effect in pepper cultivation. Sadanandan (1986) reported that addition of neem cake, FYM and bone meal together with dolomite resulted in an overall beneficial nutrient balance and hence good establishment and yield of pepper. Grass cover helped in conditioning the soil due to its root effect and improvement of soil structure beside checking soil splashing and reducing soil temperature. Sadanandan *et al.* (1992) reported that pepper vines trailed on *Erythrina indica* resulted in higher percentage of survival than on other standards. The pruning from the standards can be effectively used as mulch for pepper vine, which after decompositions enhances the organic matter and retains higher soil moisture. Ramachandran *et al.* (1988) reported the beneficial effect of grass/legume cover in reducing foot rot diseases incidence. Othman Yaacob and Wan Sulaiman (1992) reported that covering the soil and terracing conserve soil moisture and fertility, reduces soil losses as much as by 150 per cent.

8.5 Fertilizer Management for Cropping System

Mixed cropping of perennials in interspace of main crop is one of agriculture system followed from time immemorial. Pepper is cultivated largely as a mixed crop in coconut and arecanut gardens.Since the income generated from the minor crop of coconut is low to sustain an average family (Thampan, 1976). So pepper is grown as mixed crop with coconut, arecanut, cardamom, tea and banana. For each cropping system, there should be different management and fertilizer recommendation to achieve maximum profit. In a multiple cropping system, there will be always competition among crops for nutrients, water and sunlight. So the system should be highly adjustable to satisfy the cropping pattern depending upon the crops need. Sadanandan *et al.* (1991) reported that a coconut-pepper mixed cropping system at Calicut district of Kerala with integrated nutrient management (black pepper vines were manured at 5 kg FYM, 0.5 kg each of neem cake and bone meal, and N, P, K at 100, 40, 140 g per vine per year and coconut palms manured at 50 kg green leaves, 25 kg FYM and N, P, K at 0.34, 0.17, 0.68 kg per palm per year) increased the soil available nutrients and also the overall productivity of coconut and black pepper by 53 and 172 per cent respectively (Table 16). In mixed cropping system, there are indications to scale down the fertilizer use to almost half the recommended dose of each of the main crop and intercrops.

In pepper based cropping system, interplanting of banana and fertilizing with recommended dose of nutrients in between rows of pepper vines reduces the ambient temperature, increases the survival rates of pepper vines (89%), improves the soil fertility status and fetches an additional annual revenue of Rs. 10,600/ha from banana alone besides a return of Rs. 23,000 from pepper, thereby improving the economic status of the farmer (Sadanandan, 1987).

Table 16 : Effect of HPT* in coconut-pepper mixed cropping system on pepper productivity (yield kg/vine)

Year	Farmers' practices	HPT	Increase (%)
1986-87	0.35	1.10	209
1987-88	0.41	1.18	185
1988-89	0.34	0.84	149
1989-90	0.50	1.23	146
Mean	0.40	1.09	172

*High Production Technology.

Growing of congosignal grass (*Brassica* sp.) in between rows of pepper vines reduced soil erosion, and soil temperature and foot rot incidence of black pepper, increases sub-soil moisture, and thereby alleviates the moisture stress on vines and improves the physical and fertility status of the soil. Maintenance of grass results in a yield of about 30 tonnes of green fodder annually leading to increases in the system productivity (Sadanandan *et al.*, 1992).

By the adoption of pepper-based farming system in the farmers' field in Calicut district, Kerala by growing intercrops of ginger and turmeric, the productivity of pepper was 1130 kg/ha. In Coorg region of Karnataka State, planting of pepper as an intercrop in coffee and tea plantations are very common. Pepper vines are tailed on the shade trees and fertilized with the recommended dose of the main crops. In such situations, very high yield levels 1 to 1.25 tonnes of pepper per ha are harvested bringing down cost of pepper production to very low level.

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