CROP - STANDARD INTERACTIONS IN BLACK PEPPER (*Piper nigrum* L.)

By
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THESIS

Submitted in partial fulfilment of the requirements for the degree of

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DECLARATION

I hereby declare that this thesis entitled "**Crop – standard interactions in black pepper (*Piper nigrum* L.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that the thesis, entitled **"Crop – standard interactions in black pepper (*Piper nigrum* L.)"** is a record of research work done independently by **Smt. Manjusha C.M.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Dedicated to my beloved Parents

Introduction

INTRODUCTION

Black pepper (*Piper nigrum* L.), known as the King of Spices, is the most important and most widely used spice in the world. This spice with its characteristic pungency and flavour is an essential ingredient in many food preparations. India is the homeland of black pepper. For the common Indians, pepper is a spice as well as a medicine, a sure cure for cold and fever and a component of many traditional Ayurvedic drugs.

Inspite of the fact that pepper was originated in India and that it was under cultivation for centuries, the yield of pepper in India is one of the lowest in the world. A very wide gap exists between the productivity in India (320 kg ha^{-1}) and that of other countries like Malaysia (3500 kg ha^{-1}), Indonesia (4500 kg ha^{-1}) etc. Area under pepper in India is enough to supply the world with pepper, if yields were only in the order of one third of what they are in Sarawak and Indonesia (Burger and Smit, 2000).

In countries like Malaysia, Indonesia and Brazil, intensive cultivation is practised, where the vines are trailed on dead standards at closer spacing. However in India, Sri Lanka, Philippines and parts of Indonesia, extensive cultivation systems prevail where pepper is grown on naturally fertile soils and trailed on live standards planted at wider spacing with a little management and attention.

In order to increase pepper production, the two practical approaches could be increasing the area under crop and increasing productivity. The scope of area expansion has limitations due to acute stress for land. Therefore, the attention should be focused on high yielding, disease resistant varieties and management practices to boost productivity. For increasing the production of pepper in Kerala, the best and the only way is to cultivate pepper as mixed/intercrop and companion crop in the homestead gardens (Sasikumaran and Nair, 1988). Homestead farming system of Kerala which is essentially an agroforestry system involving multispecies annuals and perennials is a sustainable land use model which has both economic and ecological advantages.

In improved varieties like Panniyur 1, a wide gap exists between potential yield and realized yield. One of the major reasons for low productivity in India is the use of undesirable standard or support. Providing ideal support plays an important role in successful establishment of black pepper plantation. According to Salam *et al.* (1991), pepper is trailed on 31 different tree species in the homesteads of Kerala. Indepth studies on interaction between pepper and its standard at different levels are limited except for the studies on root level interaction between pepper and *Erythrina* by Sankar (1985). Most of the studies are limited to analysis of yield and a few yield contributing characters of pepper. Eventhough studies by Sankar (1985) showed a high root level competition between pepper and its standard *Erythrina*, a high yield was reported for pepper when trailed on *Erythrina* by Sadanandan *et al.* (1991). The competition between the crop and standard while sharing the soil space for below ground resources like nutrients if studied can assess the partitioning of nutrients between them. The effect of different standards on pepper with respect to rhizosphere characteristics, nutrient uptake, growth, yield and quality of pepper will give an idea about the most ideal standards for trailing pepper which have the least root and shoot level competition with pepper. Live standards also have the added advantage of providing valuable products like fruits, timber, medicines, organic biomass etc.

With this background, present study on "Crop-standard interactions in black pepper (*Piper nigrum* L.) was proposed with the following objectives:

1) To study the effect of standards on growth, yield and quality of pepper
2) To study the effect of standards on the chemical and biological properties of rhizosphere soil of pepper
3) To study the root level interactions between pepper and standards employing radiotracer technique
4) To study the variation in foliar nutrient status of pepper and standards in different pepper-standard combinations

Based on the above analyses, mechanisms underlying suitability of different standards to trail pepper can be understood thereby suggesting the most feasible and economic ones.

Review of Literature

2. REVIEW OF LITERATURE

Different aspects of crop-standard interactions in black pepper are reviewed in this chapter.

2.1 STANDARDS (SUPPORTS) OF BLACK PEPPER

Black pepper is cultivated in India in homestead gardens and seldom it is grown as a monocrop. This climber needs a support to grow or to trail and clings itself to the support with the help of roots produced at each node. The supports or standards generally used vary depending upon the plants available in the homestead gardens when grown as a mixed crop.

2.1.1 Live standards

A variety of tree species commonly grown in the homesteads for meeting the food, fodder, fuel and timber requirements of the home can be effectively utilized to trail pepper. Many survey results have indicated that the use of trees as live supports for black pepper vines is an economically attractive and biologically sustainable agroforestry technology.

Menon (1981) observed significant difference in the mean growth as well as percentage of flowering in pepper vines (cv. Panniyur 1) trailed on different standards. The percentage of aborted spikes varied from 4.01 to 26.31 per cent in the different standards and no significant differences were noted for the mean number of spikes per shoot between standards.

Effect of variations in the plant species used as standards on infestation of black pepper by pollu beetle (*Longitarsus nigripennis* Mats) was studied by Kumar and Nair (1987). It was observed that berry damage was more under shady plants like *Artocarpus incisa, Ailanthus excelsa, Terminalia tomentosa* and *Erythrina indica* than under shady trees like *Cocos nucifera, Moringa oleifera, Glyricidia maculata* and *Garuga pinnata.*

In east Kalimantan (Indonesia), pepper is usually planted on iron poles. Seibert (1988) conducted a research to compare the growth of pepper on dead iron wood poles and on twing poles of *Gliricidia sepium* and *Erythrina lithosperma*. The living poles were as good as dead iron wood poles as indicated by the initial observations and farmers readily accepted the new technology.

Sasikumaran and Nair (1988) suggested that while selecting the living standards for pepper, preference should be given to leguminous trees or other economically important species which bring an additional income or reduce the investment in establishing the garden. Leguminous live posts have been tried as support for pepper so as to offer better soil protection, improve soil fertility and reduce establishment and weeding costs (Nair, 1989). *Erythrina fusca, Gliricidia sepium* and *Leucaena leucocephala* have been found very successful. A rubber and black pepper intercropping trial was set up by Cunha *et al.* (1989) in Brazil and observed that production of both crops was best for the treatments combining 667 to 889 black pepper plants per ha and 392 to 513 rubber plants per ha. The mixture of black pepper and rubber also reduced the immature period of the rubber clone.

In a survey of homegardens in southern Kerala, Salam *et al.* (1991) identified 31 different tree species used to support black pepper and results indicated that use of trees as living supports for black pepper vines is most suitable for a sustainable crop production. Wardell (1991) reported the use of trees like mango, jackfruit, coconut, *Chlorophora excelsa, Bridelia micrantha, Cedrela odorata* etc. as support trees for black pepper vines in Tanzania.

Effect of variety, spacing and support material on nutrition and yield of black pepper was studied by Cheeran *et al.* (1992). Three to four fold increase in yield was obtained by trailing the vines on teak pole instead of on live supports. The decrease in yield of the vine trailed on *Erythrina indica* and *Garuga pinnata* as compared to that on teak pole was discussed in the light of probable competitive interactions between the crop vine and support tree as in mixed cropping system.

Ranjith *et al.* (1992) reported *Cyclopelta siccifolia* as a pest causing appreciable damage in pepper plantations with *Erythrina* as standards.

Investigations on pepper as intercrop in coconut and arecanut gardens indicated 37 and 30 per cent higher profitability due to adoption of pepper as intercrop in arecanut and coconut gardens respectively (Bhosale *et al.*, 1994).

Mathew *et al.* (1996) evaluated the performance of seven selected fast growing tree species as live standards for trailing pepper. The growth characters and yield attributes of pepper were not influenced by these seven standards. However, the pepper vine trailed on *Garuga pinnata* recorded the highest vine height, number of leaves, nodes, leaf area index, number of spikes and yield. It was closely followed by *Thespesia populnea*, while in the case of *Gliricidia sepium*, the pepper vine had registered the lowest values for all growth parameters and yield attributes. As *Garuga pinnata* recorded comparatively higher values for radial growth, bole volume, foliage and branch wood biomass without hindering the growth and productivity of pepper vine, it was suggested as an ideal live-standard for pepper. Effect of different standards on yield characters of pepper (cv. Karimunda) was studied by Rajagopalan and Mammootty (1996). Pepper vines trailed on *Ailanthus* produced the maximum number of spikes per vine followed by *Gliricidia* and *Erythrina*. With respect to green berry and dry berry yield, *Ailanthus* showed its significant superiority over other type of standards. Vines grown on *Gliricidia* showed high percentage of pollu beetle attack while those trailed on subabul recorded minimum infestation.

When monocultured pepper gardens were shifted to mixed cropping systems with the introduction of Robusta coffee, changes had occurred in shade and moisture management systems in fourteen pepper gardens in Wayanad and the transition was seen economically viable (Damodaran *et al.*, 1998). Surveys and economic analyses conducted in various cardamom plantations adopting mixed cropping systems in Kerala and Karnataka indicated that inclusion of black pepper alone or in combination with coffee and arecanut was highly remunerative giving high cost benefit ratios (Srinivasan *et al.*, 1999).

Kandiannan *et al.* (1999) recommended *Ailanthus malabarica* as a suitable live standard for trailing pepper as it has rough bark and deep tap root system which enables to draw water and nutrients from deeper profile which will not interfere with pepper root activity. It is also less susceptible to pest and disease infestation. Raising black pepper on live standards reduced the capital cost apart from increasing productivity on long term basis (Sivaraman *et al.*, 1999). Although growing black pepper on non living standards like reinforced concrete posts, granite pillars and teak poles at closer spacing is known to enhance the yield, during summer they absorb heat and become hot resulting in drying of clinging roots and poor growth of black pepper vines under exposed situations.

Performance of black pepper var. Panniyur-1 trailed on different shade trees as live standards was evaluated by Korikanthimath and Ankegowda (1999). The yield of black pepper was maximum in vines trailed on *Terminalia bellerica* (37.5 kg green berries per vine), which was significantly higher than in other trees. Vines trailed on *Grevillea robusta* yielded 19.16 kg green berries per vine indicating that it is a suitable standard in high ranges and also for high density planting of black pepper. Korikanthimath *et al.* (2000) observed that cultivation of cardamom and pepper along with silver oak as shade trees contributes to enhancing the over all productivity per unit of soil, light and water and safeguards the environment. The system can also improve the economic returns of small and marginal farmers.

The results of trials conducted by KAU (2001) revealed that pepper varieties trailed on *Ailanthus malabarica* produced the highest number of spikes and green yield per standard which was on par with *Erythrina.* The yield of pepper varied significantly when trailed on different standards (George, 2005). *Acacia* and *Artocarpus* were foremost in terms of dry berry yield (2.56 and 1.91 t/ha respectively). Pepper trailed on *Macaranga* (0.83 t/ha) and *Ailanthus* (0.93 t/ha) recorded the lowest yield. Among the different support trees tested, *Artocarpus* served as the best standard. It had good physical suitability, high lopped out turn over potential which helped in better maintenance of organic matter status and soil nutrients.

Leucaena leucocephala and *Flemingia macrophylla* were found unsuitable as live supports of yam (Budelman, 1990) as the former showed a strong competitive power expressed in terms of leaf productivity and relative density of the root mass in the upper soil stratum. The zone explored by the yam crop and the latter had a weak structure which could not sufficiently carry the yam leaf mass.

2.1.2 Dead standards

In the major pepper producing countries like Malaysia and Indonesia dead standards are mostly used and this is one of the reasons for the higher production and productivity (Raj, 1978). Investigations on the suitability of teak poles for black pepper varieties had clearly indicated their superiority over live supports in respect of both growth and yield of vines (Menon *et al.*, 1982).

Comparative performance of pepper vines (varieties Panniyur 1 and Karimunda) trailed on dead teakwood, *Erythrina indica* and *Garuga pinnata* was studied by Kurien *et al.* (1985). Results revealed that teak standards are the best and yield from the vines trailed on dead teak poles had excelled those trailed on *E. indica* and *G. pinnata*. The live standards showed almost the same competition in the first year but in the second year *G. pinnata* showed a higher competition than *E. indica*. Among the yield components like the length of spike, number of spikes and height and spread of vine also *Erythrina* excelled over *Garuga* though the result were not statistically significant.

Alvim (1988) in his study observed that much higher pepper yields were obtained with dead supports than with live supports. The low yield in the live post treatment was attributed to their rapid growth so that the vines were rapidly over shaded. Sankar *et al.* (1988) observed that the nutrient uptake decreased when the vine was trailed on live trees. According to them, the two plant species *viz.* the vine and the support tree are competing for nutrient and water as they share the same soil resources. They also suggested that besides competitive interaction, there was also evidence of support tree exerting an inhibitory effect on the vine.

Stone wall planting of pepper was experimented by Jayakrishnakumar *et al.* (1991). It was observed that a partially shaded condition in the down slope side of the hill was very congenial for the successful growth and production of vine. Ravindran and Johny (2000) conducted studies to find out the most suitable among the different living and non living standards for black pepper. The data on vegetative, flowering and yield characters indicated that dead standards are better than live standards. However, initial cost of the dead standards is much higher. *Ailanthus malabarica* followed by *Erythrina indica* are the best standards to grow pepper in Malabar regions in the plains.

In a fertilizer cum standard trial conducted at KAU (2001), it was observed that dead standards were superior to live standards with regard to plant height, length of spikes, number of spikes and weight of spikes.

2.2 TREE-CROP INTERACTION IN AN AGROFORESTRY SYSTEM

Agroforestry land use systems are relatively complex where environmental resources are shared, hence the species may interfere with one another. While describing the nature of interactions, Harper (1961) focused that plants may influence their neighbouring species not only by adding or removing of some factor, but by affecting conditions such as temperature, light or wind movement and by altering the balance between beneficial and harmful organism. Main effects of tree-crop interactions are complementary (for example, increase productivity, soil fertility improvement, nutrient cycling, microclimatic improvement and sustainability) or competitive (yield reduction of crop components in various system due to tree components) (Huxley *et al.*, 1987; Ong and Huxley, 1996).

Donald (1963) opined that morphologically and physiologically contrasting species will together be able to exploit the total environment more effectively and thereby will give increased yield. Nutrient competition between interplanted species was investigated by Gillespie (1989). Though tree and crop plant roots may occupy the same soil volume, nutrient competition was seen to be dependent on soil supply mechanisms. Nutrient competition was most likely for the more mobile nutrients and a mechanistic modeling could be used to select tree and crop species with superior rooting and physiological characteristics for interplantings to better manage below ground competition.

In most cases, the yield of agricultural crop is the criterion by which the merit of an agroforestry system is assessed; yield depressions of this component therefore receive more attention than those of the associated tree species. Since crop is usually a smaller component, its root system will usually be confined to soil horizons that are also available to the roots of the trees; but the trees can exploit soil volume beyond reach of the crop. However, direct evidence as to where and how severely, nutrient competition occurs is limited due to the difficulties of separating nutrient competition from competition for light, water and from allelochemical interactions (Young, 1989). Toky and Bisht (1992), Mathew *et al.* (1992), George (1993) and Jamaludheen (1994) reported the influence of canopy architecture and crown characteristics of tree components on the productive efficiency of agroforestry systems.

In mixed cropping system involving tree components, there is probability of sharing of nutrient ions between the rhizospheres of the neighbouring plants. The tree roots may release, leach out or exude mineral and organic materials into the rhizosphere of neighbouring plants if they interact with one another (Sureshkumar *et al.*, 1999). Trees being the dominant component, their species and density have overriding influence on productivity of the crops grown underneath (Sharma, 2005).

2.3 ROLE OF MULTIPURPOSE TREES IN POLYCULTURE SYSTEM

The presence of woody perennials in an integrated land use system has both advantages and disadvantages. Many tropical spice crops (ginger, pepper, cardamom, clove, nutmeg etc.) and beverage crops (tea, coffee and cacao) are grown in association with either planted tree crops or as understorey crops in natural resources (Nair and Varghese, 1976; Nair and Sreedharan, 1986; Tejwani, 1994; Kumar *et al.*, 1995).

Traditionally multi purpose trees are included in the coconut gardens as scattered trees or on farm boundaries for green manure and fodder purposes and or as support trees for trailing pepper vines. *Gliricidia sepium, Erythrina indica, Pajanelia rheedii* and *Leucaena leucocephala* are prominent in this respect (Ghosh *et al.*, 1989; Liyanage *et al.*, 1990). Many field or tree crops are grown in association with *Ailanthus* and owing to its compact crown, moderate root spread and deep rooting tendency, it is thought to be less competitive with associated crops (Mathew *et al.*, 1992; Sureshkumar *et al.*, 1999). Thomas (1996) observed that rhizome yield in *Ailanthus* - ginger combination was consistently higher than the sole crop. Vegetative growth, leaf area development and foliar nutrient level, particularly nitrogen of ginger was favoured in association with *Ailanthus.* Kumar *et al.* (2001) reported *Ailanthus triphysa* as a prominent multi purpose tree in the traditional land use systems of Kerala.

2.3.1 Nitrogen fixation

Many of the tree species in an agroforestry system fix atmospheric nitrogen. With reduced demand for nitrogen at the root surface, competition will be reduced for this nutrient with the possibility of nitrogen transfer to inter planted non nitrogen fixing species. Inter planted nitrogen fixing species can acidify their rhizosphere and can as well enhance phosphorus uptake of companion plants (Gillespie, 1989).

Multipurpose nitrogen fixing trees like *Leucaena leucocephala, Acacia mangium, Gliricidia sepium, Erythrina indica* etc. have shown promise as effective fallow improvement crop and have been widely tested and provides a good source of fuel, wood and green manure while controlling weeds and stabilizing soil (IITA, 1986). Importance of nitrogen fixing trees in soil fertility improvement by efficient cycling of nutrients in agroforestry system was studied by Dhaneshkumar (1998). Singh *et al.* (2002) studied the importance of above ground and below ground competition in a *Leucaena leucocephala* based alley cropping system on growth and productivity of wheat crop. Nitrogen uptake and photosynthetic rate was 1.39 times and 1.72 times respectively greater under *Leucaena* shrub in fertilized compared to unfertilized condition.

Nitrogen fixing trees like *Calliandra calothyrsus, Leucaena leucocephala, Acacia auriculiformis* and *Gliricidia sepium* interplanted coconut plots had higher soil water content than the sole stand of coconut. Water loss from the topsoil was significantly lower than the base soil (Arachchi and Liyanage, 2003).

2.3.2 Soil enrichment

Trees and shrubs are known to use their extensive root system to absorb substantial quantities of nutrients from lower soil horizons and enrich the topsoil through leaf fall. In monocropping and multiple cropping systems, the integrated interaction effect of crop on soil helps in conservation and depletion of nutrients. The components of nutrient enrichment includes rainwater, fertilizers and organic manures, organic recycling, crop residue addition and native soil nutrients and that of nutrient depletion are leaching, volatalisation, microbial immobilization, fixation and plant produce utilization (Biddappa *et al.*, 1984). Linehan *et al.* (1985) found that the rhizosphere acidification was related to the solubilization of Cu, Mn and Zn.

George (2005) studied the litter dynamics of selected multipurpose tree species used as pepper standards. N, P and K content of the soil remained reasonably stable under pepper on various support trees. The organic carbon content in the soil under each species showed considerable difference among the trees. The soil under *Artocarpus* and *Macaranga* showed maximum organic carbon content.

Multipurpose trees like *Gliricidia* can produce 6 to 8 t per ha of fresh foliage from three prunings a year. On decomposition this can restore physical condition of the soil. For example, decomposed *Gliricidia* foliage can improve the water holding capacity of soil from 45 to 99 mm/m, organic content from 0.83 to 1.73 per cent and reduce bulk density from 1.49 to 1.39 g cm^{-3} (Liyanage and Wijeratne, 1987). *Gliricidia* has shown an exceptional ability to tolerate acidic soil conditions where as *Leucaena leucocephala* was found to thrive well only in non acid light sandy soils in the intermediate and dry zones (Liyanage and Jayasundara, 1989).

Handawela *et al.* (1989) found that intercropping sesame and maize with *Gliricidia sepium* and mulching between the crop rows with tree loppings increased crop yield and soil fertility.

Effect of three agroforestry systems involving *Leucaena leucocephala* and *Gliricidia sepium* were evaluated on changes in soil chemical and nutritional properties by Lal (1989). Soil organic matter, total N, pH and exchangeable bases declined significantly in all treatments. The total acidity and exchangeable Al^{+3} was also significantly less in agroforestry than non-agroforestry systems. Sarong *et al.* (1989) showed there were lower concentrations of Zn in water extract of the rhizosphere relative to the bulk soil. Similar results were reported by Knight *et al.* (1997) for Zn in the soil solution of *Thlaspi caerulescens* in a pot experiment. Young (1989) observed that trees with intercropped maize influenced soil properties to a 6-10 m radius, under *Prunus capuli* and *Juniperus* sp., nitrogen was 1.5-3 times higher under trees, available phosphorus 4-7 times, potassium 1.5-3 times and Ca, Mg, organic carbon and CEC were also increased. *Leucaena*, *Gliricidia* and *Cassia* prunings released most nitrogen within 60 days of application to soil.

According to Harwood and Getahun (1990) roots of *Grevillea* penetrate deep into the soil, far below the zone utilized by agricultural crops and recycles nutrients from these layers back into surface. Dhyani *et al.* (1990) reported that under the tree canopy cover, there was significant enrichment with regard to total nitrogen, available potassium in comparison to outside the tree canopy. Exchangeable calcium and magnesium values were about 1.5 and 2.5 times higher under the tree canopy than outside the canopy.

Sadanandan *et al.* (1991) reported an increase in soil fertility in N, P, K, Ca, Mg and micronutrient status in coconut - pepper mixed cropping system.

Soil physicochemical properties were improved on including tree species in a pastoral system through enhanced nutrient cycling, N fixation and amelioration of soil physical properties (George, 1993). Soil pH was significantly lower under *Acacia* and *Leucaena* stands compared to the tree less controls, *Ailanthus* and *Casuarina*. The organic matter status decreased in the order *Acacia* > *Leucaena* > *Casuarina* > *Ailanthus*. A higher soil N was seen below the N fixing trees and higher P and K levels were reported in plots with tree components. Generally *Leucaena* had the highest concentration for most elements in the foliage. Liyanage *et al.* (1993) reported substantial improvements in soil organic carbon content, water holding capacity and bulk density by planting *Leucaena leucocephala* under coconut and incorporating the tree loppings.

Marked variations in the soil chemical properties had been noticed among the plots under different tree species like *Casuarina, Emblica, Pterocarpus, Leucaena, Acacia, Paraserianthes* and *Artocarpus hirsutus* plots by Jamaludheen (1994). The soil organic matter status was significantly high in *Leucaena* and *Acacia* plots. Comparatively higher N status of N-fixing tree plots was noticed. *Casuarina, Emblica* and *Pterocarpus* plots were having significantly higher P. Soil K was almost uniform and was statistically on par for most of the species except a markedly higher level in *Acacia, Paraserianthes* and *Artocarpus hirsutus* plots.

In the *Eucalyptus* rhizosphere soil, a reduction in micronutrients except Mn was observed probably caused by their uptake by the growing plant. Mn though taken up by the plants was replenished from the upper layers because of its greater mobility than Zn and Cu (Baddesha *et al.*, 1997). Evaluation of a multi species cropping system involving banana, pineapple, black pepper and cocoa during immaturity phase of rubber was conducted by Jessy *et al.* (1998). An increase in organic matter and available phosphorus and a decline in available, potassium content in the soil was noticed after 30 months. Growth of *Hevea* was significantly superior in the present system compared to that in monoculture and the nutrient budget of the system indicated a net gain of all the nutrients studied. Intercropping *Leucaena* promoted soil status by increasing total nitrogen and available phosphorus contents in teak plantations (Kumar *et al.*, 1998).

Mongia *et al.* (1998) observed a lowering of pH and increase in organic carbon content under the plantations of forest trees like *Prosopis julifera* and *Casuarina equisetifolia.* Variation in the concentration of micronutrients in the soil may be due to their differential uptake by the trees and subsequent recycling in the soil through litter decomposition. Acidification of rhizosphere at the soil-root interface was reported by Gahoonia (1993) who found a higher soluble Al content in the rhizosphere of *Lolium perenne* associated to a decrease in pH. Lorenz *et al.* (1997) also indicated that rhizosphere contains less free metals as they are bound to dissolved organic matter released during plant growth. But Youssef and Chino (1989) measured a higher Fe and Mn solubility in the rhizosphere region despite a higher pH. It is well established in the literature that pH and organic matter content are two key factors influencing the concentrations of metals. For example, the chemical activity of most metals increases as the pH of the solution decreases (Lindsay, 1979).

Tree species can cause direct (e.g. litter fall, organic acids, biocycling) or indirect (e.g. mycorrhizae, microorganisms) effects in the rhizosphere soil chemical properties (Finzi *et al.*, 1998; Watmough, 2002). Tree species create different environmental conditions in their respective rhizosphere. Wang *et al.* (2001) found differences between the rhizosphere solutions of *Picea abies* and *Fagus sylvatica* in terms of metal concentrations. Even when using plants from the same genus such as *Thlaspi caerulescens* and *Thlaspi ochroleucum*, Mc Grath *et al.* (1997) found opposite trends for Zn in the rhizosphere solutions. It is difficult to establish if the absence of differences between soil components is specific to the environmental conditions used for if tree species are only a minor variable explaining differences in the metal content of the rhizosphere between sites. Hazra and Tripathi (1986) and Sharma (2005) observed a favourable microclimate as well as physical and chemical properties of soil under *Acacia albida* which was explained as due to higher surface area covered by tree canopy resulting in greater leaf fall.

Studies on impact of neem plantation on soil properties were conducted in four and eight year old neem plantations by Pandey *et al.* (2002). . An increase in organic C, available N, P and K was 0.11%, 38.90 kg ha^{-1}, 5.14 kg ha^{-1} and 62.55 kg ha^{-1} respectively in four year old plantation and 0.18 per cent, 35.75 kg ha^{-1}, 3.96 kg ha^{-1} and 67.55 kg ha^{-1} in eight year old plantation. The increment in organic carbon and available N, P and K was lower in 15-30 cm soil depth compared to 0-15 cm and the soil pH was slightly lower in both the plantations compared to control.

Patil and Prasad (2004) while characterizing *Shorea robusta* supporting soils in Madhya Pradesh, observed a high exchangeable calcium in the surface soil due to redistribution of Ca by tree species and a high DTPA extractable Fe, Mn, Cu and Zn in the surface layers of soils due to the chelating effect with humus.

Narain *et al.* (2004) reported an increased organic C, N, P and K content by 7.8 per cent, 91.9 per cent, 153.62 per cent and 6.5 per cent respectively in soil in an agroforestry system involving *Eucalyptus* and *Leucaena* together with maize or wheat.

2.3.3 Litter addition and nutrient recycling in tree- crop association

Loss of nutrients below the rooting zone can be considerably reduced in mixed species system depending on the species, age, root spread and related factors (Nair, 1984). The main effect of the trees on soil properties is above ground organic matter inputs through litter fall decomposition and thus improves nutrient cycling (Sanchez *et al.*, 1985). Accumulation of soil organic matter through litter fall might have regulated organic matter decomposition and the formation of stable and labile soil organic matter pool (Vitousek and Sanford, 1986). Beer (1988) studied litter production and nutrient cycling in coffee and cocoa plantation with shade trees at Costa Rica and reported that the litter fall has potential importance for the cycling of N, P, K, Ca and Mg since the litter inputs frequently exceeds nutrient inputs from inorganic fertilizers even when applied at highest recommended levels.

The return of nutrients through litter in several tree species has been reported by various workers (Vogt *et al.*, 1986; Sugar, 1989; Tandom *et al.*, 1996). In low input agroforestry systems, leaf litter incorporation offers a strong base for low cost sustainable agricultural production (Budelman, 1989).

George and Vargheese (1990) reported that nutrient return through litter fall of *Eucalyptus globulus* was 58, 46 and 49 kg ha^{-1} for N, P and K respectively.

Prasad *et al.* (1991) reported that incubation of the leaves like sal, teak, eucalyptus, subabul mixed with the soil for 12 months increased the available P, K and exchangeable Ca and Na significantly. Accumulation of soil organic matter through litter fall of *Acacia tortilis* have caused an increase in available N, P, organic carbon and decreased availability of Ca and Mg. Decreased availability of Ca and Mg might be due to its fixation through phosphate and or less return through litter fall and increase in available N was probably due to leaf litter addition and subsequent decomposition and mineralization.

An investigation on the growth and nutrition of black pepper as influenced by decaying litter materials in soil was conducted by Sivakumar (1992). Biomass production in black pepper was significantly increased following the incorporation of leaf materials of *Coffea arabica, Erythrina indica, Garuga pinnata, Grevillea robusta* and pepper leaves themselves were used as organic sources. Significant increase was noticed in N, P, K, Mg, Fe and Mn content of leaves of black pepper receiving organic treatments. Intensive farming leads to the reduction of soil fertility, which is a menace for productivity of agricultural crops and sustainable development on long-term basis. In last three decades, incorporation of trees in the farmlands is well recognized under agro forestry systems for maintaining soil fertility and productivity.

The soil loss, nutrient recycling, yield and economic returns from arecanut and coconut based intercropping systems involving cinnamon and black pepper were studied by Pramanik *et al.* (1998). A huge quantity of organic matter was recycled through the leaves and branches of intercrops after harvesting. It was concluded that interplanting of spices and grasses in the coconut and arecanut gardens not only increases the profit but also arrests the colossal loss of soil and water and enhances soil fertility.

Kumar *et al.* (2001) observed that influence of decomposition of leaf litter of *Acacia mangium* on changes in soil pH was not significant. Addition of leaf litter to soil brought out fluctuations in total N, available P and exchangeable potassium contents. Gowda (2002) could find marked variation in soil organic carbon and available P concentrations in different multipurpose tree plots. *Ailanthus* and *Grevillea* plots in general had higher organic carbon and available P level than *Vateria*, which may be due to the increased litter addition of the former. Suhyb (2004) observed that nutrient return through different components of litter indicated that for the three species *Acacia mangium, Acacia aulacocarpa* and *A. crassicarpa*, leaf litter returned maximum quantity of all nutrients especially nitrogen when compared to potassium and phosphorus. Biomass productivity of *Acacia* was the highest followed by *Leucaena, Casuarina* and *Ailanthus*.

The availability of metal ions *viz.* Fe, Mn, Cu and Zn increased with increase in organic matter content in an experiment conducted by Sharma (2005) to study the effect of inclusion of *Acacia* on yield of rainfed cowpea. Decomposition of organic matter reduced the pH of soil which helped in increased solubility of metal ions from soil.

2.3.4 Allelopathy

Molish (1937) coined the term allelopathy to refer to biochemical interactions between all types of plants including microorganisms. He meant the term to explain both detrimental and beneficial reciprocal biochemical interactions. Rice (1979) modified the above definition and defined allelopathy as any direct or indirect harmful effect by one plant on another through production of the compounds that escape into the environment.

Al-Monsawi and Al-Naib (1975) observed that leaf extracts, decaying leaves and soil collected under *Eucalyptus* canopies inhibited seed germination and seedling growth of associated species. Toxic substances released by leaves and plant residues (allelochemicals) have important implications for agro forestry systems. This is especially true for systems that depend on the use of tree prunings to supply nutrients and organic matter, protect soil from erosion or conserve moisture. Root exudation and subsequent uptake of minerals by other trees and transfer by mycorrhiza and rhizospheric organisms were explained by Smith (1976). Release of allelopathic chemical by leaching, excretion, exudation and volatalisation and decay either directly or by microbial activity is well documented (Lerner and Evenari, 1961; Hoffman and Carroll, 1996).

Allellopathic effect of *Azadirachta indica* on agricultural crops was tested by Divya and Yassin (2003).

2.4 FOLIAR NUTRIENT COMPOSITION OF MULTIPURPOSE TREES

Studies conducted on the nutritive value of different tree species add information to the potential of different tree species in the nutrient cycling in an agroforestry system.

Jones (1979) reported 3.8 to 4.4 percent N, 0.15 to 0.21 percent P, 1.5 to 2.1 per cent K, 0.5 to 0.66 per cent Ca and 0.17 to 0.31 per cent Mg in leaves of *Leucaena*. Although *Gliricidia sepium* had higher levels of nutrients than *Leucaena leucocephala* as reported by Vearasilp (1981), the higher leaf dry matter productivity in the latter species ensures a higher annual yield of nutrients and *Leucaena* was therefore considered as a better means to recycle nutrients. Foliar nutrient content of *Leucaena* was reported as 3.12 percent N, 0.16 per cent P, 2.0 per cent K, 2.0 per cent Ca and 0.40 per cent Mg and that of *Gliricida maculata* as 3.63 percent N, 0.17 per cent P, 2.35 per cent K, 2.44 per cent Ca and 0.58 per cent Mg by Chadhokar (1982).

Considerable variation was found in the leaf biomass nutrient content in the three species *viz. Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla. Gliricidia sepium* generally had the highest levels of leaf nutrient contents (N - 2.75 to 3.51 per cent, P - 0.19 to 0.25 per cent, K - 1.48 to 1.88 per cent, Ca - 0.96 to 1.52 per cent and Mg - 0.40 to 0.61 per cent) followed by *Leucaena* (N - 2.95 to 3.6 per cent, P - 0.19 to 0.25 per cent, K - 1.22 to 1.82 per cent, Ca - 0.75 to 1.09 per cent, Mg - 0.31 to 0.37 per cent) while *Flemingia* systematically had the lowest levels. Better part of the nutrients in the leaf biomass originates from the nutrient pool in the soil and that the value of the perennial lies in making the nutrients available for primary production purposes (Budelman, 1989).

Studies conducted on the nutrient status and nutritive value of 19 tree species (Sreemannarayana *et al.*, 1994) revealed that the concentration was maximum in leaves followed by twigs and bark. Leaves of *Leucaena* contained 3.6 per cent N, 0.57 per cent P, 2.2 per cent K, 74 ppm Zn, 18 ppm Cu, 1320 ppm Fe and 320 ppm Mn whereas that of *Azadiracta indica* contained 2.43 per cent N, 0.15 per cent P, 1,85 per cent K, 128 ppm Zn, 22 ppm Cu, 540 ppm Fe and 344 ppm Mn. The significant variation between tree species in micronutrient status might be due to differences in their ability to produce biomass of variable magnitudes.

Foliar phosphorus and potassium content of kacholam (*Kaempferia galanga*) were significantly higher when grown in association with coconut and multi purpose trees (Sureshkumar, 1997). In ginger and turmeric, Bai (1981) observed an increase in N, P and K content with increasing intensities of shade. In the case of ginger grown under *Ailanthus* canopy, nutrient content was found to be more for open grown plants, in the early stages whereas towards maturity, plants grown under shaded conditions exhibited higher nutrient contents (Thomas, 1996).

2.5 PRUNING OF MULTI PURPOSE TREES

Support trees should be pruned during the pre flowering stage of black pepper vine which increase the light availability and produce greater leaf area and more compact canopy structure with shorter lateral shoots. Wahid (1987) studied the effect of fertilizing and pruning the live supports on pepper yield in Indonesia and obtained the best results with pruning the support trees three times a year.

Pruning allows the vine to accumulate higher levels of metabolites which led to greater production of lateral shoots during the second flush; more flower spikes, a greater number of berries per vine and higher dry weight of berries per vine (Mathai and Sastry, 1988). Removal of parts or the entire crown will obviously reduce the competitive ability of trees, which will automatically increase the growth of black pepper by providing green manure and by allowing more light to penetrate to the crop. Below ground competition may also be reduced as a result of pruning induced root die back (Cannell, 1983). These observations also apply to pruning or pollarding operations on trees grown for shade or as live supports, such as *Erythrina, Gliricidia* etc. Species such as *Erythrina berteroana* which have large thick leaves and high rates of biomass production when grown as a shade tree will require more intensive pruning than trees with a less dense canopy such as *Gliricidia sepium* (Muschler, 1991).

Nitrogen contributions from the prunings of *Erythrina berteroana, E. fusca* and *Gliricidia sepium* exceeded 50 per cent of the fertilizer recommendation for black pepper while the contributions were less than 10 per cent for phosphorus and less than 40 per cent for potassium (Muschler *et al.*, 1993).

Mathew *et al.* (1996) while studying various live standards of black pepper reported that the foliage and branch wood biomass obtained in the loppings were significant and *Gliricidia sepium* recorded consistently maximum values for the parameters like height, number of branches, foliage and branch wood biomass and thereby exhibiting maximum vegetative growth.

2.6 NUTRITIONAL FACTORS INFLUENCING YIELD IN BLACK PEPPER

Kumar and Cheeran (1981) studied the nutrient requirement of pepper vines trailed both on live and dead standards. The interaction effect of N and P with standards was statistically significant. As regards to the growth of vine, dead standards were found superior to live ones.

Sushama (1982) observed positive correlation between dry berry yield and nitrogen and phosphorus content of first mature leaf of black pepper. Nitrogen content of leaf failed to establish significant positive correlation with yield.

Sankar (1985) compared the nutrient removal by pepper vine and the live standard *Erythrina* and observed that the total nutrient contents of the whole vine with an annual yield of 1.284 kg black pepper were much less than that of its support plant, *Erythrina*. The differences were more marked with respect to total content of N, P, K, Ca, Mg, Fe, Mn and Zn.

According to Nybe (1986) highly significant positive linear and quadratic correlations existed between yield and macronutrients, except N, in black pepper. However no significant correlation could be observed between yield and micronutrients (Fe, Mn and Zn). The element K had the maximum positive direct effect on yield followed by P, Ca, Mg and S. Though very meagre, the direct effects of N, Fe, Mn and Zn on yield were negative. Ibrahim *et al.* (1987) observed significant positive correlation between leaf nutrient concentration and yield of black pepper. Significant positive correlation also existed between foliar N and soil organic carbon and between foliar N and soil pH. Very high positive correlation observed between foliar P and S and foliar Ca and Mg indicated the synergistic interaction between these nutrients in black pepper. Foliar K maintained negative correlation with foliar Mg indicating the antagonistic effect between monovalent and divalent cations.

Relationship between leaf nutrient composition and yield in black pepper was worked out by Sadanandan and Rajagopal (1989). The yield of pepper did not correlate with each nutrient in the soil and the plant individually showing the fact that factors affecting yield are not controlled by the function of a single nutrient individually. Also no significant correlation of indices of N, K and Ca was obtained with pepper yield. But P indices of both youngest matured and next matured leaves gave significant correlations with pepper yield indicating that P index can be efficiently used to find out the probable yield from a pepper plantation. The pattern of growth and nutrient uptake in bush pepper and vine pepper and the relative efficiencies of black pepper varieties in the utilization of applied phosphorus were investigated by Geetha (1990). Leaf was found to be a better accumulator of N, K, Ca, S, Fe and Mn whereas P and Mg were more accumulated in the stem. The order of nutrients removed by black pepper was K > N > Ca > Mg > P > S > Fe > Mn > Zn.

Yield variability existing in a black pepper plantation was examined in relation to the soil fertility at the root zone by Mathew *et al.* (1995). Near neutral soil pH, high organic matter content and high base saturation with Ca and Mg were found to enhance the productivity of black pepper vines. Among the soil characteristics studied, pH, organic carbon, available Ca and available Mg were found to be positively correlated with yield and available S and Fe were negatively correlated. Significant positive correlations were also observed between foliar N and soil organic carbon and pH.

Singh and Singh (1996) observed a definite relationship between Fe, Mn, Cu and Zn in plants with their available status of soil and also with organic carbon content of soil. Turmeric yield was found to be positively and significantly correlated with available zinc whereas no significant correlation between yield and Fe, Mn and Cu was observed (Vijayakumar *et al.*, 1997).

Sreekumaran (1998) analysed various soil and plant nutrient factors in the rhizosphere soil of different yield group levels in black pepper and obtained different patterns of variations in the interaction of elements in soil and plant systems as well as with yield. The disproportional high variability of non-applied elements like secondary and micronutrients in the rhizosphere and at foliar levels observed in the study suggested their positive involvement in the cause of an expressed variability. Zn had a positive effect while Mn had a negative effect on yield. Nutrient ratios were found to be better indicators of black pepper productivity.

In Nendran banana, higher doses of N and P could not bring about any increase in the yield of banana. The plant may not be able to absorb and utilize higher levels of N and P unless absorption of Fe and Mn are curtailed and kept at below critical level (Sulekha, 2003). In mustard, application of manganese and copper alone failed to record any significant variation in the yield possibly due to the adequate level of DTPA Mn and Cu in the soil (Akbari *et al.*, 2003).

2.7 MORPHOLOGICAL CHARACTERS OF BLACK PEPPER INFLUENCING THE YIELD

Sujatha (1991) and Sujatha and Namboodiri (1995) reported that characters such as green berry yield per vine, number of spikes per vine, length of spike, number of developed berries per spike and thickness of nodes and internodes of orthotrope registered a high positive correlation with yield in black pepper. Almost all spike and berry characters showed positive association with yield of pepper according to the study conducted by Satheesan (2000). He obtained a significant positive correlation for spike length, number of berries, number of spikes, hundred berry weight and hundred berry volume with yield of pepper. Stephen (2002) obtained highly significant positive correlations between height of bearing column of pepper and canopy spread with yield of pepper. Number of laterals and spikes also showed significant positive correlations with yield. Thanuja (2003) reported that number of spikes per vine, length of spike and number of developed berries per spike were the most important characters influencing net yield in black pepper.

2.8 BIOLOGICAL CHARACTERISATION OF RHIZOSPHERE SOIL

Rhizosphere microbial communities carry out fundamental processes that contribute to nutrient cycling, plant growth and root health. The variations in the rhizosphere effect due to different plant communities were first noticed by Starkey (1929). He recognised the unequal stimulation of different microbial types by roots and also that kind and condition of any given plant influenced the microflora of the rhizosphere.

The rhizosphere regions from which plants derive most of their nutrients are considered to be the seat of intense microbial activity.

2.8.1 Soil Microflora

Microbial processes in the rhizosphere of plants are crucial to plant and soil health. Processes in the rhizosphere influence disease, nutrition and root architecture of plants by affecting the dynamics of microbial populations and communities

(Nautiyal, 2000). Rhizosphere microflora can be categorised as deleterious, beneficial or neutral with respect to root or plant health. Beneficial interactions between roots and microbes do occur in rhizosphere and can be enhanced. Hence there is an interest to manipulate the rhizosphere microflora, which could in turn have an impact on soil health, plant health, yield and sustainability (Gupta *et al.*, 2000).

The idea that different plant species harbour somewhat specific microorganisms in their rhizosphere has been supported by Peterson (1958), Parkinson *et al.* (1963) and Rao (1962). Krasilnikov (1958) reported only slight differences in the density of microbes in the rhizosphere of different plants. He did not observe differences in the number of bacteria in the rhizosphere of different plants of the cereal and leguminous families. According to Agnihotrhudu (1961) and Mishra and Kanaujia (1972), the leguminous plants exhibited richer rhizosphere microflora than cereals. Leelavathy (1966) and Sullia (1968) found no significant differences in the qualitative nature of fungal population in the rhizosphere of plants belonging to the same family. Different plant species in the same field had widely divergent number of organisms in their rhizosphere (Alexander, 1961; Ibekwe and Kennedy, 1998). Nair (1974) reported that mixed cropping of coconut and cocoa stimulated the population of bacteria and fungi in the rhizosphere of coconut. According to him, the increased microbial activity in the rhizosphere may be attributed to an increase in organic matter content of soil as a result of periodic shedding of cocoa leaves. Potty (1977) found that mixed cropping with certain fodder crops increased the population of fungi, bacteria and actinomycetes in the rhizosphere of coconut irrespective of the condition of the palms. Keswani *et al.* (1977) reported that in an intercropping system of maize and soyabean, a decrease in the fungal population was noticed in soybean rhizosphere whereas cropping systems little affected fungal counts in the maize rhizosphere.

Malajczuk and Mc Comb (1979) found qualitative and quantitative differences in the rhizosphere microflora of two Eucalyptus species. Significant qualitative and quantitative differences were observed between the rhizosphere fungal flora of two cultivars of black pepper *viz.* Panniyur-1 and Karimunda (Sankaran, 1981). Density of fungi was more in the rhizosphere compared to non rhizosphere and no positive correlation could be established between moisture per cent or pH of the soil and density of fungal population.

Plants may even have very similar microbial community structures in different soils (Grayston *et al.*, 1998; Miethling *et al.*, 2000). However plant species growing in the same soil having similar rhizosphere microbial communities have been reported by Buyer *et al.* (1999) and Latour *et al.* (1999) indicating that the influence of the soil may be greater than that of the plant. Liebig and Doran (1999) reported higher microbial mineralization rates of C and N in organic farming system which was an indicator of higher availability of nutrients enhanced by microbial activity.

Soils have very distinct microbial communities which are the result of many different selection factors (Gelsomino *et al.*, 1999; Carelli *et al.*, 2000). These include the physical and chemical characteristics of the soil (e.g. soil texture, nutrient and organic matter content and pH) and environmental factors such as climate and vegetation. Incorporation of residues of *Lantana camera, Pongamia glabra*, subabul etc. significantly increased the populations of aerobic non symbiotic nitrogen fixing, phosphate solubilising and sulphur oxidizing micro organisms. Among the organic materials, subabul leaves favoured maximum number of these organisms (Lal *et al.*, 2000). Under a system of different intercropped fruit trees, the cultivation of coconut intercropped with guava enhanced soil microbial activity approximately two fold after 38 years over 10 years of the same intercropped system. The increase was attributed to greater recycling of biolitters and levels of dehydrogenase, phosphatase and soil microbial biomass under field conditions which generally depended more on the nature of cropping system than on soil types (Manna and Singh, 2001). Enumeration of soil samples for bacteria, fungi, actinomycetes and phosphobacteria indicated higher total microbial populations in rhizosphere of *Hevea* under intercropping system but the count varied with the type of intercrop. The vesicular arbuscular mycorrhiza (VAM) colonization and number of phosphobacteria harboured were more in the roots of *Hevea* under intercropping (Vimalakumari *et al.*, 2001).

Stephen (2002) reported an increased soil nutrient availability due to the application of farmyard manure, Azospirillum, phosphobacteria and arbuscular mycorrhizal fungi (AMF) in black pepper. Marschner *et al.* (2004) reported that rhizosphere microbial communities are important for plant nutrition and plant health and are influenced by soil pH, type of P fertilization, soil type and the interactions between soil and plant effects on the rhizosphere community were apparent. He concluded that many different factors would contribute to shaping the species composition in the rhizosphere, but that the plant itself exerts a highly selective effect that is at least as great as that of the soil.

2.8.2 Soil enzymes

Soil enzymes or soil biocatalysts not only play a major role in the soil chemical and biochemical environment but also affect the rate at which nutrients become available to crop plants as well as to other forms of life in soil. Soil enzyme activity is considered as an index of microbial activity as well as soil fertility (Burns, 1982). The activities of soil enzymes such as urease and dehydrogenase were positively correlated with increasing organic carbon, total nitrogen and total phosphorus content (Barush and Mishra, 1984). Bolton *et al.* (1985) reported an increased activity of soil enzymes due to the application of green manures. Significant increase in the activity of soil enzymes *viz.* dehydrogenase, phosphatase, cellulase and amylase due to the incorporation of N fixing green manures such as *Sesbania rostrata, S. speciosa* and *Azolla microphylla* has been noticed (Kumar and Kannaiyan, 1992).

2.8.2.1 Dehydrogenase

The dehydrogenase enzyme systems apparently fulfill a significant role in the oxidation of soil organic matter as they transfer it from substrates to acceptors. Many different specific dehydrogenase systems are involved in the dehydrogenases of soils. These systems are an integral part of the microorganisms. Therefore, the result of the assay of dehydrogenase activity would show the average activity of the active population (Skujins, 1976). Smith and Pugh (1979) suggested that dehydrogenase activity can be correlated with the number of micro organisms isolated and the assay could be advocated in determining soil microbial activity in ecological investigations.

Sethi *et al.* (1990) observed that soil characteristics, the associated vegetation and soil biological activities were closely related. Soil dehydrogenase activity and total nitrifier population were greatest in the soil planted with wheat and lowest in barren virgin soil. Soil enzyme activities were significantly and positively correlated with soil pH and EC. Dehydrogenase activity was used to monitor the degradation of four different forest litters in a red sandy loam soil namely *Leucuena leucocephala, Acacia auriculiformis, Grevillea robusta* and *Eucalyptus* sp. Highest activity was observed with *Eucalyptus* followed by *A. auriculiformis, G. robusta* and *L. leucocephala* irrespective of organic matter level (Kumari and Devi, 1994).

Effect of varying levels of soil alkalinity on soil microbial biomass, soil dehydrogenase activity and decomposition of sesbania green manure was studied in natural alkali soils by Kumar and Kapoor (1995). Organic carbon and soil dehydrogenase activity declined with increasing soil pH.

Batra (1998) while studying the effect of different cropping sequences on dehydrogenase activity of three sodic soils observed that the activity was greater under rice based than under sorghum based cropping sequences. The greater dehydrogenase activity with the growth of rice without any appreciable change in organic carbon status of the soil may be because of the root exudates which might have resulted in the increased soil microbial population and thus microbially mediated processes.

2.8.2.2 Phosphatase

The size of microbial populations in soil can determine the levels of phosphatase activity as microorganisms are the major source of the phosphatases in soils (Greaves *et al.,* 1965). Phosphorus is the most limiting nutrient for crop production in large parts of the tropics, and is primarily a consequence of adsorption and precipitation reactions with sesquioxides rather than low amounts of total P (Sanchez, 1976; Hue, 1991). Large quantities of organic phosphorus is present in soil organic matter or plant and animal residues that cannot be utilized directly by plant without microbial conversion to inorganic form, i.e., mineralization. Soil phosphatases hydrolyse phosphate esters to inorganic phosphate and make them available to higher plants. Thus phosphatase activity measurements provide an index of potential availability of phosphate in soil (Skujins, 1976). Unlike leguminous plants fixing N through biological N fixation, there are no ways in which trees can add P to the soil plant system.

Tiwari *et al.* (1988) observed that higher phosphatase activity was noted from a ten-year-old pineapple plantation compared to one and five year old ones and bacterial population of soils followed a trend analogous to that of the phosphatase activity. Tarafdar and Rao (1990) carried out investigations to study the potential status of phosphatases and dehydrogenases in different vegetable crop soil ecosystems and reported that a higher activity of both enzymes was observed as a result of increased microbial activity in the rhizosphere soil. Populations of fungi, bacteria and actinomycetes increased significantly in the rhizosphere of vegetable crops.

Phosphatase activity correlated positively with soil temperature, organic carbon and bacterial population and negatively with soil moisture, pH and fungal population. If trees in a simultaneous agroforestry system (that is, where tree and crop species are grown concurrently) exhibit P mobilizing adaptations then these species may acquire P from sources in a way that is not in competition with the crop. Further if the rhizospheres of tree and crop root overlap, i.e., if the tree and crop roots do not exclude one another, there is a potential for the crop to benefit from the increased P availability in tree rhizosphere soil (Noordwijk *et al.*, 1999).

One of the challenges of agroforestry research is to identify species that are able to transform unavailable P into forms that may be utilized by the crop, either by nutrient cycling or by direct root effects and which will result in improved crop growth (Jama *et al.*, 2000).

Acid phosphalase activity in rhizosphere soil of different tree species studied was two to five times compared with bulk soil. Organic anion exudation and acid phosphatase activity of tree roots may increase the mobilization of P in the rhizosphere, the extent of which depends on the species, the organic anion and pH (Radersma and Grierson, 2004).

2.9 EFFECT OF SOLAR RADIATION ON CROP PRODUCTION

Light infiltration is the amount of available light infiltrated through a plant canopy which can affect the productivity of crop plant (Jackson, 1980).

2.9.1 Black pepper

Generally, the pepper plants require good sunlight, especially during the bearing season from June to December for maximum productivity. A check in the availability of solar radiation due to the wide spread foliage of the live standards can possibly affect the productivity character of pepper vines trailed on it. Wide difference has been reported among varieties in their response to intensities of light. The light requirement of Panniyur 1 was reported to be more compared to other varieties of pepper (Mathai, 1983).

Chandy *et al.* (1984) reported that vines with smaller leaves, shorter inter nodes, vigorous branching and smaller canopy surface received increased sunlight penetration and air movement within the canopy. Such conditions although reduced the number of lateral branches, increased the number of productive laterals and number of spikes on each lateral.

Mathai and Sastry (1988) reported that in black pepper, highest light availability during pre flowering stage (March-April) produced greater leaf area and more compact canopy structure with shorter lateral shoots. This allowed the vines to accumulate higher levels of metabolites which led to greater production of lateral shoots during the second flush, more spikes, greater number and berries per vine and higher dry matter of berries per vine. The vines under high growth light regime were found to produce more number of berries per unit surface area and it was low under low growth light regime (Mathai and Chandy, 1988).

Effect of shading on leaf chlorophyll content and yield performance in black pepper was studied by Vijayakumar and Mammen (1990). In pot experiments, leaves of pepper plants exposed to full sunlight turned yellow and developed necrotic patches while leaves of plants kept under shade from jack fruit trees remained green and healthy. In a field trial at Panniyur, spraying leaves of vines supported on *Erythrina indica* plants with 20 per cent china clay increased yield in the subsequent year by 41 per cent. High irradiance results in high rates of transpiration which are likely to result in internal deficiencies of water and a consequent retardation of cell division or cell elongation (Attridge, 1990).

Devadas and Chandini (2000) observed significant influence by varying light intensities on all growth characters of bush pepper plants studied including length and number of primary and secondary branches, number of leaves and total leaf area. Length of primary and secondary branches increased with decrease in light intensity from 100 to 50 per cent. Increased vegetative growth was obtained under partially shaded condition. Similar results were obtained in black pepper vines by Senanayake and Kirthisinghe (1983) and Mathai and Sasthry (1988).

Satheesan (2000) compared light compensation point in Panniyur-1 to Karimunda and found that Panniyur 1 can fix increased carbon at higher light intensities which supports its high production nature under increased light at all canopy levels as it is having less compact canopy and the laterals are more exposed to light compared to Karimunda.

2.9.2 Other Spice Crops

Ravisankar and Muthuswamy (1986) studied the dry matter production and recovery of dry ginger under arecanut plantation in relation to light intensity. The recovery of dry matter was high under a six year old stand than under a two year old stand and monoculture of ginger. Open grown ginger recorded highest values with respect to essential oil and oleoresin. Rhizome quality was not adversely affected by shade in ginger (Ravisankar and Muthuswamy, 1987). Non-volatile ether extract was reported to be positively correlated with shade (Ancy and Jayachandran, 1993). Babu and Jayachandran (1994) however observed that non-volatile ether extract and fibre content decreased while oil content increased with increasing shade. In an experiment on growth of ginger under the shade of *Ailanthus*, an understorey photosynthetic photon flux density level of 60 per cent of that in the open was considered favourable (Thomas, 1996).

A study conducted at Regional Research Station of Indian Cardamom Research Institute, Thadiankudisai by Ravindran and Kulandaivelu (1998) indicated that growth and biomass were adversely affected in leaf scorched seedlings of cardamom grown under full light (100% of total sunlight) when compared to healthy seedlings grown under medium light (45-55% of total sunlight). About 40 per cent reduction in growth character and 60 per cent reduction in yield character were observed under full sunlight when compared to those of medium sunlight.

2.9.3 Multipurpose trees

Canopy architecture and structure play an important role in interception of the incoming solar radiation. Terjeing and Louise (1972) reported that conical trees intercepted a higher amount of radiation, especially at higher altitudes.

Shading was found to be more important than below ground competition in an intercropping study with pearl millet and groundnut in India (Willey and Reddy, 1981). Similarly, Verinumbe and Okali (1985) showed that competition for light was a more critical factor than root competition for intercropped maize between teak trees (*Tectona grandis*) in Nigeria.

Kellomaki *et al.* (1985) reported that crown shape had only a small influence on interception of solar radiation and that a dense regularly spaced stand of trees with tall, narrow symmetrical crown was most efficient in attenuating incoming light. Available solar energy is more efficiently used in agrisilviculture owing to the vertical stratification of vegetative components (Payne, 1985). Fundamental advantage of this system is the partitioning of incoming solar radiation between two or more strata and consequently more efficient light utilization in comparison to monoculture situations. Under shaded condition, reduced radiation may prevent scorching or wilting of leaves caused by marked increase in temperature within the leaf tissue from strong sunlight (Aasha, 1986) and thereby increases the leaf life under shade resulting in maximum retention of leaves.

Trees with spreading dense crowns result in greater shading effect *Leucaena leucocephala* was reported to have greater shading effect than *Azadirachta indica, Eucalyptus* and *Dalbergia sissoo* (Ramshe *et al.*, 1990).

Productivity of field crops grown in association with wild jack tree (*Artocarpus hirsutus*) is generally low probably due to the shading effect of tree rows and also the extensive lateral spread of tree roots (Jamaludheen, 1994). Sureshkumar *et al.* (1999) while assessing the performance of multipurpose trees in coconut based agrisilviculture system observed that interception of incoming solar radiation was strongly influenced by multipurpose tree species. *Ailanthus* interplanted in coconut intercepted as much as 82 per cent of the total solar radiation compared to coconut monoculture with lighter canopy which intercepted only 55 per cent of incoming solar radiation.

The attenuation of incoming solar radiation was highest for *Acacia* perhaps due to its dense crown structure and least for *Ailanthus* due to its compact crown.

Fractional light interception was greatest for the unpruned sole *Gliricidia* as trees provided a closed canopy. However regrowth following pruning was vigorous, demonstrating the risk to crop productivity if *Gliricidia* is not pruned when grown in mixture with shade in tolerant understorey crops (Chirwa *et al.*, 2003). Light available to understorey crops was more in pruning of trees up to 70 per cent plant height than trees allowed to grow normally. Similar observations were made by Datta and Dhiman (2001) in the case of *Acacia auriculiformis* in which light intensity was minimum without pruning but the intensity under went a sharp rise on pruning. Several studies have already been proved that the light availability in a tree crop system is less as compared to open field (Hazra and Patil, 1986; Basavaraju and Gururaja Rao, 2000; Newaj *et al.*, 2003).

The effect of photosynthetically active radiation (PAR) on the yield in arecanut based mixed cropping systems was studied by Shahapurmath *et al.* (2003). The maximum mean PAR was recorded in monocropping of arecanut and the minimum value in arecanut + cardamom + banana + pepper mixed cropping system. The total yield of arecanut palm and pepper exhibited non-significant correlation whereas the total yield of banana and cardamom showed strong association with the total PAR.

2.10 STUDIES ON ROOT LEVEL INTERACTION USING RADIOTRACER APPLICATION

Root competition or relative utilization of an applied nutrient in multispecies cropping systems can be evaluated based on the application of radioactive isotopes and total radioactivity uptake. Sankar *et al.* (1988) studied the root activity patterns of black pepper vines (var. Panniyur 1) trailed on *Erythrina* standard or on teak pole and compared in field experiments employing ^{32}P soil injection technique. Vines trailed on teak pole absorbed more ^{32}P than the vines trailed on *Erythrina* standards. The differential absorption of ^{32}P by the vine in the monoculture and mixed systems was attributed to the effect of competitive interaction between black pepper vine and the *Erythrina* standard. The severe root competition for ^{32}P uptake occurring in the system may be due partly to the coincidence of the peak absorption periods of the two species. It was noted that *Erythrina* preferred to explore the soil laterally more or less within 20 cm depth, the feeder roots of the vine supported on it were uniformly distributed up to 40 cm depth. The confinement of a major portion of root activity of the support tree within the surface layer may thus lead to competition for nutrients, as nutrients are generally more concentrated in the upper soil layer. In the absence of an associated plant species the vine tends to forage deeper layers of soil more efficiently than in its presence.

Geetha (1990) while studying the influence of method of fertilizer application on nutrient absorption by black pepper vines, evaluated pepper variety Panniyur 1 vines supported by teak poles or living *Erythrina indica* trees supplied with ^{32}P. Recovery of the soil applied ^{32}P from leaves of vines supported by teak poles was greatest with fertilizer placement in a full circle 30 cm from the vine. However, for vines supported by living *E. indica* trees there were no significant differences between treatments.

The fate of applied N in soil and its relative uptake by black pepper vine and *Erythrina* tree on which the vine was trailed were determined using ^{15}N labeled urea by Wahid *et al.* (2004). Both vine and support tree absorbed N from the labeled fertilizer applied to the soil basin of the vine. Fertilizer use efficiency in black pepper vine was very low in the range of 6 to 12 per cent. On the other hand, the contribution of applied urea towards N uptake by *Erythrina* support tree was 24 to 40 per cent. Poor utilization of the applied N by the vine was due to leaching of the nutrient and also severe root competition from the support tree.

Woods and Brock (1964) found radiation isotopes injected stumps of one species from other adjacent species to which they were not directly connected. Evidence for mutual avoidance of soil areas by the root systems of different plants when grown together was reported (Willey, 1979).

Tree to tree variability in the absorption of ^{32}P among trees receiving the same treatment has been reported by several workers. In several experiments conducted by IAEA, variability to the extent of 100 per cent was observed (Broeshart and Nethsinghe, 1972; IAEA, 1975). Tree to tree variations of still higher magnitude were also reported by others (Anilkumar and Wahid, 1988; Sankar *et al.*, 1988). One of the probable reasons for the tree to tree variability is the natural variation in the distribution of roots both laterally and vertically.

Asokan *et al.* (1988) used ^{32}P for studying interspecific root competition involving annual crops namely cassava, banana and elephant foot yam by computing the relative absorption of ^{32}P by the treated plant as the ratio of the whole plant count in the intercropping system to the whole plant count in the sole crop situation. Both competitive and complementary interactions in ^{32}P uptake depending on the associated species were reported by them.

The root activity pattern of *Gliricidia sepium* was studied by Vasu *et al.* (1994). About 30-35 per cent of the active roots of this plant were distributed within 50 cm radius from the plant and the vertical distribution of active roots was more or less uniform up to 120 cm soil depth. The recovery pattern of ^{32}P in wild jack tree *Artocarpus hirsutus* indicated that more than 75 per cent of fine roots responsible for water and nutrient absorption are concentrated in the 75 cm radius and 30 cm depth from the base of the tree (Jamaludheen, 1994). In a mixed crop system involving fodder crops and multipurpose trees, the tree less controls were consistently more efficient in terms of ^{32}P uptake than the tree-grass combinations. However, ^{32}P recovery of the tree monocultures were generally lower than the respective species mixtures, indicating a stimulatory effect on the nutrient absorption of trees by the associated field crops (George *et al.*, 1996). Of the tree species, acacia and *Leucaena* adversely affected ^{32}P uptake by grass species.

To acquire information on the nature of below ground interactions in intercropping system involving ginger (*Zingiber officinale*) and *Ailanthus triphysa*, their root activity was evaluated based on ^{32}P recovery by each species in mixed and sole crop situations (Thomas *et al.*, 1998). Neighbouring *Ailanthus* trees absorbed a substantial portion of the ^{32}P supplied to ginger. This in turn suggests that the effective root zones of ginger and *Ailanthus* might have overlapped when the trees were four years old. Observations also suggest that competition between the tree and herbaceous crop for nutrients applied to the tree component is unlikely in the ailanthus-ginger mixed species system studied.

Instead of applying ^{32}P at one or more fixed positions in the root zone, the results will be more realistic and useful when ^{32}P application is made at several points in the root zone covering the entire EFS (effective foraging space) of the plant, a concept introduced by Wahid (2000). Effective foraging space of a plant is defined as the soil cylinder around the plant that accounts for 80 per cent or more root activity. Such a procedure was adopted by Sureshkumar *et al.* (1999) for studying root level interactions between coconut palm and interplanted multipurpose trees (MPTs) like *Ailanthus triphysa, Grevillea robusta* and *Vateria indica*. The three MPTs absorbed substantial quantities of ^{32}P from the EFS of coconut palm. Whereas the root level interaction of coconut with *Grevillea* was one of complementary effect, the interaction with the other two MPTs was one of the competitions. Wide spread root proliferation of coconut and MPTs occurred in the well fertilized kacholam beds taken in the interspaces of coconut and MPTs which led to the absorption of large amount of ^{32}P by the kacholam. The selection of tree species with low root competitiveness and or trees with complimentary root interaction is thus of strategic importance in agroforestry and other tree based polyculture systems. Joseph (1999) also followed a similar method for studying the root level interactions between three year old rubber trees and interplanted banana (cv. Poovan). ^{32}P was applied to rubber tree covering its EFS (L_{150}/D_{75}) around the tree in sole crop and mixed crop situations. Absorption of ^{32}P by rubber trees in monoculture was greater than in mixed cropping systems which suggested the existence of interspecific competition between rubber and banana.

Root competition between bamboo and associated tree component in two mixed species systems and root distribution pattern of boundary planted bamboo clumps were evaluated by Divakara *et al.* (2001). Isotopic studies revealed that bamboo clumps may exert a competitive effect up to 5-6 m radial distance in ten year old clumps grown on laterite soil. Gowda (2002) assessed the performance of selected multipurpose trees *Ailanthus triphysa, Grevillea robusta* and *Vateria indica* in a coconut based agrisilviculture system and root competition between them was evaluated using the ^{32}P soil injection technique. ^{32}P uptake by coconut was not adversely affected by MPTs eventhough the latter absorbed substantial quantities of the applied ^{32}P.

Bavappa and Murthy (1961) reported that in arecanut, the roots were concentrated within 60 to 90 cm around the base of the palm. Bhat and Leela (1969) pointed out that in eight-year-old arecanut palms, 61 to 76 per cent of all types of roots and 51.3 to 66.6 per cent of fine roots were concentrated within a circle of 50 cm radius around the palm. Mohapatra *et al.* (1971) reported that in twelve year old arecanut palms, about 75 per cent of the roots were confined within a radius of 100cm. Bhat (1983) observed that in the mixed cropping system, more than 90 per cent of the roots of arecanut were found within 100 cm depth. The quantity of fine roots in the top 50cm layer was 57 per cent under the mixed crop condition as against 73 per cent in the pure crop.

2.11 ENVIRONMENTAL FACTORS INFLUENCING QUALITY OF SPICES

Though oil and oleoresin content of spice crops are primarily governed by the cultivar, the conditions during growth can also contribute some amount of variability (Purseglove *et al.* 1981). Higher levels of N, P and K fertilization have been reported to decrease the curcumin content in turmeric (Rao *et al.*, 1975). However later studies by Mohanbabu and Muthuswamy (1984) and Ahmedshah *et al.* (1988) showed that graded doses of potassium significantly improved the curcumin content in turmeric rhizome. Singh and Randhawa (1988) reported that the oil and curcumin content in turmeric were not affected by intercropping. Rao *et al.* (2005) observed that in turmeric, contents of oil, oleoresin and curcumin were significantly increased by the application of organic amendments like neem cake, farmyard manure, vermicompost etc.

In a study conducted at TNAU, Coimbatore, the quality of ginger improved when grown under arecanut tree canopy (Ravisankar and Muthuswamy, 1988). Varughese (1989) observed a progressive decrease in the oleoresin content up to 50 percent level of shade in ginger after which there was a marginal increase. The higher oleoresin content in open condition may be due to the unobstructed photosynthesis leading to accumulation of the secondary metabolites like resins, resin acids and unoxidised sugars which are the major components of the acetone extracted oleoresin of ginger rhizome. George (1992) observed higher values for oil and oleoresin content in ginger when grown under shade than in the open. However, Thomas (1996) observed that in ginger, oil and oleoresin content were unaffected by the canopy of *Ailanthus* under which it was grown.

Both content and yield of oil in clocimum were high in the open compared to that under shade (Pillai, 1990). Latha (1994) reported that oil yield in kacholam was independent of shade. But Sureshkumar (1997) reported that the volatile oil content of kacholam rhizomes was modestly lower under the canopy of coconut and multipurpose trees than in the open. Maheswarappa *et al.* (2000) obtained a higher essential oil and oleoresin contents in kacholam when treated with farmyard manure along with recommended NPK fertilizers followed by FYM and vermicompost treatments.

Quality of bush pepper was not significantly influenced by varying light levels (Devadas and Chandini, 2000). But nitrogen levels had significant effect on the volatile oil content and phosphorus levels on oleoresin in content. Varying levels of nutrients significantly influenced the quality of mango ginger rhizome (Mridula and Jayachandran, 2001). There was a progressive increase in volatile oil content with increasing N and P levels whereas K application at higher levels decreased the volatile oil content.

Materials and Methods

3. MATERIALS AND METHODS

The present investigations on 'Crop - standard interactions in black pepper (*Piper nigrum* L.)' were carried out at the College of Horticulture, Vellanikkara during the period from 2001 to 2004.

3.1 LOCATION, CLIMATE AND SOIL

The experimental field of study was the pepper garden under the Department of Plantation Crops and Spices (Plate 1). It is situated at 10°32'N latitude and 76°13'E longitude with an altitude of 22.5 m above mean sea level. The area enjoys a warm humid tropical climate and the soil is deep laterite with sandy clay loam texture.

3.2 SELECTION OF EXPERIMENTAL PLANTS

Black pepper var. Panniyur 1 was used for all the experiments. Rooted cuttings planted in 1992, which were trailed on different standards or supports were utilized for the study (Table 1, Plates 2, Appendix 1). Based on the previous year's yield data and uniformity in growth of pepper and standards, healthy plants were selected. All the selected plants received uniform management practices as per the package of practice recommendations (KAU, 2002).

3.3 DETAILS OF EXPERIMENTS

3.3.1 EXPERIMENT I

CHARACTERIZATION OF RHIZOSPHERE SOIL OF BLACK PEPPER TRAILED ON DIFFERENT STANDARDS

3.3.1.1 Chemical analysis of soil

Standard procedures were followed for the estimation of various fertility parameters of the soil.

Table 1. List of standards of black pepper

Treatment	Scientific Name	Common name/ Vernacular name	Family
T_1	*Acacia mangium* Willd	Mangium	Mimosaceae
T_2	*Ailanthus triphysa* (Dennst.) Alston	Pongalyam / Matti	Simaroubaceae
T_3	*Areca catechu* L.	Arecanut	Palmae
T_4	*Artocarpus heterophyllus* Lamk.	Jack	Moraceae
T_5	*Azadirachta indica* A. Juss.	Neem	Meliaceae
T_6	*Bombax malabaricum* DC	Ilavu	Bombacaceae
T_7	*Caesalpinia sappan* L.	Pathimukham	Caesalpiniaceae
T_8	*Cocos nucifera* L.	Coconut	Palmae
T_9	*Erythrina indica* Lamk.	Erythrina	Leguminosae
T_{10}	*Garuga pinnata* Roxb.	Kilingil	Burseraceae
T_{11}	*Gliricidia sepium* (Jack.) Kunth	Gliricidia	Leguminosae
T_{12}	*Grevillea robusta* A. Cunn.	Silver oak	Proteaceae
T_{13}	*Leucaena leucocephala* (Lamk.) de Wit	Subabul	Mimosaceae
T_{14}	*Moringa oleifera* Lamk.	Moringa	Moringaceae
T_{15}	*Pajanelia longifolia* (Willd.) k. Schum	Azhantha / Payyani	Bignoniaceae
T_{16}	*Thespesia populnea* Soland. ex. Correa	Poovarasu	Malvaceae
T_{17}	Teak pole (dead standard)		

Plate 1. General view of the experimental field

Acacia mangium

Ailanthus triphysa

Areca catechu

Artocarpus heterophyllus

Azadirachta indica

Bombax malabaricum

Plate 2. Standards used for trailing pepper

Plate 2. continued

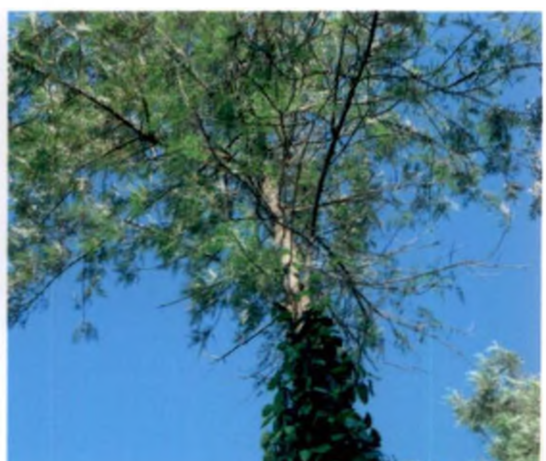
Caesalpinia sappan

Cocos nucifera

Erythrina indica

Garuga pinnata

Gliricidia sepium



Grevillea robusta

Plate 2. continued

Leucaena leucocephala

Moringa oleifera

Pajanelia longifolia

Thespesia populnea

Teak pole

3.3.1.1.1 Collection and processing of soil samples

Soil samples were collected immediately before flushing of the pepper vines in May. Considering the 'effective foraging space' (EFS – the soil cylinder around the plant which accounts for 80 per cent or more of the root activity) of black pepper (L30 / D40 - L refers to lateral distance from the vine and D refers to the depth of soil) as explained by Wahid (2000), soil samples were drawn from two depths *viz.*, 20 cm and 40 cm at a lateral distance of 30 cm from the vine. Samples were collected from four locations in the EFS of each vine, mixed and quartering was done. They were then air dried, powdered gently, passed through a 2 mm sieve and stored in airtight plastic containers for analysis.

3.3.1.1.2 Electrochemical properties of soil

3.3.1.1.2.1 Soil pH

Soil-water suspension in the ratio 1:2.5 was prepared for determining soil pH potentiometrically using a pH meter (Jackson, 1958).

3.3.1.1.2.2 Electrical conductivity (EC)

Supernatant liquid of the suspension used for the determination of pH was used for determining the electrical conductivity with a conductivity meter (Jackson, 1958).

3.3.1.1.3 Available nutrients

3.3.1.1.3.1 Organic carbon

Organic carbon was determined by wet digestion method proposed by Walkley and Black (1934).

3.3.1.1.3.2 Phosphorus

Available phosphorus was determined by extracting with Bray No.1 reagent and estimating colorimetrically by reduced molybdate ascorbic acid blue colour method using spectronic 20 spectrophotometer (Bray and Kurtz, 1945).

3.3.1.1.3.3 Sodium and potassium

Available sodium and potassium were extracted with neutral normal ammonium acetate solution and their contents determined by flame photometry (Jackson, 1958).

3.3.1.1.3.4 Calcium and magnesium

Available calcium and magnesium from the ammonium acetate extract were estimated by versenate titration method (Hesse, 1971).

3.3.1.1.3.5 Micronutrients (Fe, Mn, Cu and Zn)

Available micronutrients were extracted using 0.1M HCl and Fe, Mn, Cu and Zn were estimated by atomic absorption spectrophotometer (Sims and Johnson, 1991).

3.3.1.1.4 Cation exchange capacity (CEC) and exchangeable cations

Cation exchange capacity of the soil was determined by the method proposed by Hendershot and Duquette (1986). The exchangeable cations (Ca, Mg, Na, K, Al, Fe and Mn) present in the exchange sites in soil were replaced by 0.1M $BaCl_2$ solution and the extracted cations were estimated using standard procedures. The sum of these exchangeable cations expressed in cmol (+) kg^{-1} soil was recorded as CEC of soil.

3.3.1.2 Estimation of soil microflora

Soil samples with sufficient moisture collected from rhizosphere region of pepper vine were utilized for the estimation of soil microbial population. Serial dilution plate technique (Johnson and Curl, 1972) was followed.

Martins' Rose Bengal Streptomycin agar medium, Thorntons standardised agar medium and Kenknight's agar medium were used for estimating fungi, bacteria and actinomycetes respectively (Appendix 2).

Jensen's medium and Pikovskaya's solid agar medium were utilized for estimation of nitrogen fixing bacteria and phosphate solubilising bacteria respectively.

3.3.1.3 Estimation of soil enzyme

Soil samples collected for estimation of soil microflora were used for analysis of soil enzymes.

3.3.1.3.1 Dehydrogenase

Dehydrogenase activity was assessed by the method of Casida *et al.* (1964) using 2,3,5 triphenyl tetrazolium chloride (TTC) as electron acceptor and expressing the results in micrograms triphenyl formazan (TPF) produced per gram of dry soil.

3.3.1.3.2 Phosphatase

Acid phosphomonoesterases in the soil samples were assayed following the method proposed by Tabatabai and Bremner (1969).

3.3.2 EXPERIMENT II

ROOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD EMPLOYING RADIOISOTOPIC TECHNIQUES

The nature of root competition experienced by pepper vine grown in association with different standards was assessed employing radiotracer technique involving ^{32}P soil injection method.

Application of the radioactive phosphorus was done during the second week of October after rains to ensure better absorption of the applied ^{32}P.

3.3.2.1 Soil injection of ^{32}P

The basin of the selected vines was cleared of weeds over a radial distance of 50 cm around the plant. Equally spaced 12 holes were dug at three lateral distances (10, 20 and 30 cm) and four depths (10, 20, 30 and 40 cm) from the plant base considering the EFS of black pepper (Wahid, 2000). PVC access tubes of sufficient length were inserted into each hole so that about 15 cm of the tube would be projected out above the soil surface (Plate 3). The PVC tubes were closed at the open ends with polythene caps to prevent filling up during rains which were removed at the time of

^{32}P application. Two mCi ^{32}P was applied to each plant. This was given through 48 ml of 1000 ppm carrier P solution (prepared using KH_2PO_4) in such a way that each tube received equal amount of activity *viz.*, 0.167 mCi in 4 ml per hole using a dispenser designed for the purpose (Wahid *et al.*, 1988) (Plate 4). After application, the radioactivity adhered on the inner side of the PVC tube was washed with a jet of about 15 ml water. The carrier solution of phosphorus was used to minimise the chances of soil fixation of the radioisotopes.

3.3.2.2 Sampling

Leaf is the most convenient plant part for evaluating the extent of absorption of the applied radioactivity by the plant and it is necessary to identify the most suitable leaf for sampling based on morphological position and physiological age (Wahid, 2001). Details of leaf sampling procedure for ^{32}P assay in different standards and pepper are given in Table 2.

3.3.2.3 Radioassay

Leaves from the treated vines and standards were sampled for radioassay at 15, 30 and 45 days after application of ^{32}P. Further analyses were carried out at the Radiotracer Laboratory of College of Horticulture, Vellanikkara.

The samples were dried in hot air oven at 70 ± 5°C. One gram of the finely powdered samples was digested using diacid mixture containing nitric acid and perchloric acid in 2:1 ratio. The digest was then transferred to a scintillation counting vial with distilled water up to a volume of 20 ml. They were then radioassayed by Cerenkov counting techniques (Wahid *et al.*, 1985) in a liquid scintillation system (Wallac-1409) (Plate 5).

Percentage distribution of ^{32}P recovered between pepper and the corresponding standard of each treatment was computed as follows

$$\text{Percentage recovery of } ^{32}P \text{ from leaves of pepper} = \frac{\text{cpm g}^{-1} \text{ of } ^{32}P \text{ recovered from pepper}}{\text{cpmg}^{-1} \text{ of } ^{32}P \text{ recovered from pepper} + \text{cpmg}^{-1} \text{ of } ^{32}P \text{ recovered from standard}}$$

Plate 3. PVC tubes installed for injection of ^{32}P solution

Plate 4. Device for soil injection of ^{32}P solution

Plate 5. Liquid scintillation system (Wallac-1409)

Table 2. Methods of leaf sampling for ^{32}P assay

Plant	Sampling method	Reference
Acacia mangium	Most recently matured leaves from around the canopy	George *et al.* (1996)
Ailanthus triphysa	,,	,,
Areca catechu	Leaflets from the fourth frond starting from the first fully opened one	Mohapatra and Bhat (1985)
Artocarpus heterophyllus	Most recently matured leaves from around the canopy	-
Azadirachta indica	,,	-
Bombax malabaricum	,,	-
Caesalpinia sappan	,,	-
Cocos nucifera	Leaflets from the sixth frond starting from the first fully opened one	IAEA (1975)
Erythrina indica	Fully matured trifoliate leaves	Sankar *et al.* (1988)
Garuga pinnata	Most recently matured leaves from around the canopy	-
Gliricidia sepium	,,	-
Grevillea robusta	,,	-
Leucaena leucocephala	,,	George *et al.* (1995)
Moringa oleifera	,,	-
Pajanelia longifolia	,,	-
Thespesia populnea	,,	-
Piper nigrum	Most recently matured leaves of the fruiting branches on the lower two-third position of the canopy	Sankar (1985)

Percentage recovery of ^{32}P from leaves of standard = $\frac{\text{cpm g}^{-1} \text{ of } ^{32}\text{P recovered from standard}}{\text{cpmg}^{-1} \text{ of } ^{32}\text{P recovered from pepper} + \text{cpmg}^{-1} \text{ of } ^{32}\text{P recovered from standard}}$

During the course of experiment, the counting efficiency remained constant at 32 per cent and hence the count rates were not converted to dpm but were expressed as cpm values. The cpm values were corrected for background as well as for decay. Logarithmic transformation was done before the data was subjected to analysis of variance.

3.3.3 EXPERIMENT III

SHOOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD

3.3.3.1 Observations on black pepper

3.3.3.1.1 Height of bearing column

An iron pole marked with measurements was used to record the height of bearing column of pepper vine.

3.3.3.1.2 Canopy spread

Spread of canopy at chest height was taken using a measuring tape.

3.3.3.1.3 Number of laterals and spikes per 0.25 m^2

With the help of square wooden frame having 0.25 m^2 area, the spike bearing laterals and number of spikes were counted from all the four sides of the vine at chest height.

3.3.3.1.4 Spike characters

Ten spikes were randomly selected from each vine at harvest and spike length, number of berries per spike and compactness of spike (number of berries per centimeter length of spike) was recorded.

3.3.3.1.5 Berry characters

Weight of 100 well developed green berries and their volume (by water displacement method) were recorded immediately after harvest.

3.3.3.1.6 Yield

Immediately after harvest, total yield of green berries per vine was recorded. Yield of ten plants for three consecutive years was recorded for each standard. Percentage recovery of dry pepper was calculated by drying 500 g of green berries in a paper cover under sunlight until berries recorded a constant dry weight. Total yield of dry berries per vine was computed by multiplying the green berry weight with percentage recovery of dry pepper.

3.3.3.1.7 Quality attributes

The major quality parameters like essential oil, oleoresin and piperine were evaluated in each treatment for two seasons *viz.* 2002 and 2003 maintaining two replications each.

3.3.3.1.7.1 Essential oil

Clevenger apparatus with trap for oil lighter than water was used for the distillation of essential oil. Twenty grams of ground pepper powder was taken in the round bottomed flask and water distilled with 200 ml of distilled water for four hours. The volatile oil being lighter than water got condensed and collected on the top of the Clevenger trap. The percentage of essential oil in the sample was worked out.

3.3.3.1.7.2 Oleoresin

The content of oleoresin in the sample was estimated using the soxhlet method of extraction as per Horowitz (1980).

Five gram of ground pepper powder was wrapped in filter paper and placed in the extraction chamber of the apparatus. Extraction was carried out with 100 per cent acetone till the solvent become colourless. The acetone extract of the sample was transferred to a pre-weighed beaker, the solvent was evaporated and the weight of the beaker recorded. The percentage of oleoresin was calculated as

$$\text{Percentage of oleoresin} = \frac{\text{Weight of oleoresin}}{\text{Weight of pepper powder}} \times 100$$

3.3.3.1.7.3 Piperine

The piperine content in dried berries was determined by spectrophotometric method described by Soubhagya *et al.* (1990). Hundred milligrams of freshly powdered pepper was transferred to a 100 ml volumetric flask and volume made up with 100 per cent acetone. The flask was shaken well and allowed to settle for two hours in the dark. Then pipetted out 0.5 ml of the solution and diluted to five ml with acetone. The absorbance of the solution was read at 337 nm. A standard curve was prepared with different concentrations of pure piperine following the same procedure to find out the piperine content of the sample.

3.3.3.2 Observations of standard

Five plants of each standard were selected to record the following observations.

3.3.3.2.1 Nature of bark of standard

Texture of the bark of standards was closely examined and important bark characters were studied.

3.3.3.2.2 Time of flushing, flowering and defoliation

Monthly observations of all the standards were taken regarding flushing, flowering and defoliation.

3.3.3.2.3 Light infiltration through standards

The quantity of light infiltrated through the canopy of different standards was measured using a Digital Lux Meter. The light availability under each standard was taken from all the four sides of the vine at two hour intervals from 10AM to 4PM and the mean value was recorded. Monthly observations were recorded and the percent of light infiltrated through the standards was calculated as follows.

$$\text{Light infiltration (\%)} = \frac{\text{Availability of sunlight in the field (in lux)}}{\text{Availability of sunlight in the open (in lux)}} \times 100$$

3.3.3.2.4 Lopping of standards

Lopping of all the live standards except coconut and arecanut was done during the second fortnight of April to first fortnight of May before the pre monsoon showers. They were incorporated in the respective basins of the vine. For coconut and arecanut, annual leaf fall was taken into consideration.

3.3.3.2.4.1 Fresh weight

Fresh weight of loppings was recorded immediately after lopping using spring scales.

3.3.3.2.4.2 Dry weight

Five hundred grams of fresh sample of the loppings were air dried under shade and then dried to constant weight at 70°C.

3.3.3.3 Foliar nutrient analysis

Oven dried samples of loppings of standards were powdered and used for nutrient analyses.

Leaf samples of pepper were collected following the procedure suggested by De Waard (1969). Sampling was done just prior to flushing of the vines in May. The first mature leaf from the fruit bearing laterals located on the lower two-third of the canopy was collected from all the four sides. The leaf samples were cleaned, first dried under shade and then dried in a hot air oven at 70°C, powdered and stored in plastic bottles for analysis.

Leaf samples were analysed for N, P, K, Ca, Mg, Na, Fe, Mn, Cu and Zn. Modified Kjeldahl's method (Jackson, 1958) was followed to estimate nitrogen. Monoacid digestion using sulfuric acid and digestion mixture followed by distillation using Microkjedahl's distillation apparatus was carried out.

Digestion of the powdered plant samples with 2:1 nitric acid - perchloric mixture was done for estimation of all other nutrients (Jackson, 1958).

Phosphorus in the digest was determined by vanadomolybdate yellow colour method (Koenig and Johnson, 1942) using Spectronic-20 spectrophotometer. Flame photometry was followed to determine potassium and sodium. Ca, Mg, Fe, Mn, Cu and Zn were estimated using atomic absorption spectrophotometer.

3.3.3.4 Pests and diseases

The field was periodically observed for the incidence of pests and diseases of pepper and standards.

3.4 STATISTICAL ANALYSIS

MSTATC package was used for computation and analysis of data. Statistical analysis was done using analysis of variance technique (Panse and Sukhatme, 1967). Intercorrelation analysis was done to work out the relationship between different parameters (Snedecor and Chochran, 1961). Necessary transformations were carried out wherever required and analysed statistically.

Results

Results

4. RESULTS

In order to study the crop-standard interaction in black pepper and assess the suitability of different live and dead standards for pepper, experiments were carried out in the pepper garden of Department of Plantation Crops and Spices at the College of Horticulture from 2001 to 2004. The results are being presented below.

4.1 EXPERIMENT I

CHARACTERISATION OF RHIZOSPHERE SOIL OF BLACK PEPPER TRAILED ON DIFFERENT STANDARDS

Rhizosphere soil of pepper vines trailed on different standards was characterized for chemical and biological properties. Surface and subsurface rhizosphere soil samples were drawn from 20 cm and 40 cm depths respectively for the estimation of electrochemical properties and available nutrients.

4.1.1 Electrochemical properties and available nutrients

4.1.1.1 Surface samples

4.1.1.1.1 pH

The pH of the surface soil samples varied from 5.04 to 5.93 (Table 3). The highest value was recorded in rhizosphere soil of pepper vine trailed on dead standard (T_{17}) and lowest in that on *Garuga pinnata* (T_{10}). Comparatively higher pH values were recorded for treatments T_9 (*Erythrina* - 5.87), T_{16} (*Thespesia* - 5.76), T_7 (*Caesalpinia* - 5.76), T_1 (*Acacia* - 5.45), T_2 (*Ailanthus* - 5.49), T_3 (Arecanut - 5.57), T_4 (Jack - 5.58), T_5 (*Azadirachta* - 5.55) and T_8 (Coconut - 5.72), which were on par with T_{17}. T_6, T_{10}, T_{11}, T_{12}, T_{13}, T_{14} and T_{15} were on par with T_{10}.

4.1.1.1.2 Electrical conductivity

The treatments did not vary significantly with respect to electrical conductivity of rhizosphere soil (Table 3). Highest value was recorded for T_1 (*Acacia* - 0.38 dS m^{-1}) followed by T_2 (*Ailanthus* - 0.25 dS m^{-1}). Lowest EC value

Table 3. Electrochemical properties of rhizosphere soil of pepper (surface samples)

Treatment	pH	EC (dS m^{-1})	Organic C (%)
T_1	5.45	0.38	1.23
T_2	5.49	0.25	1.14
T_3	5.57	0.18	1.15
T_4	5.58	0.11	1.04
T_5	5.55	0.09	1.11
T_6	5.29	0.08	1.04
T_7	5.75	0.13	0.96
T_8	5.72	0.09	1.26
T_9	5.87	0.06	0.98
T_{10}	5.04	0.05	1.22
T_{11}	5.36	0.08	0.96
T_{12}	5.32	0.04	1.00
T_{13}	5.39	0.19	1.21
T_{14}	5.38	0.06	1.11
T_{15}	5.38	0.05	1.07
T_{16}	5.76	0.10	1.32
T_{17}	5.93	0.16	1.04
Mean	5.52	0.12	1.11
CD (0.05)	0.40	NS	NS

Table 4. Available nutrient status of rhizosphere soil of pepper (surface samples)

Treat-ment	P (mg kg^{-1})	K (mg kg^{-1})	Na (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
T_1	19.87	67.33	37.67	170.00	63.33	30.00	143.33	45.67	2.67
T_2	28.47	66.67	27.33	156.67	76.67	25.00	103.33	27.00	3.00
T_3	30.00	67.00	21.67	126.67	77.00	38.33	85.00	29.00	2.33
T_4	23.67	81.33	19.33	113.33	123.33	23.33	100.00	29.33	1.33
T_5	27.04	62.67	18.33	130.00	83.33	26.67	91.67	23.67	1.34
T_6	39.80	70.00	16.33	130.00	90.00	16.69	91.70	27.00	3.00
T_7	26.83	116.70	24.00	143.33	80.00	16.67	100.00	27.33	6.00
T_8	22.90	88.60	18.33	223.33	86.67	25.00	43.33	15.67	1.67
T_9	9.93	63.33	19.00	153.33	50.00	30.00	100.00	36.00	3.33
T_{10}	19.40	64.00	12.67	120.00	113.33	20.00	86.67	25.33	1.33
T_{11}	46.77	92.67	15.00	110.00	83.33	25.00	93.33	30.00	2.30
T_{12}	36.03	72.00	16.67	130.00	70.00	38.33	125.00	34.33	3.30
T_{13}	16.33	69.33	20.00	153.33	80.00	26.67	131.67	34.00	3.70
T_{14}	8.98	44.00	14.67	133.33	66.67	20.00	85.00	25.67	2.00
T_{15}	25.84	86.00	20.67	134.00	103.33	23.33	96.67	28.00	3.30
T_{16}	32.33	72.00	16.33	153.33	63.88	28.33	110.00	27.67	3.30
T_{17}	31.23	102.00	21.33	166.67	120.00	36.67	123.30	50.00	7.30
Mean	27.34	75.61	19.96	143.92	84.12	26.47	100.58	30.33	3.02
CD(0.05)	NS	NS	7.95	NS	NS	NS	31.90	14.58	1.18

was recorded by T_{12} (*Grevillea* - 0.04). The differences were not statistically significant.

4.1.1.1.3 Organic carbon

The organic carbon content of the experiment field varied from 0.96 per cent to 1.32 per cent (Table 3). Rhizosphere soil of pepper trailed on *Thespesia* recorded the highest content of organic carbon (1.32%) and that on *Caesalpinia* and *Gliricidia* recorded the lowest (0.96%). However, the variation among various treatments was not significantly different.

4.1.1.1.4 Phosphorus

Available phosphorus content of rhizosphere soil varied from 8.98 to 46.77 mg kg^{-1} (Table 4). Highest phosphorus content was obtained in T_{11} (*Gliricidia* - 46.77 mg kg^{-1}) and lowest in T_{14} (*Moringa* - 8.98 mg kg^{-1}). Availability of phosphorus was also higher when the standards used were *Bombax* (39.80 mg kg^{-1}), *Grevillea* (36.03 mg kg^{-1}), *Thespesia* (32.33 mg kg^{-1}), Teak pole (31.23 mg kg^{-1}) and arecanut (30.00 mg kg^{-1}). However, the treatments were not statistically significant.

4.1.1.1.5 Potassium

Maximum potassium content was recorded in the rhizosphere soil of pepper vines trailed on *Caesalpinia* (116.7 mg kg^{-1}) followed by teak pole (102.0 mg kg^{-1}) (Table 4). T_{14} (*Moringa*) had the least availability of potassium (44.0 mg kg^{-1}) as in the case of phosphorus.

4.1.1.1.6 Sodium

The different treatments varied significantly in the sodium content of rhizosphere soil, which ranged from 12.67 to 37.67 mg kg^{-1} (Table 4). *Acacia* recorded the maximum availability of sodium (37.67 mg kg^{-1}) and was significantly higher than all other treatments. This was followed by T_2 (*Ailanthus* - 27.33 mg kg^{-1}). T_{10} (*Garuga*) recorded the minimum content of sodium (12.67 mg kg^{-1}). T_3 (arecanut - 21.67 mg kg^{-1}), T_7 (*Caesalpinia* - 24.0 mg kg^{-1}), T_{15} (*Pajanelia*- 20.67 mg kg^{-1}) and

T_{17} (Teak pole - 21.33 mg kg^{-1}) had significantly higher content of sodium in the rhizosphere soil. All other treatments were on par with T_{10}.

4.1.1.1.7 Calcium

Available calcium content of rhizosphere soil ranged from 110.00 to 223.33 mg kg^{-1} (Table 4). Maximum availability was recorded in T_8 (Coconut - 223.3 mg kg^{-1}) followed by T_1 (*Acacia* - 170.0 mg kg^{-1}) and T_{17} (Teak pole - 166.67 mg kg^{-1}). T_{11} (*Gliricidia)* recorded the minimum calcium content in the rhizosphere soil (110.00 mg kg^{-1}). The variability noticed was not statistically significant.

4.1.1.1.8 Magnesium

Available magnesium content was maximum in T_4 (*Artocarpus* - 123.33 mg kg^{-1}) followed by T_{17} (Teak pole - 120.00 mg kg^{-1}). T_9 (*Erythrina*) recorded the minimum content of available magnesium (50.00 mg kg^{-1}), which followed T_{16} (*Thespesia* - 63.88 mg kg^{-1}) and T_1 (*Acacia* - 63.33 mg kg^{-1}) (Table 4). Treatment differences were statistically not significant.

4.1.1.1.9 Iron

Arecanut and *Grevillea* had the maximum availability of iron in the rhizosphere soil (both had 38.33 mg kg^{-1}) followed by T_{17} (teak pole - 36.67 mg kg^{-1}) (Table 4). T_6 (*Bombax*) and T_7 (*Caesalpinia*) had comparatively lesser content of available iron in the rhizosphere soil (16.69 and 16.67 mg kg^{-1} respectively). Treatments did not differ significantly with regard to available iron content.

4.1.1.1.10 Manganese

Available manganese content in the rhizosphere soil varied significantly among various treatments (Table 4). Maximum content was recorded in T_1 (*Acacia* - 143.33 mg kg^{-1}) followed by T_{13} (*Leucaena* - 131.67 mg kg^{-1}). T_{12} and T_{17} were also on par with T_1. T_8 (Coconut) had the least amount of manganese (43.33 mg kg^{-1}) in the rhizosphere soil. All other treatments had significantly higher manganese content in the rhizosphere soil compared to T_8.

4.1.1.1.11 Copper

There was significant variation among treatments for copper content in the rhizosphere also. Maximum copper content was recorded in T_{17} (teak pole - 50.00 mg kg^{-1}) followed by T_1 (*Acacia* - 45.67 mg kg^{-1}). T_9 was also on par with T_{17} (Table 4). Minimum copper content was available in T_8 (Coconut - 15.67 mg kg^{-1}). All other treatments except T_7, T_{12} and T_{13} were on par with coconut.

4.1.1.1.12 Zinc

Available zinc content varied from 1.33 to 7.3 mg kg^{-1}. T_{17} (teak pole) had significantly higher Zn content (7.30 mg kg^{-1}) in the rhizosphere soil compared to other treatments (Table 4). T_4 (*Artocarpus*) and T_{10} (*Garuga*) had lowest content of available zinc (1.33 mg kg^{-1} soil) in the rhizosphere soil. Treatments T_5, T_8, T_{12} and T_{14} were on par with T_4 and T_{10}.

4.1.1.2 Subsurface samples

4.1.1.2.1 Soil pH

Soil pH in the subsurface samples ranged from 5.14 to 5.73 with T_{14} (*Moringa*) having the minimum value (5.14) and T_7 (*Caesalpinia*) having the maximum value (5.73). The variation in soil pH was not statistically significant (Table 5).

4.1.1.2.2 Electrical conductivity

Electrical conductivity (EC) of the subsurface soil samples varied significantly between treatments (Table 5). Highest EC was recorded in T_1 (0.20 dS m^{-1}) followed by T_2 (*Ailanthus* - 0.15 dS m^{-1}), which were on par, as in the case of surface samples. T_9 recorded the minimum value (0.03). T_3 (arecanut - 0.11), T_4 (*Artocarpus* - 0.11) and T_{16} (*Thespesia* - 0.09) also had significantly higher electrical conductivity in the subsurface soil of rhizosphere compared to T_9. All other treatments were on par with T_9.

Table 5. Electrochemical properties of rhizosphere soil of pepper (subsurface samples)

Treatment	pH	EC (dS m^{-1})	Organic C (%)
T_1	5.30	0.20	1.14
T_2	5.68	0.15	1.34
T_3	5.63	0.11	1.20
T_4	5.32	0.11	1.06
T_5	5.66	0.07	1.25
T_6	5.44	0.05	0.99
T_7	5.73	0.08	1.36
T_8	5.71	0.08	1.05
T_9	5.39	0.03	1.01
T_{10}	5.31	0.07	1.00
T_{11}	5.43	0.05	0.99
T_{12}	5.44	0.04	1.02
T_{13}	5.32	0.06	1.18
T_{14}	5.14	0.07	1.13
T_{15}	5.19	0.06	1.26
T_{16}	5.42	0.09	1.28
T_{17}	5.67	0.07	1.04
Mean	5.46	0.08	1.14
CD (0.05)	NS	0.06	NS

Table 6. Available nutrient status of rhizosphere soil of pepper (subsurface samples)

Treat-ment	P (mg kg^{-1})	K (mg kg^{-1})	Na (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
T_1	20.43	60.60	30.33	206.67	70.00	23.33	108.33	38.67	5.07
T_2	11.07	69.00	25.33	96.67	64.00	16.67	90.00	27.67	4.67
T_3	34.30	89.30	27.67	153.33	30.00	38.33	83.33	16.00	2.00
T_4	23.57	76.00	20.67	116.67	70.00	45.00	75.00	32.00	2.00
T_5	16.40	60.67	17.67	146.67	93.33	18.33	91.67	28.00	1.83
T_6	21.97	61.33	15.00	133.33	100.00	20.00	85.00	33.33	3.33
T_7	24.37	96.07	23.67	146.67	113.33	21.67	108.33	20.00	3.00
T_8	17.37	85.33	23.00	153.33	83.33	16.67	51.67	15.33	1.67
T_9	16.03	70.33	14.00	110.00	113.40	13.33	95.00	31.00	1.00
T_{10}	21.20	90.00	21.33	183.33	116.67	18.33	108.38	29.33	4.00
T_{11}	25.73	85.33	13.33	166.67	73.33	30.00	113.33	34.67	2.00
T_{12}	31.10	75.33	13.67	110.00	66.67	46.67	110.00	40.00	5.33
T_{13}	24.80	75.00	16.33	123.33	96.67	28.33	110.00	34.33	2.33
T_{14}	19.64	60.00	14.67	130.00	56.67	30.00	105.00	39.67	5.33
T_{15}	44.57	60.67	13.70	100.00	60.00	38.33	111.67	27.67	5.33
T_{16}	49.87	78.00	15.60	126.67	80.00	33.33	96.67	35.67	2.67
T_{17}	32.53	78.67	19.00	136.67	53.33	36.67	101.67	55.00	6.00
Mean	25.58	75.35	19.12	137.65	78.86	27.95	96.77	31.67	3.42
CD (0.05)	NS	NS	8.75	58.40	NS	11.80	NS	15.48	NS

4.1.1.2.3 Organic carbon

Organic carbon content of subsurface samples varied from 0.99 to 1.36 per cent in different treatments (Table 5). Maximum availability of organic carbon was recorded in the rhizosphere soil of T_7 (*Caesalpinia* - 1.36 per cent) followed by T_2 (*Ailanthus* - 1.34) and T_{16} (*Thespesia* - 1.28 per cent). T_{11} (*Gliricidia*) had the least content of organic carbon (0.99%) in the subsurface samples as in the case of surface samples. T_6 (*Bombax*) also recorded 0.99 % of organic carbon in the rhizosphere soil.

4.1.1.2.4 Phosphorus

Available phosphorus content in the subsurface samples of rhizosphere soil ranged from 11.07 to 49.87 mg kg^{-1} (Table 6). T_2 (*Ailanthus*) recorded the minimum value (11.07 mg kg^{-1}) and T_{16} (*Thespesia*) the maximum value (49.87 mg kg^{-1}). As in the case of surface samples, availability of P was low in T_9 (*Erythrina*- 16.03 mg kg^{-1}).

4.1.1.2.5 Potassium

Maximum availability of potassium was recorded in T_7 (*Caesalpinia* - 96.67 mg kg^{-1}) and minimum availability (60.00 mg kg^{-1}) in T_{14} (*Moringa*) (Table 6). Similar trend was noticed in the surface samples also.

4.1.1.2.6 Sodium

Different treatments varied significantly with regard to available sodium content of subsurface samples (Table 6) as in the surface layer. Sodium content was maximum in T_1 (30.33 mg kg^{-1}) like in surface samples. Minimum sodium content was recorded in T_{11} (13.33 mg kg^{-1}). Other treatments, which possessed higher sodium content, were T_7 (*Caesalpinia* - 23.00), T_8 (coconut - 23.00 mg kg^{-1}), T_2 (*Ailanthus*) and T_3 (arecanut) which were on par with T_1.

4.1.1.2.7 Calcium

Available calcium content in the subsurface samples ranged from 96.67 to 206.67 mg kg^{-1} (Table 6). Unlike surface soil, variability was significant in subsurface soil layer. T_1 recorded the maximum content (206.67 mg kg^{-1}) followed by T_{10} (183.33

mg kg^{-1}) and T_{11} (166.67 mg kg^{-1}). T_3 and T_8 were also on par with T_1. T_2 (*Ailanthus*) had the minimum content of calcium (96.67 mg kg^{-1}). T_{15} (*Pajanelia*), T_9 (*Erythrina*) and T_{12} (*Grevillea*) had comparatively lower content of calcium (100.00, 110.00 and 110.00 mg kg^{-1} respectively). All the treatments except T_1, T_{10} and T_{11} were on par with T_2.

4.1.1.2.8 Magnesium

Maximum magnesium content was observed in the rhizosphere soil of pepper vines trailed on *Garuga* (116.67 mg kg^{-1}) followed by *Erythrina* (113.40 mg kg^{-1}) (Table 6). Minimum content of magnesium was recorded in T_3 (30.00 mg kg^{-1}). Differences were not significant as in surface soil.

4.1.1.2.9 Iron

Available iron content in the rhizosphere soil ranged from 13.33 to 46.67 mg kg^{-1} in the subsurface samples (Table 6). The variation was statistically significant unlike in surface soil. T_{12} (*Grevillea*) had the maximum content of iron (46.67 mg kg^{-1}) as in the case of surface samples. T_3, T_4, T_{15} and T_{17} were on par with T_{12} with regard to available iron content in subsurface soil. The mean content of iron was higher (27.95) in subsurface samples than surface samples (26.47 mg kg^{-1}). Minimum iron content was noticed in T_9 (*Erythrina*- 13.33 mg kg^{-1}). Treatments which possessed significantly higher content of iron were T_4 (*Artocarpus* - 45.00 mg kg^{-1}) and T_3 (arecanut - 38.33 mg kg^{-1}).

4.1.1.2.10 Manganese

Available manganese content in the rhizosphere soil ranged from 51.67 to 113.33 mg kg^{-1} soil in the subsurface samples (Table 6). T_{11} (*Gliricidia)* recorded the maximum manganese content of 113.33 mg kg^{-1} followed by T_{15} (*Pajanelia*- 111.67 mg kg^{-1}). Minimum manganese content was recorded in coconut (T_8 - 51.67 mg kg^{-1}).

4.1.1.2.11 Copper

Available copper content of subsurface samples of rhizosphere soil ranged from 15.33 to 55.00 mg kg^{-1} (Table 6). T_{17} (Teak pole) recorded the maximum copper content (55.00 mg kg^{-1}) as in the case of surface samples. T_{12} and T_{14} were on par with T_{17}. Minimum value was recorded in T_8 (coconut - 15.33 mg kg^{-1}) similar to surface samples. T_2, T_3, T_5, T_7, T_{10} and T_{15} were on par with T_8.

4.1.1.2.12 Zinc

Available zinc content of rhizosphere soil in the subsurface samples ranged from 1.00 to 6.00 mg kg^{-1} soil (Table 6). Maximum zinc content was recorded in T_{17} (teak pole - 6.00 mg kg^{-1}) as in the surface samples. Minimum content of available zinc was recorded in T_9 (*Erythrina*- 1.00 mg kg^{-1}). There was no significant variation among treatments.

4.1.1.3 Nutrient ratios of rhizosphere soil

4.1.1.3.1 P/Fe+Mn

There was no significant difference in the nutrient ratio P/Fe+Mn among various treatments in both surface and subsurface samples (Table 7). In the surface samples, lowest ratio was recorded in T_9 (*Erythrina*- 0.08) and highest in T_6, T_8 and T_{11} (0.38). In subsurface samples, the ratio ranged from 0.10 to 0.39. T_{16} (*Thespesia*) recorded the maximum ratio of 0.39 followed by T_8 (coconut) and T_{15} (*Pajanelia*). Minimum value of 0.10 was recorded in T_2 (*Ailanthus*). The mean value was lower (0.21) in the subsurface samples than surface samples (0.24).

4.1.1.3.2 K/Ca+Mg+Fe+Mn

The ratio K/Ca+Mg+Fe+Mn was highest in T_7 (*Caesalpinia* - 0.31) in surface samples and T_3 (arecanut - 0.30) in subsurface samples (Table 7). Lowest value was recorded in T_{14} (*Moringa* - 0.15) in surface samples and T_1 (*Acacia* - 0.14) in subsurface samples. In both layers of soil, the variation in the nutrient ratio K/Ca+Mg+Fe+Mn was statistically nonsignificant.

Table 7. Nutrient ratios in the rhizosphere soil of pepper

Treatment	P/ Fe + Mn		K/ Ca+Mg+Fe+Mn	
	Surface	Subsurface	Surface	Subsurface
T_1	0.16	0.17	0.17	0.14
T_2	0.23	0.10	0.18	0.27
T_3	0.25	0.28	0.21	0.30
T_4	0.18	0.21	0.23	0.25
T_5	0.32	0.15	0.18	0.17
T_6	0.38	0.20	0.21	0.18
T_7	0.24	0.24	0.31	0.27
T_8	0.38	0.30	0.20	0.28
T_9	0.08	0.15	0.19	0.26
T_{10}	0.18	0.17	0.19	0.19
T_{11}	0.38	0.18	0.30	0.21
T_{12}	0.22	0.21	0.20	0.21
T_{13}	0.11	0.20	0.18	0.17
T_{14}	0.09	0.15	0.15	0.17
T_{15}	0.36	0.30	0.25	0.19
T_{16}	0.23	0.39	0.21	0.23
T_{17}	0.21	0.22	0.29	0.27
Mean	0.24	0.21	0.21	0.22
CD (0.05)	NS	NS	NS	NS

4.1.2 Exchangeable cations in the rhizosphere soil

4.1.2.1 Surface soil

4.1.2.1.1 Calcium

Exchangeable calcium content of different treatments varied from 213.33 to 359.33 mg kg^{-1} in the rhizosphere soil (Table 8). Maximum content of calcium was recorded in T_8 (Coconut - 359.33 mg kg^{-1}) as in the case of available calcium content. Minimum content was recorded in T_3 (213.33 mg kg^{-1}). As in the case of available calcium, exchangeable calcium was high in T_1 (*Acacia* - 292.67) and low in T_{11} (217.00 mg kg^{-1}). There was no significant difference among treatments with regard to exchangeable calcium.

4.1.2.1.2 Magnesium

Exchangeable magnesium content varied from 87.33 to 179.00 mg kg^{-1} (Table 8). Highest magnesium content was observed in T_7 (*Caesalpinia* - 179.00 mg kg^{-1}) and lowest in T_{15} (*Pajanelia*- 87.33 mg kg^{-1}). Coconut (167.00 mg kg^{-1}), *Leucaena* (160.33 mg kg^{-1}), *Acacia* (151.33 mg kg^{-1}) and *Garuga* (134.00 mg kg^{-1}) were on par with *Caesalpinia.*

4.1.2.1.3 Sodium

There was significant variation in the sodium content in the exchange sites of the rhizosphere soil (Table 8). Maximum content was recorded in T_9 (144.70 mg kg^{-1}) followed by T_{10} (*Garuga* - 142.70 mg kg^{-1}) and T_1 (*Acacia* - 142.7 mg kg^{-1}). Minimum content of sodium was recorded in T_6 (*Bombax* - 92.67 mg kg^{-1}). T_8 (coconut - 134.00 mg kg^{-1}), T_{11} (*Gliricidia* - 133.33 mg kg^{-1}), T_{17} (Teak pole - 134.00 mg kg^{-1}), T_{12} (*Grevillea* – 128.70), T_{13} (*Leucaena* – 127.30), T_{15} (*Pajanelia* – 122.00) and T_{16} (*Thespesia* – 122.00) were on par with T_9.

4.1.2.1.4 Potassium

Exchangeable potassium content in the rhizosphere soil varied from 74.67 to 123.33 mg kg^{-1} (Table 8). Maximum value was recorded in T_9 (*Erythrina*- 123.33

Table 8. Exchangeable cations (mg kg^{-1} soil) and CEC (cmol (+) kg^{-1}) in rhizosphere soil of pepper (surface samples)

Treatment	Ca	Mg	Na	K	Fe	Mn	Al	CEC
T_1	292.67	151.33	142.70	84.67	3.00	106.67	25.90	4.23
T_2	276.00	96.33	117.3	78.67	3.00	76.67	19.70	3.69
T_3	213.33	102.33	109.30	84.67	2.67	70.00	13.20	3.41
T_4	222.00	123.67	105.30	90.67	2.67	71.60	18.10	3.67
T_5	242.67	125.67	102.00	78.67	2.33	70.00	16.33	3.73
T_6	242.00	101.00	92.67	76.67	2.67	68.30	10.50	3.56
T_7	258.33	179.00	96.67	90.00	3.00	76.70	16.40	4.28
T_8	359.33	167.00	134.00	88.00	3.00	16.70	18.60	4.69
T_9	272.00	92.33	144.70	123.33	2.33	65.00	21.50	3.63
T_{10}	230.33	134.00	142.70	102.00	2.67	68.30	35.70	3.77
T_{11}	217.00	104.00	133.33	100.00	3.00	70.00	23.60	3.45
T_{12}	242.07	95.00	128.70	84.67	2.67	88.30	17.10	3.50
T_{13}	272.00	160.33	127.30	82.00	3.00	103.30	25.30	4.20
T_{14}	232.00	96.33	120.00	74.67	2.67	78.30	18.30	3.43
T_{15}	226.67	87.33	122.00	80.00	2.67	76.70	20.10	3.37
T_{16}	264.00	109.33	122.00	91.33	2.33	70.00	28.40	3.70
T_{17}	252.33	114.00	134.00	100.67	2.67	83.30	13.40	3.72
Mean	253.84	119.82	122.64	88.86	2.73	74.12	20.12	3.77
CD(0.05)	NS	51.16	23.50	NS	NS	28.27	NS	0.60

mg kg^{-1}) as in the case of sodium, followed by T_{10} (*Garuga* - 102.00) and T_{17} (teak pole - 100.67 mg kg^{-1}). Minimum potassium content was recorded in T_{14} (*Moringa* - 74.67 mg kg^{-1}). There was no significant difference among treatments for exchangeable potassium.

4.1.2.1.5 Iron

There was no significant variation in the exchangeable iron content among different treatments (Table 8). The value ranged from 2.33 to 3.00 mg kg^{-1} soil. Maximum value was recorded in T_1, T_2, T_7, T_{11} and T_{13} with 3.0 mg kg^{-1} soil and minimum in T_5, T_9 and T_{16} with 2.33 mg kg^{-1} soil.

4.1.2.1.6 Manganese

The treatments differed significantly in the exchangeable Mn content content in the rhizosphere soil. As in the case of available manganese content, exchangeable manganese content was recorded maximum in T_1 (*Acacia* – 106.67mg kg^{-1}) followed by T_{13} (*Leucaena* - 103.30 mg kg^{-1}) (Table 8). Minimum content of manganese was observed in T_8 (coconut - 16.70 mg kg^{-1}). Treatments which had significantly higher content of manganese were T_{12} (*Grevillea* - 88.30 mg kg^{-1}), T_{17} (83.30 mg kg^{-1}), T_{14} (78.30 mg kg^{-1}), T_2 (*Ailanthus* - 76.69 mg kg^{-1}), T_7 (*Caesalpinia* - 76.7 mg kg^{-1}), T_{13} (*Leucaena* - 103.30 mg kg^{-1}) and T_{15} (*Pajanelia*- 76.67 mg kg^{-1}).

4.1.2.1.7 Aluminium

Exchangeable aluminium varied from 10.5 to 35.7 mg kg^{-1} in the rhizosphere soil (Table 8). Maximum content of aluminium was recorded in T_{10} (*Garuga* - 35.7 mg kg^{-1}) followed by T_{16} (*Thespesia* - 28.4 mg kg^{-1}), T_1 (*Ailanthus* - 25.9 mg kg^{-1}) and T_{13} (*Leucaena* - 25.3 mg kg^{-1}). Minimum content of aluminium was recorded in T_6 (*Bombax* - 10.5 mg kg^{-1}). The treatments did not differ significantly in the exchangeable aluminium content in the rhizosphere soil.

4.1.2.1.8 Cation exchange capacity

The cation exchange capacity of the surface samples of rhizosphere soil ranged from 3.37 to 4.69 cmol (+) kg^{-1} (Table 8). Maximum CEC was recorded in T_8 (Coconut - 4.69) and minimum CEC was recorded in T_{15} (*Pajanelia*- 3.37). CEC was significantly higher in T_{13} (*Leucaena* - 4.20), T_1 (*Ailanthus* - 4.23), T_7 (*Caesalpinia* - 4.28) and T_8 (Coconut - 4.69).

4.1.2.2 Subsurface samples

4.1.2.2.1 Calcium

As in the case of surface samples, exchangeable calcium was maximum in T_8 (Coconut - 373.67 cmol (+) kg^{-1}) and minimum in T_{11} (*Gliricidia* - 247.67) (Table 9). The variation between different treatments was not statistically significant.

4.1.2.2.2 Magnesium

Magnesium content in the exchange sites of subsurface soil ranged from 88.33 to 133.00 mg kg^{-1} (Table 9). Highest content was recorded in T_{13} (*Leucaena* - 133.00 mg kg^{-1}) followed by T_5 (*Azadirachta* - 128.33 mg kg^{-1}). T_4 (*Artocarpus*) recorded the minimum magnesium content of 88.33 mg kg^{-1} in the exchange sites of rhizosphere soil. However the variation was not statistically significant.

4.1.2.2.3 Sodium

The only cation with a significant difference among treatments in the subsurface soil was sodium. Exchangeable sodium content in the subsurface samples was maximum in T_9 (*Erythrina*- 144.00 mg kg^{-1}) followed by T_{10} (*Garuga* - 141.30 mg kg^{-1}) as in the case of surface samples (Table 9). The treatments T_1, T_8, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{17} were on par with T_9. Sodium content was significantly lower in T_4, T_5 and T_7 with a sodium content of 108.00, 104.70 and 99.33 mg kg^{-1} soil respectively. Minimum content of exchangeable sodium was recorded in T_6 (*Bombax* - 91.33 mg kg^{-1}) similar to surface samples.

4.1.2.2.4 Potassium

Exchangeable potassium content in the subsurface samples was maximum in T_{17} (teak pole - 110.00 mg kg^{-1}) followed by T_4 (*Artocarpus* - 102.00 mg kg^{-1}) and T_2 (*Ailanthus* - 101.33 mg kg^{-1}) (Table 9). Lowest content was recorded in T_6 (*Bombax* - 69.33 mg kg^{-1}).

4.1.2.2.5 Iron

Different treatments did not vary significantly with respect to exchangeable iron content in the subsurface samples (Table 9). The values ranged from 2.00 to 4.30 mg kg^{-1} where T_{17} (teak pole) recorded the maximum value (4.00) and T_1 (*Ailanthus)* and T_8 (Coconut) recorded the minimum value (2.00 mg kg^{-1}).

4.1.2.2.6 Manganese

T_7 (*Caesalpinia*) and T_{11} (*Gliricidia*) had the maximum content of exchangeable manganese in the rhizosphere soil (both 83.30 mg kg^{-1}) (Table 9). Minimum content of manganese was observed in the exchange sites of rhizosphere soil of T_8 (Coconut - 46.70 mg kg^{-1}) as in the case of surface samples.

4.1.2.2.7 Aluminium

Exchangeable aluminium content in the subsurface samples ranged from 13.07 to 30.57 mg kg^{-1} (Table 9). Minimum content was recorded in T_3 (arecanut - 13.07 mg kg^{-1}) followed by T_7 (*Caesalpinina* - 13.6 mg kg^{-1}) and T_{17} (teak pole - 14.43). Maximum exchangeable aluminium content was recorded in T_{15} (*Pajanelia*- 30.57 mg kg^{-1}) followed by T_{13} (*Leucaena* - 27.13) and T_{11} (*Gliricidia* - 24.90 mg kg^{-1}).

4.1.2.2.8 Cation exchange capacity

The treatments did not vary significantly with respect to cation exchange capacity of subsurface samples (Table 9). It ranged from 3.42 to 4.92 c mol (+) kg^{-1}. T_{13} (*Leucaena*) recorded the maximum CEC (4.92 c mol (+) kg^{-1}) followed by T_8 (coconut - 4.39 c mol (+) kg^{-1}) and T_{10} (4.11 c mol (+) kg^{-1}). Minimum value was observed in the rhizosphere soil of pepper vines trailed on *Thespesia* (T_{16} - 3.42 c mol (+) kg^{-1}).

Table 9. Exchangeable cations (mg kg^{-1} soil) and CEC (cmol (+) kg^{-1}) in rhizosphere soil of pepper (subsurface samples)

Treatment	Ca	Mg	Na	K	Fe	Mn	Al	CEC
T_1	271.00	93.33	128.00	83.33	2.00	81.67	21.30	3.63
T_2	261.67	101.00	112.70	101.33	3.00	58.30	21.43	3.63
T_3	275.33	100.00	114.70	98.67	3.30	66.70	13.07	3.71
T_4	270.67	88.33	108.00	102.00	2.70	61.70	21.10	3.60
T_5	302.67	128.33	104.70	84.67	2.70	76.70	24.47	3.75
T_6	289.00	92.00	91.33	69.33	2.60	76.70	16.23	3.71
T_7	312.33	91.67	99.33	8.200	2.60	83.30	13.60	3.82
T_8	373.67	123.67	136.00	90.00	2.00	46.70	21.63	4.39
T_9	252.33	112.33	144.00	95.33	3.70	75.00	23.70	3.70
T_{10}	341.67	113.67	141.30	96.67	2.70	80.00	18.23	4.11
T_{11}	247.67	102.33	127.30	92.00	2.60	83.30	24.90	3.59
T_{12}	312.67	95.67	130.70	90.67	2.60	80.00	21.47	3.87
T_{13}	301.67	133.00	124.70	85.33	2.30	71.70	27.13	4.92
T_{14}	252.00	92.00	128.00	82.67	3.30	78.30	23.57	3.52
T_{15}	257.67	103.33	123.30	84.67	2.30	73.30	30.57	3.59
T_{16}	303.00	108.30	120.00	94.67	2.30	71.70	17.90	3.42
T_{17}	247.69	104.30	126.70	110.00	4.30	68.3	14.43	3.60
Mean	286.69	105.02	121.22	90.78	2.78	72.55	20.90	3.56
CD(0.05)	NS	NS	21.30	NS	NS	NS	NS	NS

4.1.3 Soil biological properties

4.1.3.1 Microbial population of rhizosphere soil

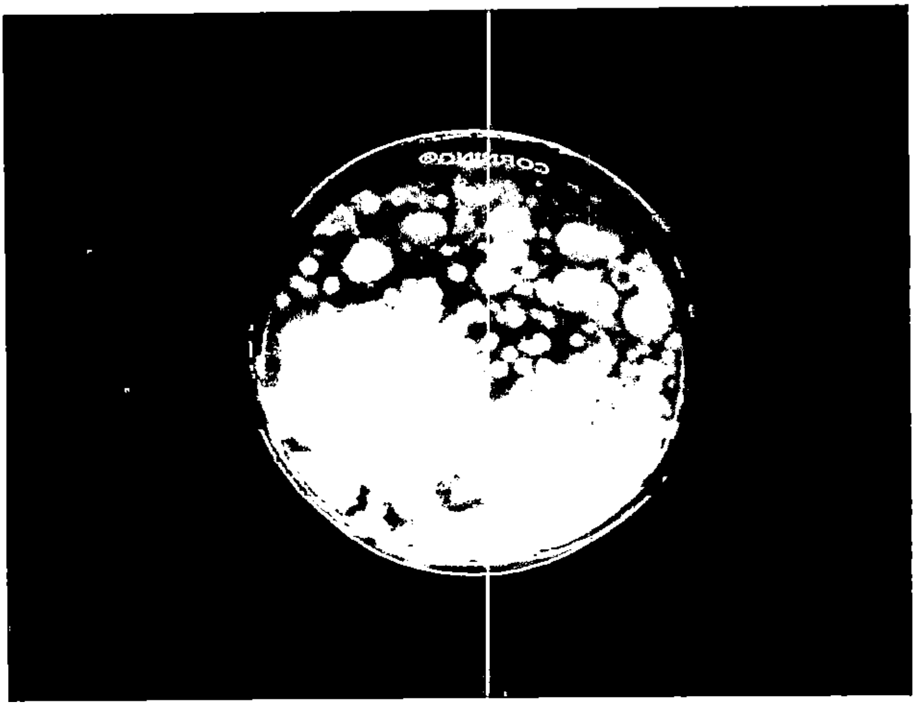
Serial dilution plating method was followed to enumerate the different microorganisms present in the rhizosphere soil of pepper trailed on different standards. There was significant variation in the total count of fungi, bacteria specifically nitrogen fixing bacteria and phosphate solubilising bacteria and actinomycetes in the rhizosphere soil of various treatments.

4.1.3.1.1 Fungus

Fungal population varied from 4.83 to 100.50 $x10^3$ cfu g^{-1} soil in the rhizosphere soil (Table 10). Rhizosphere soil of pepper vines trailed on *Thespesia* (T_{16}) had the maximum population of total fungi (100.50 $x10^3$ cfu g^{-1} soil) followed by T_2 (*Ailanthus* - 87.17), which were statistically on par. T_{12} (*Grevillea* - 73.17) also recorded a high fungal count on par with T_2. T_1 (*Acacia*) recorded the minimum fungal population of 4.83 $x10^3$ cfu g^{-1}. Other treatments with comparatively higher population of fungi were T_8 (Coconut - 63.33), T_3 (arecanut - 56.00), T_{14} (*Moringa* - 54.17), T_{15} (*Pajanelia*- 45.83), T_{10} (*Garuga* - 41.17), T_{17} (teak pole - 43.33), T_6 (*Bombax* - 30.17) etc. (Plate 6).

4.1.3.1.2 Bacteria

There was significant difference in the population of bacteria in different treatments (Table 10). It ranged from 8.50 to 45.77 $x10^5$ cfu g^{-1} of rhizosphere soil in different treatments. T_{12} (*Grevillea*) possessed the minimum population of bacteria in the rhizosphere soil (8.50) followed by T_6 (*Bombax* - 10.17) and T_9 (*Erythrina*- 11.00 $x10^5$ cfu g^{-1}). Rhizosphere soil of pepper trailed on arecanut (T_3) contained the maximum bacterial population (45.77 $x10^5$ cfu g^{-1} soil) followed by T_5 (*Azadirachta* - 43.67 $x10^5$ cfu g^{-1} soil), T_{10} (*Garuga* - 41.67 $x10^5$ cfu g^{-1} soil), T_8 (coconut - 39.67), T_7 (*Caesalpinia* – 37.00 $x10^5$ cfu g^{-1} soil) and T_{14} (*Moringa* - 33.83 $x10^5$ cfu g^{-1} soil), which were statistically on par (Plate 6).



Fungus

Bacteria

Plate 6. Soil microflora

Table 10. Microbial population of rhizosphere soil of pepper

Treatment	Fungus ($x10^3$ cfu g^{-1} soil)	Bacteria ($x10^5$ cfu g^{-1} soil)	Actinomycetes ($x10^4$ cfu g^{-1} soil)	NFB ($x10^5$ cfu g^{-1} soil)	PSB ($x10^5$ cfu g^{-1} soil)
T_1	4.83	27.50	19.00	15.50	2.83
T_2	87.17	28.17	15.83	9.67	1.50
T_3	56.00	45.77	27.50	18.00	5.33
T_4	24.00	30.17	14.67	25.17	8.17
T_5	24.17	43.67	13.17	15.67	2.50
T_6	30.17	10.17	23.17	8.00	4.17
T_7	18.00	37.00	17.00	14.33	6.33
T_8	63.33	39.67	32.83	18.33	5.33
T_9	21.83	11.00	25.17	1.33	2.17
T_{10}	41.27	41.67	26.20	28.00	8.83
T_{11}	19.00	28.00	21.33	10.00	7.83
T_{12}	73.17	8.50	12.50	4.17	6.50
T_{13}	17.00	23.17	22.17	10.67	3.17
T_{14}	54.17	33.83	14.17	12.17	6.00
T_{15}	45.83	21.17	2.33	6.83	7.50
T_{16}	100.50	22.50	9.83	21.83	3.67
T_{17}	43.33	22.00	4.67	20.83	7.33
Mean CD (0.05)	80.93 20.30	31.51 16.25	24.29 9.58	22.12 7.81	6.40 3.23

Fungus

Bacteria

Plate 6. Soil microflora

4.1.3.1.2.1 Nitrogen fixing bacteria (NFB)

There was significant variation in the population of nitrogen fixing bacteria among different treatments (Table 10). It ranged from 1.33 to 28.00 $x10^5$ cfu g^{-1} rhizosphere soil. Highest population was observed in T_{10} (*Garuga* - 28.00) followed by T_4 (*Artocarpus* - 25.17), T_{16} (*Thespesia*- 21.83 $x10^5$ cfu g^{-1}) and T_{17}, which were on par with T_{10}. Treatments, which possessed poor level of nitrogen fixing bacteria in their rhizosphere soil, were T_9 (*Erythrina*) having the lowest value of 1.33 $x10^5$ cfu g^{-1} soil, T_{12} (*Grevillea* - 4.17), T_6 (*Bombax* - 8.00) and T_2 (*Ailanthus* - 9.67).

4.1.3.1.2.2 Phosphate solubilising bacteria (PSB)

The rhizosphere soil population of PSB varied from 1.50 to 8.83 $x10^5$ cfu g^{-1} soil in different treatments (Table 10). Maximum population was observed in T_{10} (*Garuga* - 8.83) followed T_4 (*Artocarpus* - 8.17) as in the case of nitrogen fixing bacteria. T_7, T_{11}, T_{12}, T_{14}, T_{15} and T_{17} were also statistically on par with T_{10}. Minimum PSB population in the rhizosphere soil was observed in T_2 (*Ailanthus* - 1.50 $x10^5$ cfu g^{-1} soil) followed by T_9 (*Erythrina*- 2.17) and T_5 (*Azadirachta* - 2.50 $x10^5$ cfu g^{-1} soil).

4.1.3.1.3 Actinomycetes

Minimum population of actinomycetes was observed in T_{15} (*Pajanelia*- 2.33 $x10^4$ cfu g^{-1} soil) and maximum in T_8 (Coconut - 32.83 $x10^4$ cfu g^{-1} soil) (Table 10). Treatments, which had comparatively higher population of actinomycetes and on par with T_8 were T_3 (arecanut - 27.50), T_{10} (*Garuga* - 26.20) and T_9 (*Erythrina*- 25.17).

4.1.3.2 Soil enzymes

4.1.3.2.1 Dehydrogenase

Soil dehydrogenase activity in the experimental plants varied from 98.63 to 258.07 µg $soil^{-1}$ h^{-1} (Table 11). T_{14} (*Moringa*) had the maximum activity of dehydrogenase (258.07 µg $soil^{-1}$ h^{-1}) and minimum activity was observed in T_9

(*Erythrina*- 98.63 μg soil^{-1} h^{-1}). The variation among treatments was not statistically significant.

4.1.3.2.2 Phosphatase

As in the case of dehydrogenase activity, maximum phosphatase activity was recorded in T_{14} (*Moringa* - 256.67 μg g^{-1} soil 24 h^{-1}) (Table 11). Minimum phosphatase activity was recorded in T_6 (*Bombax* - 107.50) followed by T_8 (Coconut - 137.50). Rhizosphere soil of pepper vines trailed on teak pole (T_{17}) had higher activity of phosphatase (245.0 μg g^{-1} soil) similar to the trend observed in the population of phosphate solubilising bacteria. The different treatments did not vary significantly.

4.2 EXPERIMENT II

ROOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD EMPLOYING RADIOISOTOPIC TECHNIQUES

4.2.1 Recovery of ^{32}P from the pepper vine as a function of time

Recovery of ^{32}P by the pepper vines trailed on different standards was recorded at 15, 30 and 45 days after application and compared (Table 12). Substantial variation was observed in the absorption pattern of ^{32}P in different treatments. Treatments which recovered maximum ^{32}P at 30 days after application were T_1 (*Acacia*), T_4 (*Artocarpus*), T_7 (*Caesalpinia*), T_9 (*Erythrina*), T_{11} (*Gliricidia*), T_{12} (*Grevillea*) and T_{17} (Teak pole). The absorption of ^{32}P by the vine was found to be maximum at 45 days after application in eight treatments *viz.* T_2 (*Ailanthus*), T_5 (*Azadirachta*), T_6 (*Bombax*), T_{10} (*Garuga*), T_{13} (*Leucaena*), T_{14} (*Moringa*), T_{15} (*Pajanelia*) and T_{16} (*Thespesia*) as standards of pepper. When arecanut (T_3) and coconut (T_8) were used as standards, absorption of ^{32}P was maximum at 15 days after application thereafter it declined.

4.2.2 Recovery of ^{32}P from standards as a function of time

Recovery of ^{32}P in the leaves of live standards was compared at 15, 30 and 45 days after application (Table 13). In treatments T_1, T_2, T_3, T_5, T_6, T_7, T_9, T_{13} and

Table 11. Enzyme activity of rhizosphere soil of pepper

Treatment	Dehydrogenase ($\mu g\ g^{-1}$ soil h^{-1})	Phosphatase ($\mu g\ g^{-1}$ soil 24 h^{-1})
T_1	182.52	143.33
T_2	194.17	181.67
T_3	176.10	217.50
T_4	200.10	156.67
T_5	245.60	174.17
T_6	189.63	107.50
T_7	146.57	203.33
T_8	176.07	137.50
T_9	98.63	198.33
T_{10}	209.47	185.83
T_{11}	232.37	200.00
T_{12}	152.80	160.67
T_{13}	216.70	195.83
T_{14}	258.07	256.67
T_{15}	231.67	218.33
T_{16}	172.60	223.33
T_{17}	152.13	245.00
Mean	190.31	188.57
CD (0.05)	NS	NS

T_{15}, absorption of ^{32}P was recorded maximum at 30 days after application thereafter it decreased. Absorption of ^{32}P was maximum at 45 days after application when *Artocarpus* (T_4), *Garuga* (T_{10}), *Gliricidia* (T_{11}), *Grevillea* (T_{12}), *Moringa* (T_{14}) and *Thespesia* (T_{16}) were used as standards.

4.2.3 Recovery of ^{32}P from the pepper vines trailed on different standards

There was significant variation in the absorption of ^{32}P by the pepper vines trailed on different standards at 30 days after application (Table 12). Maximum absorption was noticed when teak pole (T_{17}), the dead standard, was used to support pepper vine with 477.529 cpm g^{-1} leaf of ^{32}P recovery. Among the different live standards, maximum recovery of ^{32}P was obtained in pepper vines trailed on *Artocarpus* (T_4 - 243.78 cpm g^{-1}) followed by arecanut (T_3 - 142.23 cpm g^{-1}) and *Azadirachta* (T_5 - 135.519 cpm g^{-1}). Minimum recovery of ^{32}P was recorded in pepper vines trailed on T_{10} (*Garuga* - 11.376 cpm g^{-1}) followed by T_6 (*Bombax* - 17.579). All the treatments except T_2, T_6, T_7, T_{10} and T_{13} were statistically on par with T_{17}.

At 45 days after application also pepper recovered maximum ^{32}P when trailed on teak pole. All the treatments except T_1, T_7 and T_{10} were statistically on par with teak pole. Pepper recovered minimum ^{32}P when trailed on *Caesalpinia*.

4.2.4 Recovery of ^{32}P from standards of pepper

When recovery of ^{32}P from different standards was assessed at 30 days after application, it was observed that *Moringa* recorded the maximum amount of ^{32}P applied (2197.85 cpm g^{-1}), which was more than double of any other treatments (Table 13). Other standards which recovered comparatively higher amount of ^{32}P were T_9 (*Erythrina* - 395.367 cpm g^{-}), T_{13} (*Leucaena* - 408.319), T_1 (*Acacia* - 354.813) and T_{11} (*Gliricidia* - 351.56 cpm g^{-1}). *Grevillea robusta* (T_{12}) recovered the minimum amount of ^{32}P (23.82 cpm g^{-1}) in the leaf. Other treatments which recovered low amount of ^{32}P

Table 12. Recovery of ^{32}P cpm g^{-1} from the leaves of pepper vine trailed on different standards after 15, 30 and 45 days of application of ^{32}P (log transformed values)

Treatment	Recovery of ^{32}P (cpm g^{-1} leaf)		
	Days after ^{32}P application		
	15	30	45
T_1	1.613(41.020)^{bcd}	1.860(72.443)^{abcd}	1.691(49.091)^{bc}
T_2	1.923(83.153)^{abc}	1.750(56.234)^{bcd}	2.212(162.929)^{ab}
T_3	2.386(243.220)^{a}	2.153(142.23)^{abc}	2.304(201.372)^{ab}
T_4	2.249(177.419)^{ab}	2.387(243.78)^{ab}	2.155(142.889)^{ab}
T_5	1.428(26.792)^{cd}	2.132(135.519)^{abc}	2.332(214.783)^{ab}
T_6	1.680(47.863)^{bcd}	1.245(17.579)^{cd}	1.944(87.902)^{ab}
T_7	1.462(28.973)^{cd}	1.664(46.132)^{bcd}	1.069(11.722)^{c}
T_8	2.553(357.27)^{a}	1.902(79.799)^{abcd}	1.743(55.335)^{abc}
T_9	1.491(30.97)^{cd}	2.077(119.399)^{abc}	2.070(117.489)^{ab}
T_{10}	1.289(19.45)^{cd}	1.056(11.376)^{d}	1.719(52.360)^{bc}
T_{11}	1.109(12.85)^{d}	2.091(123.310)^{abc}	1.838(68.865)^{abc}
T_{12}	1.605(40.27)^{bcd}	1.751(56.363)^{bcd}	1.736(54.450)^{abc}
T_{13}	1.471(29.58)^{cd}	1.925(84.139)^{abcd}	2.272(187.068)^{ab}
T_{14}	1.552(35.65)^{bcd}	2.028(106.659)^{abc}	2.213(163.306)^{ab}
T_{15}	1.247(17.66)^{cd}	1.548(35.318)^{bcd}	2.030(107.151)^{ab}
T_{16}	1.546(35.16)^{bcd}	1.830(67.608)^{abcd}	2.060(114.815)^{ab}
T_{17}	2.249(177.42)^{ab}	2.679(477.529)^{a}	2.567(368.978)^{a}
Mean	1.697(82.66)	1.887(110.319)	1.997(127.09)

Values in parentheses denote retransformed values

Values with a common letter in the superscript did not differ significantly at 5 per cent level

Table 13. Recovery of ^{32}P (cpm g^{-1}) from the leaves of different standards after 15, 30 and 45 days of application ^{32}P (log transformed values)

Treatment	Recovery of ^{32}P (cpm g^{-1} leaf) Days after ^{32}P application		
	15	30	45
T_1	1.944(87.902)^{bc}	2.550(354.813)^{bc}	1.938(86.696)^{bcde}
T_2	1.445(27.861)^{c}	1.500(31.623)^{ef}	1.377(23.823)^{de}
T_3	1.643(43.95)^{bc}	1.929(84.918)^{bcdef}	1.842(69.502)^{bcde}
T_4	1.422(26.424)^{c}	1.887(77.090)^{bcdef}	2.359(228.559)^{bc}
T_5	1.644(44.055)^{bc}	2.354(225.944)^{bcd}	1.266(18.450)^{e}
T_6	2.387(243.781)^{b}	2.447(279.898)^{bcd}	1.544(34.995)^{cde}
T_7	1.496(31.332)^{c}	1.829(67.453)^{cdef}	1.617(41.399)^{cde}
T_8	1.879(75.683)^{bc}	1.693(49.317)^{def}	1.580(38.019)^{bcde}
T_9	2.214(163.682)^{bc}	2.597(395.367)^{b}	2.168(147.231)^{bcd}
T_{10}	2.143(140.605)^{bc}	2.200(158.489)^{bcde}	2.247(176.603)^{bc}
T_{11}	2.165(146.218)^{bc}	2.546(351.560)^{bc}	2.550(354.813)^{b}
T_{12}	1.383(24.155)^{c}	1.377(23.823)^{f}	1.548(35.318)^{cde}
T_{13}	2.038(109.144)^{bc}	2.611(408.319)^{b}	2.325(211.349)^{bc}
T_{14}	3.345(2213.095)^{a}	3.342(2197.859)^{a}	3.406(2546.830)^{a}
T_{15}	1.619(41.591)^{bc}	2.348(222.844)^{bcd}	1.879(75.683)^{bcde}
T_{16}	2.040(109.648)^{bc}	2.387(243.781)^{bc}	2.626(422.66)^{b}
Mean	1.926(220.57)	2.22(323.32)	2.017(282.00)

Values in parentheses denote retransformed values

Values with a common letter in the superscript did not differ significantly at 5 per cent level

Table 14. Percentage distribution of ^{32}P absorption in pepper and standard

Treatment	Pepper		Standard	
	30 DAA	45 DAA	30 DAA	45 DAA
T_1	16.96	36.15	83.04	63.85
T_2	64.01	87.24	35.99	12.75
T_3	62.61	74.34	37.38	25.66
T_4	75.97	38.47	24.03	61.53
T_5	37.49	92.10	62.51	7.90
T_6	5.91	71.52	94.09	28.48
T_7	40.61	22.07	59.39	77.93
T_8	61.80	59.27	38.19	40.73
T_9	23.20	44.38	76.80	55.62
T_{10}	6.70	22.87	93.30	77.13
T_{11}	25.97	16.25	74.03	83.75
T_{12}	70.29	60.66	29.71	39.34
T_{13}	17.09	46.95	82.91	53.05
T_{14}	4.63	6.03	95.37	93.97
T_{15}	13.68	58.60	86.32	44.40
T_{16}	21.71	21.36	78.29	78.64

DAA - Days after application of ^{32}P

were T_2 (*Ailanthus*), T_3 (arecanut), T_4 (*Artocarpus*), T_7 (*Caesalpinia*) and T_{12} (*Grevillea*).

At 45 days after application also *Moringa* recovered maximum ^{32}P (2546.83 cpm g^{-1}) which was significantly higher compared to all other treatments. Minimum recovery was noticed for *Azadirachta*. Other treatments where standards recovered low quantity of ^{32}P were T_1, T_2, T_3, T_6, T_7, T_8, T_{12} and T_{15}.

4.2.5 Percentage distribution of ^{32}P absorption in pepper and standard

Relative uptake of ^{32}P by pepper vines and the corresponding standard was computed by estimating the percentage distribution of ^{32}P absorbed in different pepper-standard combinations at 30 and 45 days after application. Pepper absorbed more ^{32}P than the corresponding standard in both periods when *Ailanthus*, arecanut, coconut and *Grevillea* were used as standards (Table 14).

When percentage distribution at 30 days after application was considered, pepper vines trailed on jack recovered the maximum ^{32}P (75.97%) followed by *Grevillea* (70.29%), *Ailanthus* (64.01%), arecanut (62.61%) and coconut (61.80%). Among the standards, *Moringa* (95.37%) followed by *Bombax* (94.09%), *Garuga* (93.30%), *Pajanelia* (86.32%), *Ailanthus* (83.04%), *Leucaena* (82.91%), *Thespesia* (78.29%), *Erythrina* (76.80%), *Gliricidia* (74.03%), neem (62.51%) and *Caesalpinia* (59.39%) recovered more ^{32}P than the pepper vine trailed on them.

At 45 days after application, recovery of ^{32}P by pepper was more than the corresponding standard when *Azadirachta* (92.1%), *Ailanthus* (87.24%), arecanut (74.34%), *Bombax* (71.52%), *Grevillea* (60.66%), coconut (59.27%), and *Pajanelia* (58.6%) were used as standards. Recovery of ^{32}P by standard was more than the pepper trailed on it in the following treatments where *Moringa* recovered the maximum ^{32}P applied (93.97%) followed by *Gliricidia* (83.75%), *Thespesia* (78.64%), *Caesalpinia* (77.93%), *Garuga* (77.13%), *Ailanthus* (63.85%), *Artocarpus* (61.53%), *Erythrina* (55.62%) and *Leucaena* (53.05%).

4.3 EXPERIMENT III

SHOOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD

4.3.1 Characters of pepper

4.3.1.1 Growth characters

4.3.1.1.1 Height of bearing column

There was significant variation in the height of bearing column of pepper vines trailed on different standards (Table 15). It was maximum when coconut (T_8) was used as the standard (7.83 m) followed by *Artocarpus* (T_4 - 6.67 m). Other standards which had pepper vines with taller bearing column were T_{12} (*Grevillea* - 6.62 m), T_5 (*Azadirachta* - 6.61 m), T_3 (Arecanut - 6.18 m), T_1 (*Acacia* - 5.98 m), T_2 (*Ailanthus* - 5.98 m) and T_{15} (*Pajanelia*- 5.81 m). Height of bearing column of pepper vine was lowest when *Caesalpinia sappan* was used as standard (2.01 m). Teak pole (T_{17}) had comparatively lower bearing column of pepper when used as the standard (3.92 m). Except for teak pole and *Caesalpinia*, all the treatments were statistically on par. Teak pole was on par with all the standards except coconut.

4.3.1.1.2 Spread at chest height

Pepper vines trailed on *Artocarpus* (T_4) was spread the most (131.67 cm) followed by coconut (123.00 cm), *Erythrina* (120.67 cm), *Gliricidia* (119.00 cm) and *Grevillea* (110.33 cm) which were statistically on par. T_7 (*Caesalpinia*) recorded the minimum spread of pepper vine (100.00 cm) followed by T_3 (arecanut - 101.33 cm) and T_{13} (*Leucaena* - 103.33 cm) (Table 15).

4.3.1.1.3 Number of laterals per 0.25 m^2

There was significant variation in the number of laterals of pepper vines per 0.25 m^2 with T_8 (coconut) recording the highest value (15.33) followed by T_2 (*Ailanthus* - 14.33), T_7 (*Caesalpinia* - 14.33) and T_1 (*Acacia* - 14.00) (Table 15). T_6, T_9, T_{11} and T_{13} were also statistically on par with T_8. Number of laterals was minimum

Table 15. Morphological characters of pepper vines trailed on different standards

Treatments	Height of bearing column (m)	Spread at chest height (cm)	No. of laterals per 0.25 m^2	No. of spikes per 0.25 m^2	Length of spike (cm)	No. of berries per spike	No. of pinheads per spike
T_1	5.98	109.33	14.00	22.94	15.43	61.30	29.67
T_2	5.98	111.67	14.33	20.33	15.70	49.30	22.00
T_3	6.18	101.33	10.33	20.67	16.70	49.30	15.00
T_4	6.67	131.67	11.33	13.00	17.10	59.00	11.00
T_5	6.61	104.00	11.00	18.33	16.17	59.67	11.67
T_6	4.94	106.00	13.00	18.40	17.20	53.33	21.00
T_7	2.01	100.00	14.33	14.23	16.80	59.33	24.00
T_8	7.83	123.00	15.33	18.67	17.13	76.33	17.67
T_9	5.41	120.67	12.33	18.67	15.90	59.67	17.00
T_{10}	4.76	105.33	11.33	18.00	16.13	66.33	16.33
T_{11}	4.12	119.00	11.67	16.67	15.30	51.67	11.33
T_{12}	6.62	110.33	10.00	10.67	16.57	63.67	9.67
T_{13}	4.24	103.33	12.33	21.00	15.67	64.33	20.67
T_{14}	4.54	106.67	9.33	14.67	17.07	56.67	13.00
T_{15}	5.81	102.00	8.67	15.00	16.47	68.33	14.67
T_{16}	4.68	111.00	11.00	19.00	16.13	64.67	11.00
T_{17}	3.92	110.33	9.67	19.00	16.93	70.00	9.00
Mean	5.36	111.39	11.77	18.12	16.38	61.35	16.16
CD (0.05)	3.81	16.77	3.72	4.77	1.05	NS	5.85

Contd.

Table 15. Continued

Treatment	Hundred berry weight (g)	Hundred berry volume (cc)	Spike compactness (No. cm^{-1})	Pedicel length (cm)
T_1	14.22	12.67	4.00	1.40
T_2	12.40	11.00	3.13	1.63
T_3	14.57	12.67	3.63	1.50
T_4	17.20	12.65	3.50	1.50
T_5	15.53	13.30	3.67	1.57
T_6	14.19	13.00	3.10	1.70
T_7	13.69	12.00	3.43	1.97
T_8	15.48	13.00	4.50	1.47
T_9	15.87	13.33	3.77	1.33
T_{10}	15.02	13.67	4.10	1.40
T_{11}	14.60	13.00	3.37	1.40
T_{12}	14.27	12.33	3.87	1.43
T_{13}	14.63	12.67	4.10	1.53
T_{14}	16.17	12.33	3.30	2.40
T_{15}	14.90	12.00	4.13	1.47
T_{16}	16.53	12.67	4.07	1.48
T_{17}	16.60	14.00	4.13	1.13
Mean CD (0.05)	15.05 1.84	12.73 NS	3.75 NS	1.55 0.45

when T_{15} (*Pajanelia*) was used as the standard (8.67) followed by T_{14} (*Moringa*) and T_{17} (teak pole) with 9.33 and 9.67 laterals per 0.25 m^2.

4.3.1.1.4 Number of spikes in 0.25 m^2 at chest height

Maximum number of spikes in 0.25 m^2 at chest height was recorded in pepper vines trailed on *Acacia* (T_1 - 22.94) followed by T_{13} (*Leucaena* - 21.00) (Table 15). Number of spikes was also higher in T_2 (*Ailanthus* - 20.33), T_3 (arecanut - 20.67), T_8 (coconut - 18.67), T_9 (*Erythrina*- 18.67), T_{16} (*Thespesia* - 19.00) and T_{17} (teak pole - 19.00). T_5 and T_6 also were on par with T_1. Minimum number of spikes was recorded in T_{12} (*Grevillea* - 10.67) followed by T_4 (*Artocarpus* - 13.00), T_{14} (*Moringa* - 14.67) and T_{15} (*Pajanelia*- 15.00).

4.3.1.1.5 Length of spike

Length of spike of pepper vines trailed on different standards ranged from 15.30 to 17.20 cm (Table 15). The variation among treatments was statistically significant. Maximum value was recorded in T_6 (*Bombax* - 17.20 cm) followed by T_8 (coconut - 17.13 cm), T_4 (*Artocarpus* - 17.10 cm) and T_{14} (*Moringa* - 17.07 cm). T_{11} (*Gliricidia)* recorded the minimum value of spike length of pepper trailed on it (15.3 cm). T_1 (*Acacia*), T_2 (*Ailanthus*), T_7 (*Caesalpinia*), T_9 (*Erythrina*) and T_{11} (G*liricidia*) were also inferior to T_6 (*Bombax*).

4.3.1.1.6 Number of berries per spike

There was no significant variation in the number of well-developed berries per spike among different treatments (Table 15). Maximum value was recorded in T_8 (coconut - 76.33) followed by T17 (teak pole-70.0), T_{15} (*Pajanelia*- 68.33) and T_{10} (*Garuga*-66.33). Minimum number of berries per spike was observed when *Ailanthus* was used as the standard (49.30).

4.3.1.1.7 Number of pinheads per spike

There was significant variation in the number of pinheads per spike among various treatments (Table 15). Minimum value was recorded in T_{17} (teak pole - 9.00) followed by T_{12} (*Grevillea* - 9.67). Number of pinheads per spike was also lower when jack (T_4 -11.00), *Azadirachta* (T_5 - 11.67), *Gliricidia* (T_{11} - 11.33), *Moringa* (T_{14} - 13.00), *Pajanelia* (T_{15} - 14.67) and *Thespesia* (T_{16} - 11.00) were used as standards which were statistically on par with T_{17}. T_1 (*Acacia* - 29.67) recorded the maximum value followed by T_7 (*Caesalpinia* - 24.0) and T_2 (*Ailanthus* - 22.00).

4.3.1.1.8 Hundred berry weight

Hundred berry weight of different treatments ranged from 12.40 to 17.2 g (Table 15). Maximum weight was recorded in T_4 (*Artocarpus* - 17.20 g) followed by T_{17} (teak pole - 16.60) and T_{16} (*Thespesia* - 16.53 g). T_5, T_8, T_9 and T_{14} were also on par with T_4. Minimum value was recorded for T_2 (*Ailanthus* - 12.40 g).

4.3.1.1.9 Hundred berry volume

There was no significant variation in the volume of hundred berries among different treatments (Table 15). T_{17} (teak pole) recorded the maximum value (14.00 cc) and T_2 (*Ailanthus*) the minimum (11.00 cc).

4.3.1.1.10 Spike compactness

Spike compactness varied from 3.10 to 4.50 no. cm^{-1} in different treatments (Table 15). Maximum value (4.50) was recorded when coconut (T_8) was used as the standard followed by T_{15} (C - 4.13) and T_{17} (teak pole - 4.13). Minimum value was recorded in T_6 (*Bombax* - 3.10 no. cm^{-1}) followed by T_2 (*Ailanthus* - 3.13).

4.3.1.1.11 Pedicel length

Different treatments varied significantly with respect to pedicel length (Table 15). Minimum value was recorded when teak pole was used as the standard (1.13 cm). Only T_2, T_6, T_7 and T_{14} showed significantly higher pedicel length compared to teak pole.

4.3.1.2 Yield characters

Average yield data for three consecutive years was recorded with ten plants per treatment.

4.3.1.2.1 Green berry yield

There was significant variation in the green berry yield of pepper vines trailed on different standards (Table 16). Maximum yield of 9.25 kg was obtained in pepper vines trailed on coconut (T_8), which was significantly superior to all other treatments. Higher yield was obtained in T_4 (*Artocarpus* - 7.14 kg), T_2 (*Ailanthus* - 6.83 kg) and T_{12} (*Grevillea* - 6.24) which were statistically on par. Minimum green berry yield was observed in T_{14} (*Moringa* - 2.81 kg) followed by T_3 (arecanut - 2.93 kg). Pepper vine trailed on the dead standard yielded 3.68 kg green berry per vine.

4.3.1.2.2 Dry recovery

Percentage of dry recovery varied from 29.40 to 34.30 per cent in different treatments (Table 16). Maximum dry recovery was recorded in T_8 (Coconut - 34.30per cent) followed by T_3 (arecanut - 34.00 per cent). T_1, T_2, T_{11} and T_{16} were on par with T_8. Minimum dry recovery was recorded in T_{13} (*Leucaena* - 29.40 per cent).

4.3.1.2.3 Dry berry yield

Maximum dry berry yield was recorded in T_8 (coconut - 3.17 kg/vine) as in the case of green berry yield (Table 16). Coconut was significantly superior to all other treatments. Minimum yield of 0.90 kg per vine was obtained in T_{14} (*Moringa*) followed by T_3 (arecanut - 1.00 kg/vine) and T_{13} (*Leucaena* - 1.03 kg/vine). T_6, T_7, T_9, T_{11}, T_{16} and T_{17} were on par with T_{14}. Among the live standards, T_1 (*Acacia* -1.35), T_2 (*Ailanthus* - 2.70 kg), T_4 (*Artocarpus* - 2.19 kg), T_5 (*Azadirachta* - 1.32 kg), T_{10} (*Garuga* - 1.59 kg), T_{12} (*Grevillea* - 1.79 kg) and T_{15} (*Pajanelia* - 1.32 kg) were other superior treatments with regard to dry yield of pepper vine.

Table 16. Yield attributes of black pepper trailed on different standards

Treatments	Green berry yield (kg/vine)	Driage (%)	Dry berry yield (kg/vine)
T_1	4.05	33.20	1.35
T_2	6.83	33.30	2.27
T_3	2.93	34.00	1.00
T_4	7.14	30.67	2.19
T_5	4.21	31.37	1.32
T_6	3.93	31.33	1.23
T_7	3.52	31.27	1.10
T_8	9.25	34.30	3.17
T_9	3.70	32.47	1.20
T_{10}	5.25	30.37	1.59
T_{11}	3.61	33.90	1.22
T_{12}	6.24	29.63	1.79
T_{13}	3.50	29.40	1.03
T_{14}	2.81	32.07	0.90
T_{15}	4.30	30.60	1.32
T_{16}	3.74	33.10	1.24
T_{17}	3.68	31.33	1.15
Mean	4.63	31.90	1.47
CD (0.05)	1.13	1.79	0.36

4.3.1.3 Quality attributes of black pepper

Essential oil, oleoresin and piperine contents of dry berries varied significantly in different treatments (Table 17).

4.3.1.3.1 Essential oil

Maximum essential oil content was obtained from berries of pepper vines trailed on *Garuga* (T_{10} - 2.85 per cent) followed by *Grevillea* (T_{12} - 2.69 per cent), which were on par. T_4 (*Artocarpus* - 2.60 per cent) and T_{11} (*Gliricidia* – 2.58 per cent) were on par with *Grevillea* (Table 17). Minimum oil content was obtained from T_6 (*Bombax* - 1.70) followed by T_{13} (*Leucaena* - 1.71 per cent). Other treatments which had higher oil content were T_1 (2.35 per cent), T_2 (2.4 per cent), T_5 (2.35 per cent), T_9 (2.48 per cent), T_{14} (2.42 per cent), T_{16} (2.42 per cent) and T_{17} (2.35 per cent) which were on par with T_{11}.

4.3.1.3.2 Oleoresin

Oleoresin content of different treatments varied from 9.36 to 13.43 per cent (Table 17). Maximum content of oleoresin was recorded when *Leucaena* (T_{13} - 13.43) was used as the standard for pepper. Other treatments which gave better recovery of oleoresin were T_{12} (12.92 per cent), T_{17} (12.89 per cent), T_5 (12.66 per cent), T_6 (12.22 per cent), T_{15} (12.15 per cent) and T_3 (11.89 per cent) which were on par. Minimum oleoresin content was obtained in T_{11} (9.36 per cent) followed by T_{10} (10.81 per cent) and T_8 which were on par.

4.3.1.3.3 Piperine

Different treatments varied significantly with respect to piperine content (Table 17). T_{15} (*Pajanelia*) recorded maximum value of 6.31 per cent followed by T_4 (*Artocarpus* - 6.25 per cent). Minimum content was observed when arecanut (T_3) was used as the standard (4.48 per cent). Other treatments which yielded comparatively higher amount of piperine were T_5 (*Azadirachta* - 6.03 per cent), T_1 (*Ailanthus* - 6.02

Table 17. Quality attributes of black pepper

Treatments	Oil (%)	Oleoresin (%)	Piperine (%)
T_1	2.35	11.22	6.02
T_2	2.40	11.14	4.51
T_3	1.79	11.89	4.48
T_4	2.60	11.25	6.25
T_5	2.35	12.66	6.03
T_6	1.70	12.22	5.45
T_7	1.83	11.60	5.89
T_8	1.77	10.88	5.70
T_9	2.48	11.00	5.11
T_{10}	2.85	10.81	5.95
T_{11}	2.58	9.36	5.47
T_{12}	2.69	12.92	5.75
T_{13}	1.71	13.43	5.34
T_{14}	2.42	11.12	5.25
T_{15}	1.79	12.18	6.31
T_{16}	2.42	11.00	4.78
T_{17}	2.35	12.89	5.06
Mean CD (0.05)	2.24 0.23	11.68 1.57	5.49 0.73

per cent), T_7 (*Caesalpinia* - 5.89), T_8 (Coconut - 5.70), T_{10} (*Garuga* - 5.95), T_{11} (*Gliricidia* - 5.47) and T_{12} (*Grevillea* - 5.75) which were on par with T_{15}.

4.3.1.4 Nutrient content of leaves of pepper vine trailed on different standards

There was significant difference for the nutrient content of leaves of pepper trailed on different standards except for P, Cu and Zn.

4.3.1.4.1 Nitrogen

There was significant variation in all the nutrient content of pepper vine trailed on different standards except for P, Cu and Zn (Table 18). Maximum nitrogen content was recorded in T_9 (*Erythrina*- 2.33 per cent) followed by T_{15} (*Pajanelia*- 2.08 per cent) and T_{12} (*Grevillea* - 1.91 per cent) which were on par. Minimum nitrogen content was observed in T_3 (arecanut - 1.08) followed by T_8 (coconut - 1.28 per cent). T_1, T_5, T_{16} and T_{17} were also on par with arecanut.

4.3.1.4.2 Phosphorus

Phosphorus content of pepper leaves varied from 0.10 to 0.46 percent in different treatments (Table 18). Maximum content was noticed in T_{10} (*Garuga* - 0.46%) followed by T_{14} (*Moringa* - 0.17) and T_{15} (*Pajanelia*- 0.17%). Minimum phosphorus content was observed in T_9 (*Erythrina*- 0.10 per cent) followed by T_3 (arecanut), T_6 (*Bombax*) and T_8 (coconut) all having 0.11 per cent of phosphorus in the leaves of pepper vines.

4.3.1.4.3 Potassium

There was significant variation in the potassium content of pepper leaves in various treatments (Table 18). Maximum content was recorded in T_2 (*Ailanthus*) and T_5 (*Azadirachta*) both having 2.63 per cent of potassium followed by T_{11} (*Gliricidia* - 2.53 per cent) and T_{12} (*Grevillea* - 2.43 per cent). T_3, T_4, T_{13} and T_{15} were also on par with T_2. Minimum potassium content was observed in T_{10} (*Garuga* - 1.10 per cent) followed by T_{17} (teak pole - 1.36) and T_6 (*Bombax* - 1.40 per cent). T_1, T_8 and T_{16} also had a significantly lower content of potassium.

Table 18. Nutrient content of leaves of pepper trailed on different standards

Treat-ment	N %	P %	K %	Na %	Ca %	Mg %	Fe mg kg^{-1}	Mn mg kg^{-1}	Cu mg kg^{-1}	Zn mg kg^{-1}
T_1	1.48	0.12	1.53	0.15	0.84	0.84	241.67	483.33	3.33	10.00
T_2	1.63	0.15	2.63	0.15	0.90	0.17	216.67	391.67	11.67	7.50
T_3	1.08	0.11	2.07	0.11	0.75	0.15	150.00	350.00	7.50	9.17
T_4	1.73	0.13	2.23	0.16	0.75	0.12	216.67	491.67	9.17	10.00
T_5	1.47	0.13	2.63	0.31	0.49	0.21	250.00	491.82	10.83	7.50
T_6	1.87	0.11	1.40	0.27	0.73	0.13	350.00	550.00	9.17	5.00
T_7	1.75	0.12	1.80	0.25	0.80	0.20	368.33	616.67	9.16	10.00
T_8	1.28	0.11	1.47	0.22	0.72	0.15	158.33	666.67	7.50	1.17
T_9	2.33	0.10	1.87	0.37	0.83	0.15	216.67	475.00	9.17	6.67
T_{10}	1.75	0.46	1.10	0.25	0.83	0.14	150.00	425.00	6.33	8.33
T_{11}	1.63	0.13	2.53	0.33	0.79	0.12	225.00	525.00	10.83	15.00
T_{12}	1.91	0.12	2.43	0.23	0.71	0.17	216.67	600.00	12.50	9.17
T_{13}	1.54	0.15	2.30	0.35	0.69	0.20	250.00	775.00	11.67	12.50
T_{14}	1.61	0.17	1.77	0.20	0.62	0.15	183.33	525.00	8.33	8.63
T_{15}	2.08	0.17	2.07	0.30	1.24	0.23	233.33	400.00	10.00	8.33
T_{16}	1.33	0.15	1.57	0.35	0.96	0.17	200.00	491.67	2.50	9.17
T_{17}	1.53	0.14	1.30	0.35	0.60	0.13	208.33	108.33	10.00	10.00
Mean	0.90	0.15	1.47	0.25	0.50	0.50	135.17	400.00	8.80	8.71
CD(0.05)	0.45	NS	0.63	0.11	0.28	0.60	85.77	165.00	NS	NS

4.3.1.4.4 Sodium

Sodium content of pepper leaves varied significantly in different treatments (Table 18). Maximum value was recorded in T_9 (*Erythrina*- 0.37 per cent) and minimum value in T_3 (arecanut - 0.11 per cent). Treatments having higher content of sodium were T_5 (*Azadirachta* - 0.27), T_6 (*Bombax* - 0.27), T_7 (*Caesalpinia* - 0.25), T_8 (coconut - 0.22), T_{11} (*Gliricidia* - 0.33), T_{13} (*Leucaena* - 0.35 per cent), T_{15} (*Pajanelia*- 0.30), T_{16} (*Thespesia* - 0.35 per cent) and T_{17} (teak pole - 0.35 per cent), which were on par with T_9. T_1, T_2, T_4, T_8 and T_{14} had low content of sodium, which was on par with T_3.

4.3.1.4.5 Calcium

There was significant variation in the calcium content of pepper leaves in different treatments (Table 18). It was maximum in T_{15} (*Pajanelia*- 1.24 per cent) which was on par with T_5 and minimum in T_5 (*Azadirachta* - 0.49 per cent). T_6, T_8, T_{12}. T_{13}, T_{14}, T_{16} and T_{17} were on par with T_5.

4.3.1.4.6 Magnesium

Magnesium content of pepper leaves of different treatments varied from 0.12 to 0.84 per cent (Table 18). Maximum content was observed in T_1 (*Acacia* - 0.84 per cent) and minimum in T_4 and T_{11} (0.12 per cent). All other treatments were on par with T_4.

4.3.1.4.7 Iron

Iron content of pepper leaves in different treatments varied from 150.00 to 368.33 mg kg^{-1} (Table 18). T_7 (*Caesalpinia*) recorded the maximum content of iron (368.33 mg kg^{-1}) followed by T_6 (*Bombax* - 350.00 mg kg^{-1}) which were on par. T_3 (arecanut) and T_{10} (*Garuga*) had the minimum iron content both having 150.00 mg kg^{-1} in the pepper leaves analysed.

4.3.1.4.8 Manganese

Manganese content was highest in the pepper leaves of vines trailed on *Leucaena* (T_{13} - 775.00 mg kg^{-1}) (Table 18). In the leaf samples, comparatively higher manganese content was observed in T_8 (coconut - 666.67 mg kg^{-1}) followed by T_7 (*Caesalpinia* - 616.67 mg kg^{-1}), which were on par with T_{13}. Minimum manganese content was observed in T_{17}. All other treatments were significantly superior to T_{17}.

4.3.1.4.9 Copper

There was no significant variation in the copper content of pepper leaves in various treatments (Table 18). Maximum content was observed in T_{12} (*Grevillea* - 12.50 mg kg^{-1}) and minimum in T_{16} (*Thespesia* - 2.50 mg kg^{-1}).

4.3.1.4.10 Zinc

Zinc content was maximum in pepper leaves when the standard used was *Gliricidia* (T_{11}-15.00 mg kg^{-1}) followed by *Leucaena* (T_{13} - 12.50 mg kg^{-1}) (Table 18). Minimum content was observed in T_8 (coconut-1.17 mg kg^{-1}) followed by T_6 (*Bombax* - 5.00 mg kg^{-1}). Other treatments with comparatively higher manganese content were T_1 (*Ailanthus*), T_4 (*Artocarpus*), T_7 (*Caesalpinia*) and T_{17} (teak pole), all containing 10.00 mg kg^{-1} of zinc in the pepper leaves trailed.

4.3.1.5 Foliar nutrient ratios of pepper

4.3.1.5.1 N/P

Significant variation was observed between the various treatments in the foliar nutrient ratio of N/P (Table 19). Highest ratio was recorded in T_9 (*Erythrina*-24.87) followed by T_{12} (*Grevillea* - 17.19) and T_6 (*Bombax* - 17.18). Lowest value was recorded in T_{16} (*Thespesia* - 9.31). T_9 was statistically superior to all other treatments. Except T_6, T_9, and T_{12}, all the treatments were on par.

Table 19. Foliar nutrient ratios of pepper

Treatment	N/P	N/K	P/K	P/Fe+Mn	K/Ca+Mg+Fe+Mn
T_1	11.97	1.48	0.12	1.71	0.87
T_2	11.18	0.62	0.06	2.45	1.93
T_3	9.71	0.53	0.05	2.34	1.72
T_4	11.49	0.77	0.07	2.13	1.43
T_5	11.63	0.56	0.05	1.82	1.64
T_6	17.18	1.67	0.09	1.31	1.48
T_7	14.23	0.98	0.07	2.46	1.69
T_8	12.26	0.87	0.07	1.35	1.55
T_9	24.87	1.22	0.06	1.39	1.78
T_{10}	14.19	1.62	0.11	2.10	1.06
T_{11}	12.94	0.66	0.05	1.70	2.22
T_{12}	17.19	0.79	0.05	1.60	2.54
T_{13}	11.83	0.67	0.06	1.28	2.02
T_{14}	9.76	0.99	0.10	2.39	1.59
T_{15}	12.16	1.05	0.08	2.77	1.45
T_{16}	9.31	0.86	0.10	2.25	1.37
T_{17}	11.07	1.17	0.10	3.59	1.50
Mean CD (0.05)	13.12 5.52	0.97 NS	0.08 0.06	2.04 1.12	1.64 NS

4.3.1.5.2 N/K

All the treatments were statistically on par regarding N/K ratio (Table 19). Highest value of 1.67 was recorded in T_6 (*Bombax*) and lowest value of 0.53 in T_3 (arecanut).

4.3.1.5.3 P/K

There was significant variation observed in the P/K ratio of pepper leaves between various treatments (Table 19). T_1 (*Acacia*) recorded the maximum value of 0.12. All the treatments except T_3, T_5 and T_{11} were on par with T_1.

4.3.1.5.4 P/Fe+Mn

When the variation in foliar nutrient ratio of P/Fe+Mn was analysed in pepper between different treatments it was noticed that, the ratio was highest in pepper leaves when the standard used was teak pole (T_{17}) (Table 19). T_{15} was on par with T_{17}. T_{13} (*Leucaena*) had the minimum value of 1.28 in the pepper leaves.

4.3.1.5.5 K/Ca+Mg+Fe+Mn

The foliar nutrient ratio, K/Ca+Mg+Fe+Mn varied from 0.87 to 2.54 in the pepper leaves of various treatments (Table 19). T_1 (*Ailanthus*) recorded the minimum value (0.87) and T_{12} (*Grevillea*) recorded the maximum value (2.54). The variation was not statistically significant.

4.3.2 Characters of standard

4.3.2.1 Nature of bark

Nature of bark surface of all the standards was observed in the field. Important bark characters of different standards are given in table 20.

4.3.2.2 Physiological stages (flushing, flowering, defoliation etc.) of standards

Observations of period of flushing, flowering and defoliation of different standards were taken regularly (Table 21).

Table 20. Bark characters of the standard

Standard	Bark characters
Acacia mangium	Dark brown, thick, rough and furrowed longitudinally
Ailanthus triphysa	Grey, thick, rough and often with reddish grains of resin
Areca catechu	Smooth when young and rough when mature
Artocarpus heterophyllus	Dark brown, rough and warty
Azadirachta indica	Dark grey, rough with longitudinal and oblique furrows
Bombax malabaricum	Rough with vertical cracks and covered with stout hard prickles
Caesalpinia sappan	Rough and thorny
Cocos nucifera	Light brown to greyish and rough
Erythrina indica	Rough, yellowish and shining with dark coloured conical prickles
Garuga pinnata	Whitish and thinly fissured
Grevillea robusta	Brown and rough
Leucaena leucocephala	Brownish grey and smooth
Moringa oleifera	Thick, corky, rough and grey with longitudinal cracks
Pajanelia longifolia	Brown, rough and fissured
Thespesia populnea	Grey to brown and rough

Table 21. Physiological growth stages of standards

Sl. No.	Standard	Vegetative phase			Reproductive phase	
		Defoliation	Flushing	Active vegetative phase	Flowering	Fruit set and maturity
1	*Acacia mangium*	-	Oct-Dec	May-Sept	Oct-Jan	Jan-March
2	*Ailanthus triphysa*	-	Jan-March	April-Nov	Feb-March	-
3	Arecanut	Throughout the year				
4	*Artocarpus heterophyllus*	-	April-May	May-Sept	Oct-Feb	Nov-May
5	*Azadirachta indica*	Nov-Dec	Jan-March	May-Oct	Jan-April	Feb-May
6	*Bombax malabaricum*	Oct-Jan	Jan-Feb	May-Oct	Jan-March	
7	*Caesalpinia sappan*	-	July-Oct	June-Sept	Sept-March	Dec-June
8	Coconut	Throughout the year				
9	*Erythrina indica*	Nov-Feb	Feb-April	June-Sept	March-May	-
10	*Garuga pinnata*	Oct-Jan	Jan-Feb	May-Sept	Sept-Oct	Oct-April
11	*Gliricidia sepium*	-	April-June	June-Oct	Jan-April	March-May
12	*Grevillea robusta*	-	May-June	June-Oct	-	-
13	*Leucaena leucocephala*	-	April-June	June-Sept	July-Aug	Aug-Dec
14	*Moringa oleifera*	-	Sept-Nov	July-Sept	Nov-March	Dec-May
15	*Pajanelia longifolia*	Nov-Feb	Jan-March	June-Sept	Jan-March	Feb-May
16	*Thespesia populnea*	-	Dec-Feb	June-Oct	Throughout the year	

1. ***Acacia mangium***: After the onset of southwest monsoon, the trees remained in the active vegetative phase till September. The tree started flowering by October which extended up to January. Flowers matured and fruits set by January-March.

2. ***Ailanthus tryphysa***: *Ailanthus* is an ever green tree which produces extensive foliage after rainy season till November. The growth rate declined during dry months and flushing started by January. Formation of drooping panicle initiated soon after flushing and developed by February. Flowering continued till March. No fruit set was observed in the field.

3. ***Areca catechu***: In arecanut, production and development of flowers and nuts is a year round process without any specific season for vegetative and reproductive phase. However, the peak harvesting season was during December-January.

4. ***Artocarpus heterophyllus***: Jack has a wide spread canopy throughout the year. After the onset of southwest monsoon, new vegetative buds developed and the tree remained in the active vegetative phase till September with profuse branching. Flowering started by October and extended up to February-March. Fruit development and maturity period extended from November to May. Number of fruits produced varied among different accessions.

5. ***Azadirachta indica***: *Azadirachta* is a deciduous tree which drops off its leaves by November. Flushing started by second week of January. Flowering extended from January to April. Fruit set and development occurred during the months of February-May. The tree remained in the vegetative phase from May to October.

6. ***Bombax malabaricum***: *Bombax* is also a deciduous tree. Extensive defoliation was started by October and remained without leaves till January. After January, flower initiation occurred and large pink flowers were formed. Flowering extended up to the end of March. Fruit set and development was not observed during the experimental period.

7. ***Caesalpinia sappan***: *Caesalpinia* remained in the active vegetative phase from June to September. Flowering panicle formation started by September. Fruit set and

development followed flowering and extended up to March. Pods at various stages of development could be seen from December to June. Mature pods dehisced and the fallen seeds remained dormant till the receipt of pre-monsoon showers.

8. *Cocos nucifera*: Vegetative and reproductive phase cannot be demarcated in coconut as flower and nut production occurs throughout the year.

9. *Erythrina indica*: *Erythrina* is a deciduous tree which drops off leaves during dry months from November to February. Flushing started by February; flowering was observed from second fortnight of March and extended up to May. The plant remained in the active vegetative growth phase from June to September.

10. *Garuga pinnata*: In *Garuga*, defoliation started by October and became extensive by December. Flowering was seen by September-October and fruits developed and matured by April. Only fruits and very few leaves could be observed on the tree from December to January. Flushing started by January and the plant started producing extensive foliage at the onset of southwest monsoon.

11. *Gliricidia sepium*: *Gliricidia* remained in the active vegetative growth phase after the receipt of southwest monsoon till October. Flowering started by last week of January and extended up to April. Purple flowers could be seen in clusters on most of the branches. Fruit set and maturity was observed during the months of March, April and May.

12. *Grevillea robusta*: *Grevillea* is an evergreen tree which remained in the vegetative phase throughout the experimental period. New flushes were seen to develop during most parts of the year. Flowering was not observed in the experimental field.

13. *Leucaena leucocephala*: *Leucaena* is also an evergreen tree which started flowering by July-August. Pod set and development occurred till December. Mature pods dehisced and small seeds remained dormant in the soil till the receipt of pre-monsoon showers as in the case of *Caesalpinia sappan.*

14. *Moringa oleifera*: In *Moringa*, after the active vegetative growth period from June to October, leaves started falling not leading to complete defoliation. Flowering started by November and extended till February-March. Fruit set and development followed flowering and mature fruits could be observed till May. Thereafter plant entered into vegetative phase and started producing extensive foliage at the onset of southwest monsoon.

15. *Pajanelia longifolia*: *Pajanelia* underwent complete defoliation during dry months from November-December to February. Flowering started by second fortnight of January and extended till March. Pinkish brown panicles bearing beautiful pink flowers could be observed. Fruit set and development occurred from February to May.

16. *Thespesia populnea*: *Thespesia* is an evergreen tree which remained in the active vegetative phase from June to October. During most parts of the year, new flushes and leaves developed without extensive leaf fall. No flowering of the tree could be observed during the experimental period.

4.3.2.3 Light infiltration through standard

Various standards depending on the height and spread of the canopy infiltered varying quantum of light to the canopy of pepper trailed on them (Table 22). Maximum light infiltration was recorded in the month of May (36.62 per cent) followed by March (34.15 per cent) and April (31.47 per cent). Months of January, June, July and August recorded comparatively lower intensity of light with 26.12 per cent, 20.65 per cent, 26.86 per cent and 25.63 per cent respectively.

Among the different standards, pepper vines trailed on teak pole (T_{17}), the dead standard received maximum sunlight of 66.17 per cent. Among the different live standards, *Bombax* (T_6) infiltered maximum sunlight through its canopy (35.07 per cent) followed by arecanut (T_3 - 30.80 per cent) and *Pajanelia* (T_{15} - 30.40 per cent). Standards which had poor light infiltration were T_7 (*Caesalpinia* - 11.50 per cent) having the minimum followed by T_{11} (*Gliricidia* - 19.3 per cent) and T_4 (*Artocarpus* - 19.8 per cent).

Table 22. Percentage of light infiltration through different standards

Treatments	Jan	Feb	Mar	Apr	May	June	July
T_1	18.63	31.77	36.97	32.00	21.63	29.10	26.13
T_2	24.57	29.30	32.53	32.20	23.73	27.17	26.03
T_3	35.30	33.50	36.27	34.20	32.23	31.70	26.87
T_4	12.53	19.17	27.10	25.87	18.13	19.10	19.47
T_5	27.70	29.33	42.87	26.17	23.60	31.07	23.40
T_6	24.43	33.70	31.87	27.01	25.57	31.77	26.57
T_7	10.53	12.33	15.00	12.80	18.17	13.03	10.87
T_8	24.20	26.63	36.1	26.37	28.77	25.57	25.00
T_9	19.63	38.33	35.83	31.90	23.40	35.57	25.17
T_{10}	17.50	31.56	33.60	28.03	32.10	26.40	26.87
T_{11}	25.43	19.53	24.70	21.00	38.00	18.10	21.20
T_{12}	21.87	34.77	29.57	27.03	19.73	34.87	22.73
T_{13}	21.87	22.70	24.57	26.27	22.40	24.10	25.63
T_{14}	28.20	30.43	31.83	35.37	24.53	32.27	17.30
T_{15}	19.20	44.00	35.90	42.13	20.77	42.07	34.03
T_{16}	31.53	31.07	37.23	33.07	24.00	32.57	27.50
T_{17}	74.57	54.65	68.63	73.53	74.97	49.50	71.87
Mean	29.63	26.33	37.88	38.04	39.04	42.26	33.06
CD (0.05)	2.92	4.77	4.74	3.47	5.03	3.41	4.35

Contd.

Table 22. Continued

Treatments	Aug	Sep	Oct	Nov	Dec	Mean
T_1	25.30	32.77	28.60	16.67	19.67	27.44
T_2	22.07	22.37	25.37	24.00	27.33	26.39
T_3	24.80	32.57	30.17	24.00	28.23	30.80
T_4	16.37	18.63	25.30	16.00	20.00	19.80
T_5	21.77	19.83	17.67	29.67	32.00	27.10
T_6	42.20	54.90	52.20	34.33	36.33	35.07
T_7	6.77	10.20	8.07	9.50	10.50	11.50
T_8	27.93	34.17	32.83	25.00	27.30	28.30
T_9	20.87	24.40	23.03	24.00	26.60	27.42
T_{10}	12.10	18.20	20.40	29.67	29.67	24.18
T_{11}	12.27	16.53	13.03	13.17	18.33	19.30
T_{12}	34.67	32.70	32.97	30.67	31.00	29.92
T_{13}	22.27	30.53	23.50	26.33	28.00	24.85
T_{14}	27.60	28.90	31.20	28.65	30.67	28.90
T_{15}	23.50	24.63	20.33	30.13	28.00	30.40
T_{16}	22.20	22.80	25.07	27.00	28.33	28.53
T_{17}	62.97	62.90	69.00	72.67	58.00	66.17
Mean CD (0.05)	25.63 3.30	28.65 3.67	28.20 4.15	27.06 10.10	28.25 8.38	

4.3.2.4 Weight of loppings of standard

Loppings of different standards were weighed freshly in the field as well as after drying in the oven (Table 23).

4.3.2.4.1 Fresh weight

Fresh weight was maximum for coconut (118.4 kg/palm/yr) considering total leaf fall of the palm for one year. This was followed by arecanut (20.1 kg), jack (15.43 kg), *Gliricidia* (15.2 kg) and *Ailanthus* (11.87 kg).

4.3.2.4.2 Dry weight

Dry weight of loppings was maximum for coconut (35.03 kg/palm/year) followed by arecanut (5.7 kg), jack (4.66 kg), *Ailanthus* (3.97 kg) and *Garuga* (3.14 kg).

4.3.2.5 Nutrient content of loppings of standard

4.3.2.5.1 Nitrogen

Loppings of *Leucaena* (T_{13}) had the maximum nitrogen content of 3.45 per cent followed by T_{11} (*Gliricidia* - 2.87 per cent) which were on par. (Table 24). Minimum nitrogen content was observed in T_3 (arecanut - 0.83 per cent) followed by T_{15} (*Pajanelia*- 1.45 per cent) and T_{10} (*Garuga* - 1.50 per cent). Other standards which had high content of nitrogen were T_1 (2.31), T_7 (2.37) and T_{14} (2.50) which were statistically on par with T_{13}.

4.3.2.5.2 Phosphorus

Phosphorus content of loppings of standard ranged from 0.06 to 0.40 per cent in various treatments (Table 24). Minimum phosphorus content was observed in coconut leaf samples (T_8 - 0.06 per cent) and maximum in *Moringa* (T_{14} - 0.40 per cent). Standards with significantly lower content of P were T_9 (*Erythrina*- 0.12) and T_{12} (*Grevillea* 0.07) besides coconut.

Table 23. Weight of loppings of standards (kg/plant)

Treatment	Standard	Fresh weight	Dry weight
T_1	*Acacia mangium*	6.44	1.61
T_2	*Ailanthus triphysa*	11.87	3.97
T_3	*Areca catechu*	20.10	5.70
T_4	*Artocarpus heterophyllus*	15.43	4.66
T_5	*Azadirachta indica*	2.60	0.95
T_6	*Bombax malabaricum*	4.37	1.05
T_7	*Caesalpinia sappan*	3.28	0.98
T_8	*Cocos nucifera*	118.40	35.03
T_9	*Erythrina indica*	5.93	0.88
T_{10}	*Garuga pinnata*	9.27	3.14
T_{11}	*Gliricidia sepium*	15.20	3.04
T_{12}	*Grevillea robusta*	2.97	1.38
T_{13}	*Leucaena leucocephala*	7.53	1.63
T_{14}	*Moringa oleifera*	1.90	0.30
T_{15}	*Pajanelia longifolia*	5.60	1.06
T_{16}	*Thespesia populnea*	3.93	0.79

Table 24. Nutrient content of loppings of standard

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
T_1	2.31	0.18	1.35	0.63	0.19	0.14	308.33	133.33	14.17	10.83
T_2	1.73	0.13	1.60	0.71	0.22	0.12	150.00	283.33	2.50	9.17
T_3	0.83	0.26	0.70	0.81	0.20	0.12	275.00	433.33	4.17	10.83
T_4	1.82	0.17	1.50	0.85	0.20	0.07	175.00	316.67	5.00	5.00
T_5	2.16	0.17	1.80	0.73	0.19	0.19	208.33	133.33	7.50	10.00
T_6	1.84	0.19	1.77	0.67	0.22	0.22	250.00	66.67	5.00	15.83
T_7	2.37	0.17	0.90	0.84	0.16	0.20	333.33	100.00	16.67	12.50
T_8	1.53	0.06	0.25	0.62	0.23	0.20	200.00	766.67	0.83	14.17
T_9	2.02	0.12	1.30	0.74	0.17	0.16	208.33	175.00	8.33	24.17
T_{10}	1.50	0.15	1.45	0.75	0.16	0.20	158.33	66.67	7.50	6.67
T_{11}	2.87	0.21	1.92	0.74	0.27	0.27	250.00	125.00	6.67	6.17
T_{12}	1.54	0.07	1.07	0.63	0.20	0.26	175.00	766.67	4.17	10.00
T_{13}	3.45	0.17	1.63	0.88	0.18	0.20	308.33	91.67	15.83	15.00
T_{14}	2.50	0.40	1.68	0.75	0.23	0.25	241.67	291.67	8.33	8.33
T_{15}	1.45	0.23	1.57	1.20	0.27	0.25	333.33	241.67	4.17	27.50
T_{16}	1.82	0.21	1.97	0.98	0.16	0.45	150.00	375.00	14.17	20.00
Mean	1.98	0.19	1.40	0.78	0.20	0.21	232.81	272.92	7.81	12.88
CD(0.05)	0.74	0.06	0.82	NS	0.06	0.14	NS	225.80	4.83	7.80

4.3.2.5.3 Potassium

Potassium content of leaf samples of various standards ranged from 0.25 to 1.97 per cent (Table 24). Minimum content of 0.25 per cent was recorded in T_8. Maximum potassium content was recorded in *Thespesia* (T_{16} - 1.97 per cent). All the treatments except T_3, T_7, T_8 and T_{12} were on par with T_{16}.

4.3.2.5.4 Calcium

There was no significant variation in the calcium content of different standards (Table 24). Minimum calcium content of 0.62 per cent was recorded in coconut leaves. *Pajanelia* (T_{15}) recorded the maximum content of calcium (1.20 per cent) followed by *Thespesia* (T_{16} - 0.98 per cent).

4.3.2.5.5 Magnesium

Magnesium content of leaf samples of different standards differed significantly among various treatments (Table 24). It varied from 0.16 to 0.27 per cent. T_7 (*Caesalpinia*), T_{10} (*Garuga*) and T_{16} (*Thespesia*) had 0.16 per cent of magnesium. T_{11} (*Gliricidia*) and T_{15} (*Pajanelia*) had 0.27 per cent of magnesium. Magnesium content of T_2, T_6, T_8 and T_{14} was on par with T_{15} and T_{11}.

4.3.2.5.6 Sodium

Maximum content of sodium was recorded in *Thespesia* (T_{16} - 0.45 per cent) (Table 24). All other treatments had significantly lower sodium content. Treatments which had higher content of sodium were T_{11} (*Gliricidia* - 0.27 per cent), T_{12} (*Grevillea* - 0.26 per cent), T_{14} (*Moringa* - 0.25 per cent), T_{15} (*Pajanelia*- 0.25 per cent), T_6 (*Bombax* - 0.22 per cent). Minimum sodium content was observed in *Artocarpus* (T_4 - 0.07 per cent).

4.3.2.5.7 Iron

Maximum iron content was observed in *Caesalpinia* (T_7 - 333.33 mg kg^{-1}) as in the case of iron content of pepper leaf samples and T_{15} (*Pajanelia*- 333.33 mg kg^{-1}) (Table 24). Minimum iron content was observed in *Ailanthus* (T_2 - 150.00 mg

kg^{-1}) and *Thespesia* (T_{16} - 150.00 mg kg^{-1}). The variation, however, was not statistically significant.

4.3.2.5.8 Manganese

Leaf manganese content of various standards varied from 66.67 mg kg^{-1} to 766.67 mg kg^{-1}. Maximum manganese content was recorded in *Grevillea* (T_{12} - 766.67 mg kg^{-1}) and coconut (T_8 - 766.67 mg kg^{-1}). All other treatments contained significantly lower content of manganese. Minimum manganese content was recorded in *Bombax* (T_6 - 66.67) and *Garuga* (T_{10} - 66.67 mg kg^{-1}) (Table 24).

4.3.2.5.9 Copper

There was significant variation in the copper content of various standards ranging from 0.83 to 16.67 mg kg^{-1} (Table 24). Maximum copper content was observed in the leaves of *Caesalpinia* (T_7 - 16.67 mg kg^{-1}) followed by *Leucaena* (T_{13} - 15.83 mg kg^{-1}), *Ailanthus* (T_1 - 14.17 mg kg^{-1}) and *Thespesia* (T_{16} - 14.17 mg kg^{-1}) which were on par with T_7. Minimum copper content was observed in coconut (T_8 - 0.83 mg kg^{-1}). T_2, T_3, T_4, T_{12} and T_{15} were on par with T_8.

4.3.2.5.10 Zinc

Zinc content in the loppings of various standards ranged from 5.0 to 27.50 mg kg^{-1} (Table 24). Maximum zinc content was observed in *Pajanelia* (T_{15} - 27.50 mg kg^{-1}) followed by T_9 (*Erythrina*- 24.17 mg kg^{-1}) and T_{16} (20.00 mg kg^{-1}) which were on par. Minimum zinc content was observed in *Artocarpus* (T_4 - 5.0 mg kg^{-1}) followed by Glyricidia (T_{11} - 6.17 mg kg^{-1}) and *Garuga* (T_{10} - 6.67 mg kg^{-1}). T_1, T_2, T_3, T_5, T_7, T_{10}, T_{11}, T_{12} and T_{14} were on par with T_4.

4.3.2.6 Foliar nutrient ratios of standard

4.3.2.6.1 N/P

Significant variation was observed in the N/P ratio of foliar samples of different standards analysed (Table 25). A maximum value of 27.37 was recorded in coconut leaves followed by *Grevillea* (T_{12} - 23.73) which was on par with T_8. T_{13} was

Table 25. Foliar nutrient ratios of standards

Treatment	N/P	N/K	P/K	P/Fe+Mn	K/Ca+Mg+Fe+Mn
T_1	12.83	2.43	0.18	5.23	1.64
T_2	13.06	1.19	0.09	3.74	1.66
T_3	3.32	1.20	0.38	3.71	0.71
T_4	10.70	1.21	0.11	3.53	1.13
T_5	13.02	1.20	0.09	4.96	1.89
T_6	9.70	1.04	0.11	6.32	1.51
T_7	14.09	2.71	0.20	4.79	0.99
T_8	27.37	6.07	0.23	0.61	0.27
T_9	16.92	1.57	0.09	3.21	1.38
T_{10}	10.53	1.03	0.11	6.88	1.54
T_{11}	13.56	1.87	0.15	5.69	1.77
T_{12}	23.73	1.55	0.07	0.79	1.17
T_{13}	20.97	2.18	0.10	4.37	1.57
T_{14}	6.37	1.52	0.26	7.79	1.44
T_{15}	6.64	1.01	0.15	4.09	1.05
T_{16}	8.73	0.93	0.12	5.50	1.78
Mean CD (0.05)	13.22 6.25	1.79 1.00	0.15 0.09	4.45 3.06	1.34 NS

on par with T_{12}. Minimum value of 3.32 was recorded in arecanut leaves. Other standards which possessed higher N/P ratio were T_1 (*Acacia* - 12.83), T_2 (*Ailanthus*), T_4 (*Artocarpus* - 10.70), T_5 (*Azadirachta* - 13.02), T_7 (*Caesalpinia* - 14.09), T_9 (*Erythrina*- 16.92), T_{10} (*Garuga* - 10.53) and T_{11} (*Leucaena* - 13.56).

4.3.2.6.2 N/K

As in the case of N/P ratio, N/K ratio was also recorded highest in coconut leaves (T_8 - 6.07) (Table 25). It was significantly superior to all other treatments. The lowest value of 0.93 was recorded in T_{16} (*Thespesia*). All other treatments except T_1, T_7, T_8 and T_{13} were on par with T_{16}.

4.3.2.6.3 P/K

P/K ratio was recorded highest in the leaves of arecanut (T_3 - 0.38), which was significantly higher compared to all other treatments. This was followed by *Moringa* (T_{14} - 0.26) and coconut (T_8 - 0.23), which were on par with T_1 and T_7 (Table 24). Lowest ratio of P/K was observed in *Grevillea* (T_{12} - 0.07). All other treatments were on par with T_{12}.

4.3.2.6.4 P/Fe+Mn

Various treatments differed significantly with respect to P/Fe+Mn ratio of foliar samples of standards (Table 25). Highest ratio of 7.79 was recorded in T_{14} (*Moringa* - 7.79) followed by T_{10} (*Garuga* - 6.88) and T_6 (*Bombax* - 6.32). In addition to these three, T_1, T_5, T_7, T_{11} and T_{16} were also on par with T_{14}. Coconut (T_8) possessed minimum P/Fe+Mn ratio of 0.61.

4.3.2.6.5 K/Ca+Mg+Fe+Mn

There was no significant variation in the foliar nutrient ratio of K/Ca+Mg+Fe+Mn among various treatments (Table 25). Highest value of 1.89 was recorded in T_5 (*Azadirachta* - 1.89) followed by T_{16} (*Thespesia* - 1.78). Minimum value of 0.27 was recorded in coconut (T_8).

4.3.2.7 Nutrient addition from loppings

Nutrient addition from loppings was computed from the weight of loppings and nutrient content of loppings.

4.3.2.7.1 Nitrogen

Nutrient addition in terms of nitrogen was maximum for coconut (535.96 g/palm/yr), which was significantly superior to all other treatments. This was followed by *Gliricidia* (87.2 g/plant), jack (84.8 g/plant), *Ailanthus* (68.68 g/plant) and *Leucaena* (56.2 kg/plant) which were on par.and arecanut (47.31 g/palm). Minimum addition of nitrogen was observed from *Moringa* (T_{14} - 7.5 g). T_1, T_5, T_6, T_7, T_9, T_{12}, T_{15} and T_{16} were on par with T_{14} (Table 26).

4.3.2.7.2 Phosphorus

Addition of phosphorus to the rhizosphere soil was maximum from the leaves of coconut (21.02 g/palm), which was significantly high compared to all other treatments. This was followed by arecanut (14.82 g/palm) (Table 26). Minimum addition of phosphorus was observed from *Grevillea* (1.0 g/plant). T_5, T_7, T_9, T_{14} and T_{16} were on par with T_{12}.

4.3.2.7.3 Potassium

Coconut (T_8) added maximum amount (87.58 g/palm/yr) of potassium through leaf fall followed by loppings of jack (T_4 - 69.90 g/plant), *Ailanthus* (T_2 - 63.52 g/plant), *Gliricidia* (T_{11}- 58.37 g/plant) and T_{10}, which were on par with coconut (Table 26). Minimum addition of potassium occurred from the loppings of *Moringa* (5.0 g/plant) followed by *Caesalpinia* (8.82 g/plant). All other treatments except T_3 were on par with *Moringa.*

4.3.2.7.4 Calcium

Addition of calcium through loppings ranged from 2.30 to 217.19 g/plant with coconut recording the maximum value which was significantly high compared to

Table 26. Nutrient addition from loppings (g/plant)

Treatment	N	P	K	Na	Ca	Mg	Fe	Mn	Cu	Zn
T_1	37.19	2.90	21.74	1.73	10.14	3.10	0.50	0.21	0.02	0.02
T_2	68.68	5.16	63.52	5.38	28.19	8.73	0.60	1.12	0.01	0.36
T_3	47.31	14.82	39.90	6.87	46.17	11.40	1.57	2.46	0.02	0.06
T_4	84.81	7.92	69.90	3.04	39.60	9.32	0.82	1.48	0.02	0.02
T_5	20.52	1.62	17.10	2.13	6.94	1.81	0.19	0.13	0.007	0.01
T_6	19.32	2.00	18.60	2.33	7.04	2.39	0.26	0.07	0.005	0.02
T_7	23.23	1.67	8.82	1.80	8.23	1.57	0.33	0.10	0.02	0.01
T_8	535.96	21.02	87.58	71.42	217.19	80.57	7.00	26.83	0.03	0.50
T_9	17.80	1.10	11.44	2.0	6.51	1.50	0.18	0.15	0.007	0.02
T_{10}	47.10	4.71	45.50	6.72	23.60	5.00	0.50	0.21	0.03	0.02
T_{11}	87.20	6.38	58.37	6.95	22.50	8.21	0.76	0.38	0.02	0.02
T_{12}	21.30	1.00	14.80	2.07	8.70	2.80	0.24	1.06	0.006	0.01
T_{13}	56.24	2.80	26.60	2.50	14.30	2.90	0.50	0.15	0.03	0.02
T_{14}	7.50	1.20	5.00	0.60	2.30	0.70	0.07	0.02	0.002	0.002
T_{15}	15.40	2.44	16.64	2.38	12.72	2.90	0.35	0.26	0.004	0.03
T_{16}	14.40	1.66	15.60	4.0	7.74	1.26	0.12	0.30	0.011	0.016
CD (0.05)	36.23	1.86	33.47	16.49	29.33	6.09	1.08	4.75	NS	0.053

all other treatments and *Moringa* had minimum amount of calcium. All other treatments except T_3 and T_4 were statistically on par with T_{14} (Table 26).

4.3.2.7.5 Magnesium

Maximum amount of magnesium was recorded by coconut (80.57 g/palm) which was significantly superior to all other treatments and minimum amount by *Moringa* (T_{14} - 0.7 g/plant) (Table 26). All other treatments except T_2, T_3, T_4 and T_{11} were on par with T_{14}.

4.3.2.7.6 Iron

Addition of iron from the foliar biomass to the soil ranged from 0.07 to 7.0 g in various treatments (Table 26). T_8 (coconut) recorded the maximum (7.0 g/palm) and was significantly superior to all other treatments. T_{14} (*Moringa*) recorded the minimum value (0.07 g/plant). Arecanut added 1.57 g of Fe, jack - 0.82 g, *Gliricidia* - 0.76 g and *Ailanthus* - 0.60 g of Fe through their leaves.

4.3.2.7.7 Manganese

Different standards added manganese in the range of 0.07 to 26.83 g through their loppings (Table 26). Coconut recorded the maximum value of 26.83 and was significantly superior to all other treatments and *Bombax* recorded the minimum (0.07 g). All other treatments were on par with *Bombax*.

4.3.2.7.8 Copper

Coconut, *Garuga* and *Leucaena* recorded maximum amount of copper (0.03 g/plant) added through their loppings to the rhizosphere soil (Table 26). *Moringa* recorded the least value of 0.002 g/plant. However, the variation was not statistically significant.

4.3.2.7.9 Zinc

Zinc addition through lopping of various standards ranged from 0.002 to 0.50 g/plant with coconut having the maximum (0.50 g/palm) and was significantly superior to all other treatments. *Moringa* had the minimum value (0.002 g/plant) (Table 26). All other treatments except T_2 and T_3 were on par with T_{14}.

4.3.3 Pest and disease incidence

Pepper vines as well as their standards were regularly observed for the incidence of pests and diseases.

Careful management and adoption of preventive measures against major pests and diseases resulted in maintenance of good health of pepper vines in the experimental field. Mild incidence of marginal leaf gall thrips and mealy bugs was observed during dry months. The vines were protected from foot rot disease by drenching the soil basins with 0.2 per cent copper oxichloride at the onset of southwest monsoon.

Among the various standards observed, *Ailanthus*, *Artocarpus*, *Azadirachta*, *Caesalpinia*, *Erythrina*, *Garuga*, *Gliricidia*, *Grevillea*, *Leucaena*, *Moringa*, *Pajanelia* and *Thespesia* were free of pest and diseases.

Observations on other standards are mentioned below:

1. ***Acacia mangium***: During dry months, leaves fell extensively, twigs and later the whole tree dried up. No external infestation of pests or disease could be noticed. The condition of the soil and root zone has to be investigated thoroughly for the exact reason.

2. ***Areca catechu***: A few of the arecanut palms showed mild yellowing symptoms. As the incidence was not serious, no control measures were adopted.

3. ***Bombax malabaricum***: Although not severe, mild symptoms of leaf spot were noticed in the leaves of *Bombax*.

4. ***Cocos nucifera***: Some of the palms showed mild symptoms of root wilt.

4.4 CORRELATION STUDIES

4.4.1 Correlation between morphological characters and dry yield of pepper

Among the different morphological characters studied, height of bearing column was highly positively correlated with dry yield of pepper ($r = 0.560^{**}$) (Table 27). Another character significantly correlated with yield was number of spike bearing laterals per $0.25m^2$ ($r = 0.340^{**}$). Negative correlation was observed with number of pinheads per spike, hundred berry volume and hundred berry weight with dry yield of black pepper. However, these were statistically not significant.

4.4.2 Correlation between available nutrients in the soil with dry yield of pepper

Dry berry yield of black pepper was negatively correlated with manganese content of surface and subsurface soil at one per cent level of significance (Table 28). Copper content in the surface soil of rhizosphere also negatively influenced the dry yield of pepper but at five per cent level of significance. Other correlations were statistically not significant.

4.4.3 Correlation between nutrient content of pepper and standard with dry yield of pepper

Plant content of any of the nutrients in the pepper leaves was not found to be correlated with dry yield of pepper significantly. Highly significant negative correlation was observed with phosphorus, iron and copper content of standard and dry yield of pepper (Table 29). Highly significant positive correlation was observed between manganese content of standard and dry yield of pepper. Eventhough a negative correlation was observed for N, K, Mg, Na, Fe and Zn of pepper plant samples with dry yield of pepper none of the correlations were statistically significant.

4.4.4 Correlation between available soil nutrients and plant nutrient content of pepper

Among the different nutrient elements analysed, organic carbon in the surface samples of rhizosphere soil and sodium in the subsurface samples were significantly and negatively correlated with nitrogen and sodium content in the leaf

Table 27. Correlation coefficients of different morphological characters with dry berry yield of black pepper

Character	Dry yield
Height of bearing column	0.560**
Spread at chest height	0.261
No. of laterals per 0.25 m²	0.340*
No. of spikes per 0.25 m²	0.080
Spike length	0.155
Pedicel length	0.122
No. of berries per spike	0.159
No. of pinheads per spike	-0.051
100 berry volume	-0.130
100 berry weight	-0.071
Spike compactness	0.121

Table 28. Correlation coefficients of available nutrients in the soil with dry berry yield of pepper

Particulars	Dry yield	
	Surface samples	Subsurface samples
Organic carbon	0.12	-0.155
Available P	0.072	-0.087
Available K	-0.011	0.065
Available Na	-0.079	0.118
Available Ca	0.126	-0.154
Available Mg	0.096	-0.037
Available Fe	-0.159	-0.113
Available Mn	-0.384**	-0.484**
Available Cu	-0.319*	-0.263
Available Zn	-0.263	-0.085

Table 29. Correlation coefficients of plant nutrient content with dry yield of pepper

Nutrient	Dry yield of black pepper	
	Standard	Pepper
N	-0.194	-0.066
P	-0.498**	0.014
K	-0.25	-0.041
Ca	-0.174	0.014
Mg	0.135	-0.075
Na	-0.123	-0.263
Fe	-0.427**	-0.225
Mn	0.459**	0.106
Cu	-0.478**	0.023
Zn	-0.145	-0.233

Table 30. Correlation coefficients of available nutrient ions in the soil with plant nutrient content of pepper

Particulars	Nutrient content of pepper	
	Surface	Subsurface
*N	-0.369**	-0.168
P	-0.212	-0.033
K	-0.037	-0.109
Na	-0.229	-0.462**
Ca	0.01	-0.179
Mg	0.162	-0.058
Fe	-0.093	-0.092
Mn	-0.079	0.048
Cu	-0.08	0.008
Zn	0.189	-0.035

*Organic carbon level of soil has been correlated with nitrogen content of pepper vine samples of pepper respectively (Table 30). Although nonsignificant, negative correlation was also observed between the soil and plant samples in the case of P, K and Fe (both surface and subsurface samples), Ca, Mg and Zn (for subsurface samples only) and Mn and Cu (for surface samples only).

4.4.5 Correlation between available soil nutrients and plant nutrient content of standard

Potassium in the subsurface samples was significantly and negatively correlated with the potassium content of standard (Table 31). Also, sodium in both surface and subsurface samples were negatively correlated with the sodium content of standard at one per cent level of significance. Both surface and subsurface samples of N (organic carbon), Ca, Mg and Cu was positively correlated with the corresponding elements in the standard although nonsignificant. A negative correlation was observed between surface samples of P, K, Fe and Mn with the corresponding nutrients of plant samples of standard.

4.4.6 Correlation between nutrient ratios of rhizosphere soil and dry yield of black pepper

There was no significant correlation noticed between the nutrient ratios *viz.* P/Fe+Mn and K/Ca+Mg+Fe+Mn of the surface and subsurface rhizosphere soil and dry yield of black pepper (Table 32). Both the ratios of surface soil had negative correlation with yield and that of subsurface soil had positive correlation with yield.

4.4.7 Correlation between foliar nutrient ratios of pepper and dry yield of black pepper

The ratios N/P and N/K of foliar samples of pepper vine had positive influence on dry yield of black pepper (Table 33). But a negative influence was observed by the ratios P/K, P/Fe+Mn and K/Ca+Mg+Fe+Mn on the dry yield of black pepper. However none of the correlations was found to be statistically significant.

Table 31. Correlation coefficients of available soil nutrient with plant nutrient content of standard

Particulars	Nutrient content of standard	
	Surface	Subsurface
*N	0.099	0.138
P	-0.018	0.169
K	-0.155	-0.293*
Na	-0.380**	-0.415**
Ca	0.008	0.019
Mg	0.111	0.230
Fe	-0.050	0.114
Mn	-0.197	-0.18
Cu	0.246	0.149
Zn	0.237	-0.059

Table 32. Correlation coefficients of nutrient ratios of rhizosphere soil and dry yield of black pepper

Nutrient ratios	Dry yield
P/Fe+Mn surface	-0.04
P/Fe+Mn subsurface	0.172
K/Ca+Mg+Fe+Mn surface	-0.09
K/Ca+Mg+Fe+Mn subsurface	0.206

Table 33. Correlation coefficients of foliar nutrient ratios of pepper and dry yield of black pepper

Nutrient ratios	Dry yield
N/P	0.066
N/K	0.018
P/K	-0.022
P/Fe+Mn	-0.201
K/Ca+Mg+Fe+Mn	-0.038

Table 34. Correlation coefficients of foliar nutrient ratios of standard and dry yield of black pepper

Nutrient ratios	Dry yield
N/P	0.465**
N/K	0.506**
P/K	-0.079
P/Fe+Mn	-0.344*
K/Ca+Mg+Fe+Mn	-0.234

4.4.8 Correlation between foliar nutrient ratios of various standards and dry yield of black pepper

Highly significant positive correlation was observed between the ratios N/P and N/K of leaves of standard and dry yield of black pepper (Table 34). The ratio P/Fe+Mn was found to exert a negative influence on the dry yield of pepper. Although non significant, the foliar nutrient ratios, P/K and K/Ca+Mg+Fe+Mn were also negatively correlated with dry yield of black pepper.

Discussion

5. DISCUSSION

Black pepper, being a vine, requires support for its growth and establishment. Providing ideal support plays an important role in successful establishment of black pepper plantation. Interactions between the crop and the standard (support) involve a large number of processes, both below as well as above ground levels, whose conceptualization and analysis are complex and difficult. Whether an association is successful or not depends on the balance between competitive, complementary and facilitative interactions between the crop and the standard. The present study on crop-standard interactions in black pepper was attempted to unravel the key rhizosphere processes and root and shoot level interactions that influence the productivity of black pepper. The results of the study are discussed in this chapter.

5.1 EXPERIMENT I

CHARACTERISATION OF RHIZOSPHERE SOIL OF BLACK PEPPER TRAILED ON DIFFERENT STANDARDS

The rhizosphere which is the zone of intense biological and chemical activity in the soil that surrounds the root is chemically, physically and biologically different from the bulk soil because it has been modified by plant roots and their associated microorganisms. Different plants modify the environment around their roots in different ways and, therefore, interaction between plants may occur as a result of rhizosphere processes (Jones *et al.*, 1998). The total amount of nutrients that are taken up from soil and air by a tree-crop association may be larger than that available to the crop alone. However, the woody perennials tend to enrich the soil during the long years of occupancy through various processes of nutrient cycling, biological nitrogen fixation in case of leguminous species, etc. (Nair, 1983). In the present study also, marked variations in the chemical and biological properties of soil have been noticed between the rhizosphere soil of different pepper-standard combinations.

5.1.1 Soil electrochemical properties

The soil pH in different treatments varied from 5.04 to 5.93 in surface soil and 5.14 to 5.73 in subsurface soil (Table 3 and Fig. 1). There was significant variation among treatments for pH in the surface soil. Rhizosphere soil of pepper vines trailed on the dead standard (teak pole - T_{17}) was least acidic in the surface samples. The treatments T_1, T_2, T_3, T_4, T_5, T_7, T_8, T_9 and T_{16} were statistically on par with T_{17}. In the subsurface also the soil samples under teak pole (T_{17}) were lower in acidity next only to *Ailanthus* (T_2). However, the variation was not statistically significant in subsurface soil. Lowering of pH in the rhizosphere soil of pepper vines trailed on live standards can be related to the weak acids formed during the organic matter decomposition which causes low base saturation (Bear, 1976). Prasad *et al.* (1991) also attributed the decrease in pH in soils subjected to litter decomposition, to the increase in humic acid and fulvic acid content resulting from the decomposition of added tree leaves. Most studies on the tree-crop soil interface show an acidification of the rhizosphere (Lal, 1989; Roces *et al.*, 1989; Drechsel *et al.*, 1991; Seguin *et al.*, 2004).

There was no significant variation among treatments with respect to electrical conductivity in the surface soil. But variation was significant in subsurface soil. It ranged from 0.04 to 0.38 dS m^{-1} in surface samples and 0.03 to 0.20 dS m^{-1} in subsurface samples. In subsurface samples, treatments with significantly higher EC were T_1, T_2, T_3, T_4 and T_{16}.

Organic carbon content of rhizosphere soil of pepper vines trailed on *Caesalpinia* (T_7), *Erythrina* (T_9), *Gliricidia* (T_{11}) and *Grevillea* (T_{12}) was lower than that of teak pole (T_{17}) in surface soil and *Bombax* (T_6), *Erythrina* (T_9), *Garuga* (T_{10}), *Gliricidia* (T_{11}) and *Grevillea* (T_{12}) in subsurface soil samples (Fig. 2). In all the other treatments, a higher organic carbon content was noticed in the rhizosphere soil. However the differences were not statistically significant. Variation in soil organic carbon content was reported by several workers with the inclusion of multipurpose trees (Agarwal *et al.*, 1976; Nair, 1985; Young, 1989; Liyanage *et al.*, 1993;

Chavan *et al.*, 1995; Contractor and Badanur, 1996; Sureshkumar, 1997; Mongia *et al.*, 1998 and George, 2005).

5.1.2 Available nutrients

The fundamental assumption in agroforestry is that the integration of trees into farming systems and landscapes can increase soil fertility, productivity and sustainability of soil by improving the nutrient balance of a site. This is achieved both by reducing nutrient losses from erosion and leaching and by increasing nutrient inputs through nitrogen fixation (Nair, 1984). It has also become clear that the intensity with which trees and tree-crop associations influence soil fertility differ widely between agroforestry practices, even if the processes are similar in principle. While most trees will take up some of the nutrients from the subsoil and deposit them in surface soil through leaf litter and root decay thus acting as a nutrient pump, some combinations of species may have negligible effect on microsite enrichment (Schroth and Sinclair, 2003).

In the present study, wide variation in the availability of soil nutrients was observed among the various pepper-standard combinations some having a complimentary effect and others having a competitive effect.

Available phosphorus content of rhizosphere soil ranged from 8.98 to 46.77 mg kg^{-1} in surface samples and 11.07 to 49.87 mg kg^{-1} in subsurface samples (Fig. 3). Availability of P was high in the rhizosphere soil of pepper trailed on *Gliricidia*, *Bombax*, *Grevillea*, *Thespesia*, teak pole and arecanut in the surface samples. In the subsurface samples, availability of P was highest under pepper-*Thespesia* combination and lowest under pepper-*Moringa* combination. The mean availability of P was higher in surface samples (27.34 mg kg^{-1}) compared to subsurface samples (25.58 mg kg^{-1}). Eventhough there was variation in the available P among treatments, it was not statistically significant.

It is a known fact that availability of P in tropical acid soils is limited due to the adsorption and precipitation reactions with sesquioxides rather than low

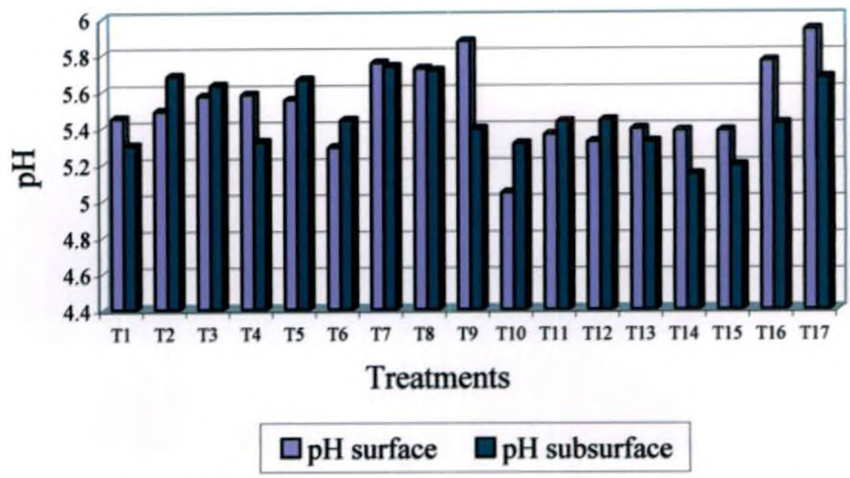


Fig. 1. Effect of standards on pH of rhizosphere soil

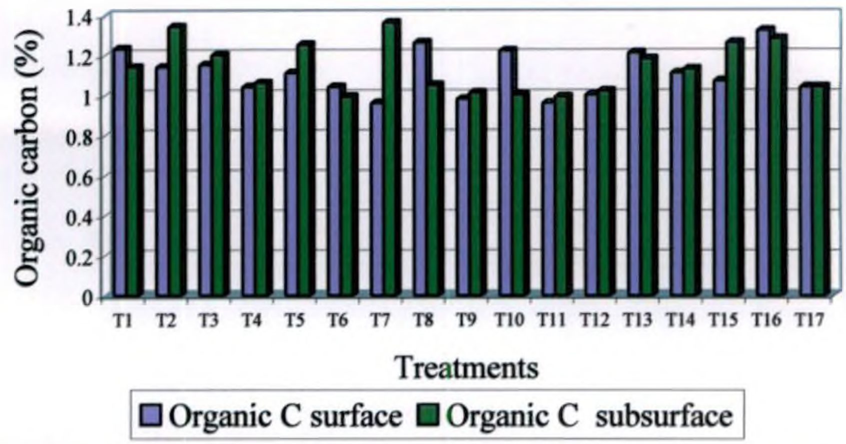


Fig. 2. Effect of standards on organic carbon content of rhizosphere soil

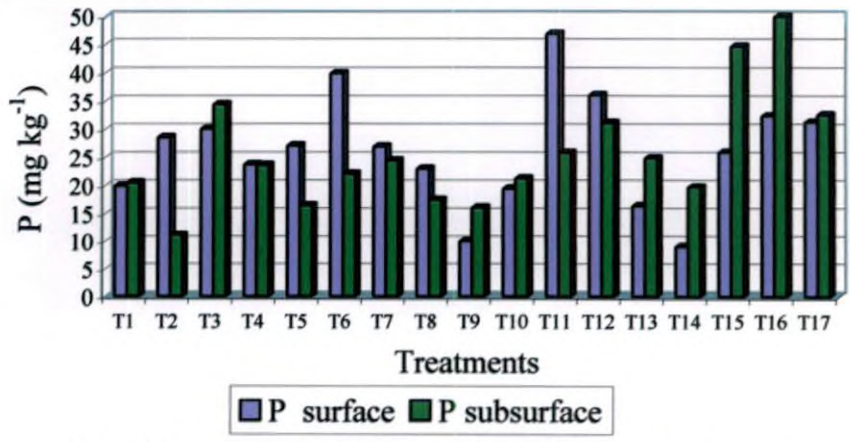


Fig. 3. Effect of standards on available P content of rhizosphere soil

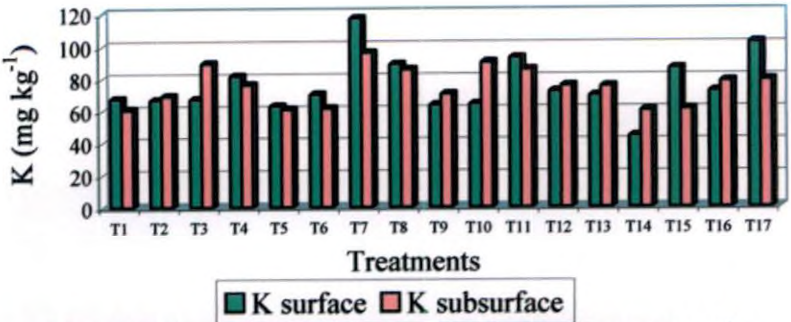


Fig. 4. Effect of standards on available K content of rhizosphere soil

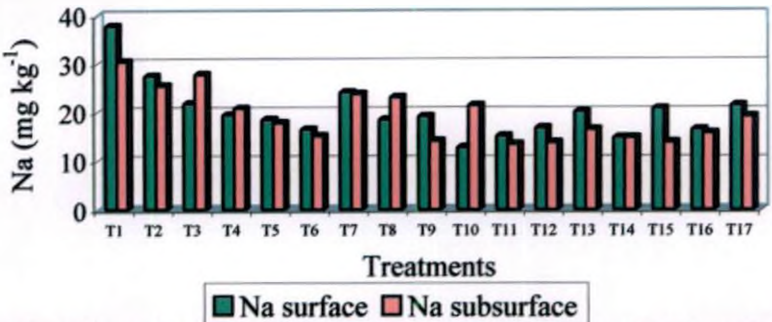


Fig. 5. Effect of standards on available Na content of rhizosphere soil

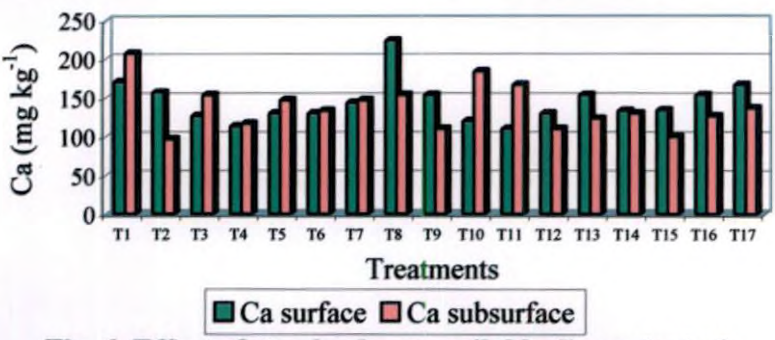


Fig. 6. Effect of standards on available Ca content of rhizosphere soil

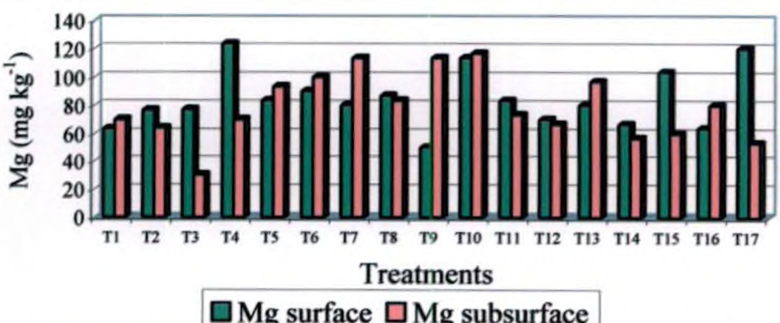


Fig. 7. Effect of standards on available Mg content of rhizosphere soil

amounts of total P. So the nutrient ratio, P/Fe+Mn was computed and compared among various treatments. The treatments with *Bombax*, coconut and *Gliricidia* as standards recorded the maximum ratio of 0.38 in surface samples. *Thespesia* (T_{16} - 0.39), coconut (T_8 - 0.30) and *Pajanelia* (T_{15} - 0.30) as standards had comparatively higher ratio in subsurface samples. The mean ratio was lower (0.21) in the subsurface samples than surface samples (0.24) as in the case of available P. The results of the study point to the fact that the ability to transform unavailable P into forms that may be utilized by the crop, either by nutrient cycling or by direct root effects, need not necessarily vary with species. George (2005) could not observe significant variation in the available P. However, variation in the available P status of soils among different tree based systems was noticed by Roces *et al.* (1989), Drechsel *et al.* (1991), Prasad *et al.* (1991), Kunhamu (1994) and Lal *et al.* (2000).

Available K content of rhizosphere soil of various treatments ranged from 44.0 to 116.7 mg kg^{-1} in surface samples and 60.00 to 96.67 mg kg^{-1} in subsurface samples (Fig. 4). In both soil layers, *Moringa* (T_{14}) recorded the minimum availability of K. However the variation was not statistically significant. A decline in the available K content in the soil due to the inclusion of multipurpose trees was reported by Contractor and Badanur (1996) and Jessy *et al.* (1998). But enrichment of soil potassium under different trees was reported by Bear (1976), Prasad *et al.* (1991) and Lal *et al.* (2000).

When the nutrient ratio K/Ca+Mg+Fe+Mn was computed and compared among various treatments, it was observed that the variation was not statistically significant in both surface and subsurface samples (Table 7). A higher ratio was recorded for *Caelsalpinia* (0.31) followed by *Gliricidia* (0.30), teak pole (0.29) and *Pajanelia* (0.25) in surface soil and arecanut (0.30) followed by coconut (0.28), teak pole (0.27), *Erythrina* (0.26) and *Artocarpus* (0.25) in subsurface soil.

Available sodium content of the rhizophere soil varied among various treatments significantly which ranged from 12.67 to 37.67 mg kg^{-1} in surface soil and 13.33 to 30.33 mg kg^{-1} in subsurface samples (Fig. 5). *Acacia* recorded the maximum availability of sodium in samples of both surfaces. The other species which had comparatively higher sodium content in rhizosphere soil were *Ailanthus*, arecanut, *Caesalpinea* and *Pajanelia* in surface soil and *Caesalpinia* and coconut in subsurface soil.

Available calcium content of rhizosphere soil ranged from 110.0 to 223.33 mg kg^{-1} in surface soil and 96.67 to 206.67 mg kg^{-1} in subsurface soil (Fig.6). Rhizosphere soil of pepper trailed on coconut possessed maximum availability of calcium followed by *Acacia* and teak pole in surface samples and the variation was not significant. The difference among species in available calcium content was reported to be due to direct (eg. litterfall, organic acids, biocycling) or indirect (eg. mycorrhizae, microorganisms) effects of the tree species (Finzi *et al.*, 1998 and Watmough, 2002).

Available magnesium content varied from 50.0 mg kg^{-1} to 123.33 mg kg^{-1} in surface samples with *Artocarpus* (T_4) having the highest and *Erythrina* having the lowest content (Table 4 and Fig. 7). In subsurface samples, maximum magnesium content was observed in the rhizosphere soil of pepper vines trailed on *Garuga* (116.67 mg kg^{-1}) followed by *Erythrina* (113.40 mg kg^{-1}) (Table 6 and Fig. 7). Other treatments with *Acacia*, *Ailanthus*, *Artocarpus*, *Azadirachta*, *Bombax*, *Caesalpinia*, coconut, *Gliricidia*, *Grevillea*, *Leucaena*, *Moringa*, *Pajanelia* and *Thespesia* as standards had higher availability of magnesium in the subsurface soil compared to teak pole as the standard. However the difference in magnesium content among treatments was not statistically significant in both soil layers.

The available micronutrient status in the rhizosphere soil of different treatments varied significantly for Mn, Cu and Zn in surface soil and Fe and Cu in subsurface soil.

Iron content was maximum in T_{12} in both surface and subsurface samples (38.33 mg kg^{-1} and 46.67 mg kg^{-1} respectively) (Fig. 8). Variation was significant only in subsurface samples. It ranged from 13.37 to 46.67 mg kg^{-1}. Treatments, T_3, T_4, T_{15} and T_{17} were on par with T_{12} regarding iron content in subsurface samples.

In the case of manganese, a noteworthy observation was that rhizosphere soil of pepper trailed on coconut had least availability in both surface and subsurface samples (43.33 and 51.67 mg kg^{-1}) (Fig. 9). Significantly higher manganese content was observed in the rhizosphere soil of pepper trailed on *Acacia, Leucaena, Grevillea* and teak pole in surface samples. Variation in manganese content was not significant in subsurface soil.

Variation in copper content was significant in both soil layers. Copper content of rhizosphere soil of pepper trailed on teak pole was the highest in surface and subsurface samples followed by *Acacia* and *Grevillea* (Fig.10). The treatment with coconut as the standard recorded the least availability of copper in both soil layers as in the case of manganese. Combinations of pepper with *Acacia*, *Grevillea*, *Artocarpus*, *Bombax*, *Erythrina*, *Gliricidia*, *Leucaena*, *Moringa* and *Thespesia* had significantly higher copper content in subsurface samples compared to other combinations.

Available zinc content of surface samples ranged from 1.33 to 7.3 mg kg^{-1} and 1.0 to 6.0 mg kg^{-1} in subsurface samples (Fig.11). Availability of zinc was high under pepper-teak pole combination in both soil layers which was statistically superior to all other treatments in surface samples. However only on surface layer, the differences were statistically significant. Live standards such as *Caesalpinia*, *Acacia*, *Ailanthus*, *Bombax*, *Erythrina*, *Grevillea*, *Leucaena*, *Pajanelia* and *Thespesia* had significantly higher zinc content in surface samples. Variation in subsurface samples was not statistically significant.

Eventhough it is established in many literature that the chemical activity of most metals increases as the pH of the solution decreases (Lindsay, 1979; Linehan *et al.*, 1985; McGrath *et al.*, 1997; Srivastava and Chhonkar, 2002), such a trend was not obtained in the present study. Rhizosphere soil of pepper vines trailed on teak pole which had the highest pH (5.93 in surface soil) was abundant in all the micronutrients analysed (Table 4). Different plant species are known to produce organic matter compounds that vary in abundance and nature as a function of species, which could

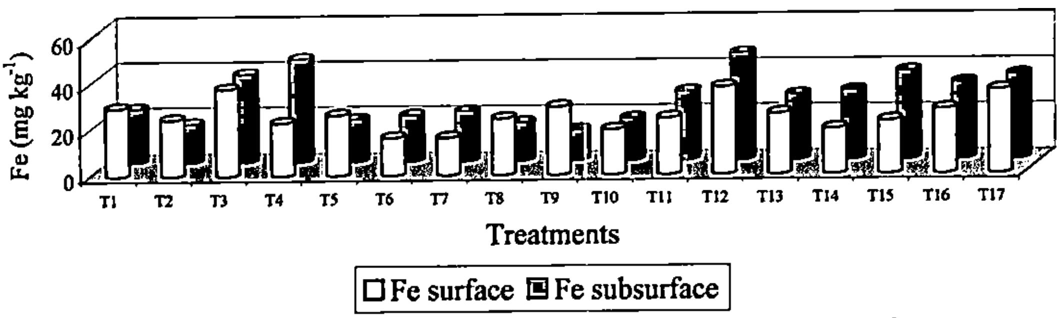


Fig. 8. Effect of standards on available Fe content of rhizosphere soil

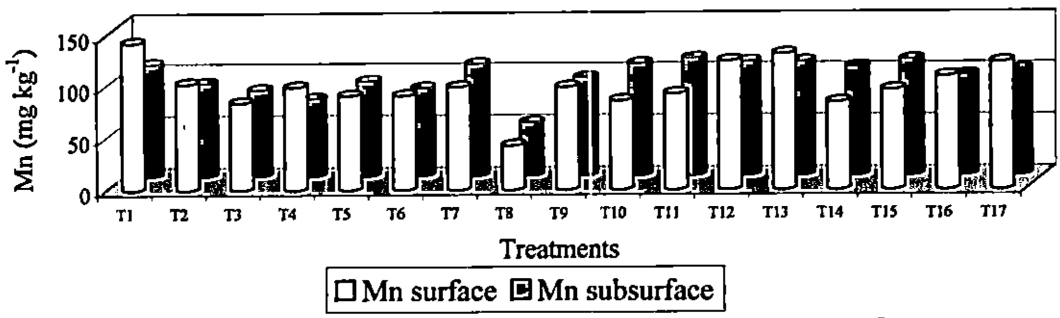


Fig. 9. Effect of standards on available Mn content of rhizosphere soil

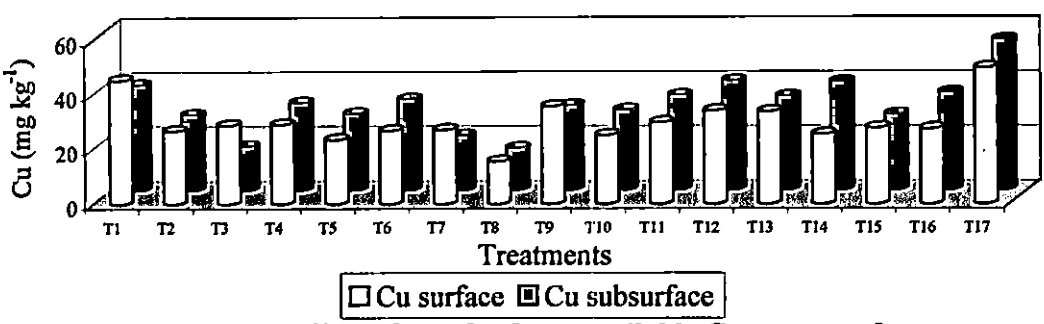


Fig. 10. Effect of standards on available Cu content of rhizosphere soil

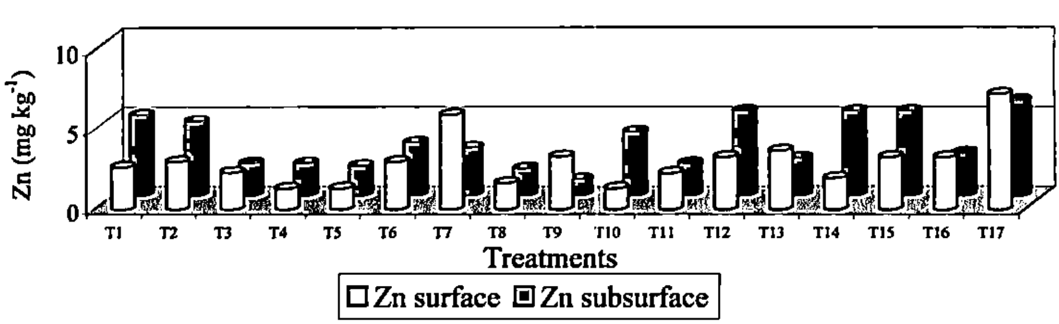


Fig. 11. Effect of standards on available Zn content of rhizosphere soil

modify the metal fraction in the rhizosphere (Grayston *et al.*, 1998). As such, the rhizosphere of each tree could have been expected to contain metals in different amounts. But Seguin *et al.* (2004) could not obtain significant differences for most metals between the rhizospere soil of various tree species studied.

The rhizosphere soil of pepper vines trailed on live standards had a lower availability of soluble metals like Fe, Mn, Cu and Zn compared to the dead standard. This was due to the uptake of metals by plants, the reduction of the ionic strength and the subsequent changes in the redistribution of metals on exchange sites. In many studies, the rhizosphere soil of tree crops had a lower content of metals (Sarong *et al.*, 1989; Knight *et al.*, 1997; Lorenz *et al.*, 1997). While reviewing previous works related to the available micronutrient concentrations of rhizosphere soil, it was seen that there was no consensus in the literature with respect to the available micronutrient concentrations in the rhizosphere of same tree species. There are also studies which suggest that the rhizosphere soil of different tree species is enriched in micronutrients (Youssef and Chino, 1989; Gahoonia, 1993; Wang *et al.*, 2002 etc).

5.1.3 Exchangeable cations and CEC

Cation exchange capacity (CEC) of soil is an important property due to which various plant nutrients are retained on the exchange surface on clay and humus fractions of the soil and are protected against leaching losses.

Exchange complex was dominated by calcium followed by sodium, magnesium, and potassium in both surface and subsurface soil (Table 8 and 9). In both layers of soil, highest exchangeable Ca was observed under rhizosphere soil of pepper trailed on coconut (359.33 mg kg^{-1}). There was no significant difference among the rhizosphere soil of various crop-standard combinations for Ca in the exchange complex in the present study.

The amount of exchangeable Mg^{2+} was higher in surface soil (119.82 mg kg^{-1}) than subsurface soil (105.02 mg kg^{-1}). The variation among treatments was significant in surface soil where the rhizosphere soil of pepper vines trailed on

Caesalpinia recorded the highest value followed by coconut, *Leucaena* and *Acacia* which were on par.

Exchangeable sodium content of both surface and subsurface soil varied significantly among the treatments as in the case of available sodium content. Maximum content was recorded under pepper-*Erythrina* combination followed by pepper-*Garuga* combination and minimum content was recorded under pepper-*Bombax* combination in both surface and subsurface soil layers. The treatments T_1, T_2, T_8, T_{11}, T_{12}, T_{13}, T_{14}, T_{16} and T_{17} were also statistically on par with T_9.

There was no significant variation in the exchangeable potassium among the various treatments. It varied from 94.67 to 123.33 mg kg^{-1} in surface soil and 69.33 to 110.0 mg kg^{-1} in subsurface soil. Exchangeable Fe also did not vary significantly among treatments in both layers of soil whereas significant variation in exchangeable Mn content was observed in surface soil. Maximum exchangeable Mn was recorded in rhizosphere soil of pepper trailed on *Acacia* (106.67 mg kg^{-1}) followed by that on *Leucaena* (103.30 mg kg^{-1}) in surface soil. In subsurface soil, pepper trailed on *Caesalpinia* and *Gliricidia* recorded maximum exchangeable Mn content. Least content of exchangeable Mn was recorded under pepper – coconut combination as in the case of available Mn content in both soil layers. Exchangeable Al^{3+} content did not vary significantly among various treatments. This shows that different standards had almost similar effect on the modification of aluminium in the soil exchange complex.

The differences in the presence of exchangeable ions lead to a significant difference in the CEC among various treatments in the surface soil, which ranged from 3.37 to 4.69 cmol (+) kg^{-1} (Table 8). Maximum CEC was recorded in the rhizosphere soil of pepper-coconut combination followed by *Leucaena*, *Acacia* and *Caesalpinia*. Mean CEC of surface soil was higher (3.77 cmol (+) kg^{-1}) compared to subsurface soil (3.56 cmol (+) kg^{-1}). Similar results were observed by Lal (1989) who reported significant difference in CEC among various treatments comprising *Leucaena* and *Gliricidia* established in an agroforestry system with maize and cowpea. A slight increase in the CEC in the surface layer was reported and the differences in CEC among treatments were related to the variations in soil organic matter contents. According to Drechel et *al.* (1991), tree and bush fallow enhanced CEC and exchangeable cations over grass fallow due to the increase of organic matter in the topsoil. Minhas *et al.* (1997) reported that CEC of soils of different forest vegetation showed an inconsistent trend. Increase in CEC in soil under multipurpose trees like *Eucalyptus, Casuarina* and *Shorea robusta* was reported earlier (Chavan *et al.*, 1995; Mongia *et al.*, 1998; Patil and Prasad, 2004). Prasad *et al.* (1991) attributed the significant difference in the availability of exchangeable cations to difference in the mineralization and solubilization effect of cations through the action of various microorganisms and organic decomposition products.

5.1.4 Soil biological properties

5.1.4.1 Soil microbial population

The rhizosphere regions from which plants derive most of their nutrients are considered to be the seat of intense microbial activity. Root exudates containing organic compounds and growth factors enrich the microbes in rhizosphere. Heterotrophic microorganisms act on organic material, degrade them in the soil consequently making the nutrients available in the soil.

In the present study, significant variation in the microbial population of fungi, bacteria and actinomycetes was observed in the rhizosphere soil of different pepper-standard combinations (Fig.12, 13 and 14). However the trends were not similar in the total population of fungi, bacteria and actinomycetes. But the population of nitrogen fixing bacteria and phosphate solubilizing bacteria was higher in the rhizosphere soil of pepper vines trailed on *Artocarpus* and *Garuga* and lower in *Ailanthus* and *Erythrina* (Fig. 15 and 16). When population of microflora was correlated with nutrient status of rhizosphere soil, it was observed that total population of bacteria as well as nitrogen fixing bacteria had a significant positive correlation with sodium and calcium content of subsurface soil. Another noteworthy observation was that all the micronutrients studied *viz.* Fe, Mn, Cu and Zn had a significant

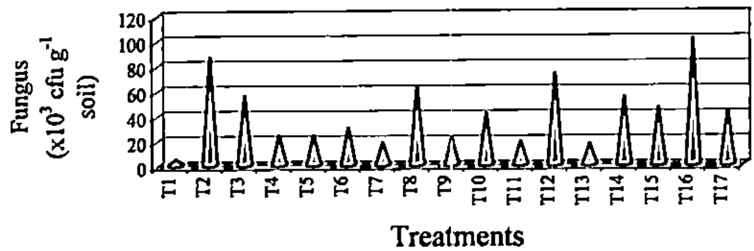


Fig. 12. Fungal population of rhizosphere soil

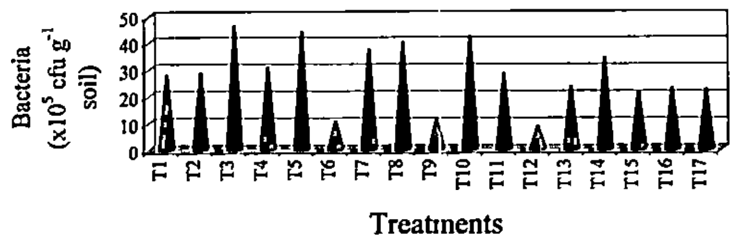


Fig. 13. Bacterial population of rhizosphere soil

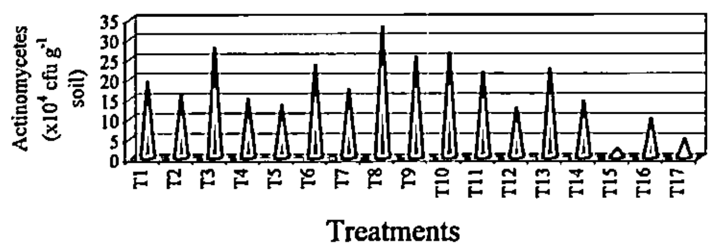


Fig. 14. Population of actinomycetes of rhizosphere soil

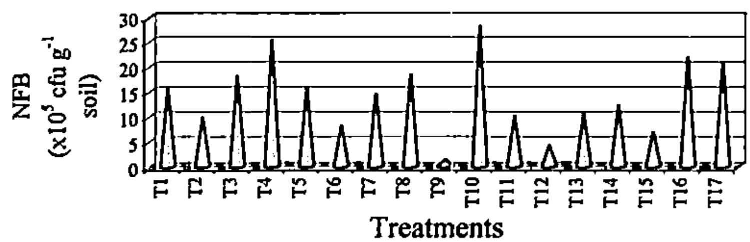


Fig. 15. Population of Nitrogen fixing bacteria of rhizosphere soil

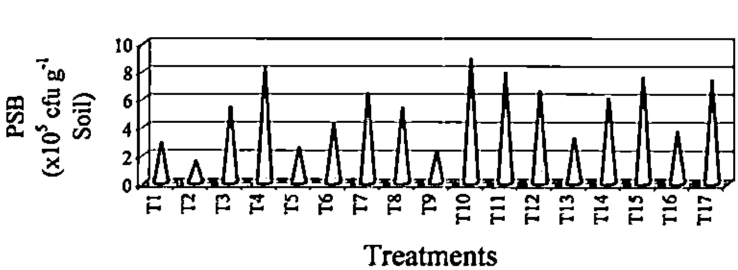


Fig. 16. Population of phosphate solubilising bacteria of rhizosphere soil

negative correlation with the population of actinomycetes as well as nitrogen fixing bacteria. Total population of bacteria was significantly correlated with Mn and Cu content of rhizosphere soil. This indicates the higher content of micronutrients in the rhizosphere soil of pepper which adversely affect the growth and multiplication of soil microflora especially nitrogen fixing bacteria and actinomycetes.

Difference in the microbial population of rhizosphere soil of different plant species growing in the same soil was reported by many workers (Alexander, 1961; Mishra, 1967; Rao, 1962; Ibekwe and Kennedy, 1998). One of the reasons of this variation is the difference in the amount and distribution of exudates produced by different plant species as the microbial species differ in their ability to metabolise and compete for different carbon sources. Subabul favoured maximum number of nitrogen fixing bacteria which indicated that the degraded products of subabul leaves were more stimulatory on free nitrogen fixing bacteria for their growth and metabolism (Lal *et al.*, 2000). Increase in grain yield of rice with the inoculation of phosphorus solubilising microorganisms was obtained by Laxminarayana (2005) which was attributed to be due to the increase in phosphorus availability through solubilisation of insoluble inorganic phosphates, decomposition of phosphate rich organic compounds and production of plant growth promoting substances (Gaur and Sunita, 1997). The phosphate solubilising micro organisms are reported to secrete a number of organic acids, which may form chelates with Fe and Al resulting into effective solubilisation of phosphates (Graeves *et al.*, 1965; Kapoor *et al.*, 1989; Ilmer and Scinner, 1992; Rao, 1999). The beneficial effect of phosphate solubilising bacteria on growth promotion and P uptake in black pepper cuttings was reported by Sumijarani (2003).

Marschner *et al.* (2004) concluded that many different factors contribute to the shaping of species composition in the rhizosphere but that the plant itself exerts a highly selective effect that is at least as great as that of the soil. Root exudates amount and composition are the key drivers for the differences in community structure observed in their study.

5.1.4.2 Soil enzymes

In the present study no significant variation was observed between various treatments with regard to dehydrogenase and phosphatase activity of rhizosphere soil (Table 11). Highest activity of both enzymes was recorded in the rhizosphere soil of pepper vines trailed on *Moringa* (T_{14}). A higher activity of phosphatase was also observed when arecanut, *Pajanelia* and *Thespesia* were used as the standards which excelled other treatments with respect to available phosphorus content and P/Fe+Mn ratio of subsurface soil. Thus it can be inferred that the root activity of multipurpose trees is more in the subsurface soil and they extract nutrients from subsurface layer where soil enzymes have greater influence. Although soil enzymes can be considered as a measure of microbial activity, such a trend could not be obtained in the present study probably due to the lack of significant variation among various treatments with respect to enzyme activity of dehydrogenase and phosphatase. A detailed study involving more enzymes may help to arrive at conclusive results.

However, the importance of dehydrogenases and phosphatases in the soil as part of various biochemical processes were studied by many scientists. Skujins (1976) had reported phosphatase activity measurements as an index of potential availability of phosphate in soil. Batra (1998) in her study found that dehydrogenase activity was greater in the rice based cropping sequence than sorghum based cropping sequence. Management practices and type of cultivation influence more the microbiological properties of soil than the physico-chemical properties of the soil. Studies on the extent of intraspecific variation in rhizosphere dehydrogenase and phosphatase activity is yet unexplored and the genetic analysis of soil enzyme activity is only at the initial stage.

5.2 EXPERIMENT II

ROOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD EMPLOYING RADIOISOTOPIC TECHNIQUES

To assess the extent of root competition between black pepper vines and the supports on which they are trailed, ^{32}P soil injection technique was employed. ^{32}P

was applied at the effective foraging space (EFS) of black pepper and radioactivity absorbed by the pepper and standards was quantified. This measures the degree of interference or competition between the two plant species for the applied radiolabel when grown side by side with each other. As the study was carried out during the northeast monsoon season when soil moisture availability was not limiting, the extent of absorption of ^{32}P can represent the root interactions of the largest possible magnitude as suggested by Wahid *et al.* (1989).

Absorption pattern of ^{32}P by pepper varied substantially among the various standards used as well as with the period of sampling. Pepper vines trailed on *Acacia*, *Artocarpus*, *Caesalpinia*, *Erythrina*, *Gliricidia*, *Grevillea* and teak pole recovered maximum ^{32}P at 30 days after application whereas those on *Ailanthus*, *Azadirachta*, *Bombax*, *Garuga*, *Leucaena*, *Moringa*, *Pajanelia* and *Thespesia* absorbed maximum ^{32}P at 45 days after application and there after declined. Variation in the absorption pattern of ^{32}P with period of sampling was also noticed in the case of standards. Comparison for the uptake of ^{32}P by pepper vines as well as standards was done at 30 and 45 days after application. An initial increase in foliar ^{32}P recovery and further decline over time was reported by earlier workers like Wahid *et al.* (1989) in cocoa, George *et al.* (1996) in *Acacia*, *Casuarina, Ailanthus* and *Leucaena*, Jamaludheen *et al.* (1997) in *Artocarpus hirsutus* and Sureshkumar (1997) in coconut. In the present study, when coconut was used as the standard, maximum recovery of ^{32}P was observed at 15 days after application and thereafter declined. Similar results were obtained by Gowda (2002). He attributed the temporal variations in ^{32}P uptake pattern as a reflection of changes in root activities in response to changes in the physical environment. Arecanut also followed a similar trend in the present study.

Considerable variability existed among various standards in influencing the uptake of ^{32}P by the pepper vines trailed on them. As expected, maximum absorption of ^{32}P by the pepper vines occurred when teak pole was used as the standard, at 15 and 30 days after application, which can be considered as a monoculture system. At 30 days after application, the treatments T_1, T_3, T_4, T_5, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{16} were statistically on par with T_{17} with respect to ^{32}P uptake (Fig. 17). At 45 days

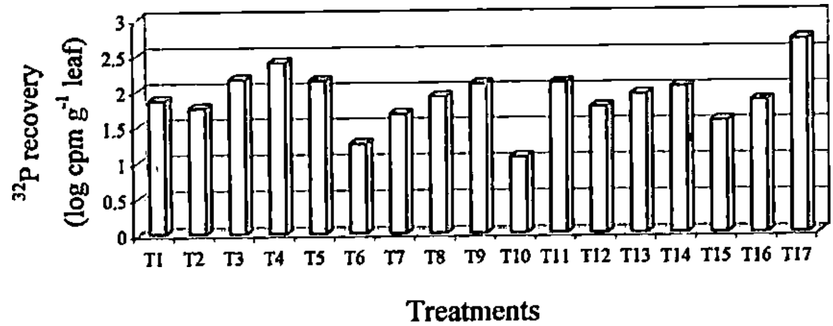


Fig. 17. ^{32}P recovery from pepper at 30 days after application

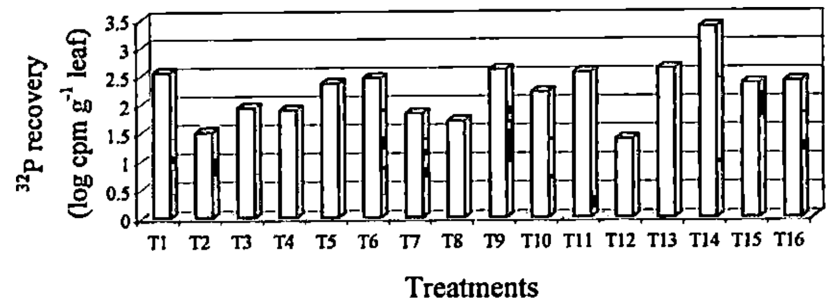


Fig. 18. ^{32}P recovery from standards at 30 days after application

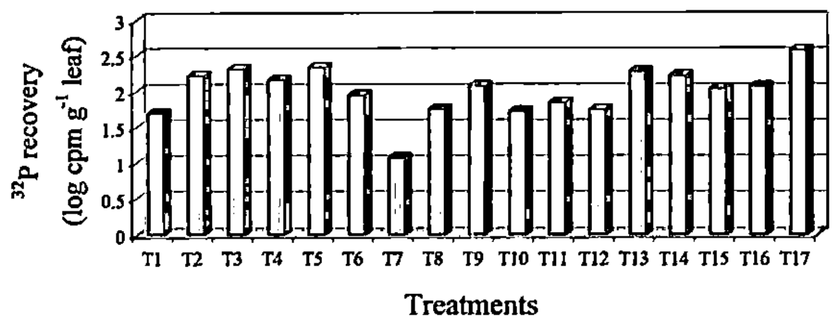


Fig. 19. ^{32}P recovery from pepper at 45 days after application

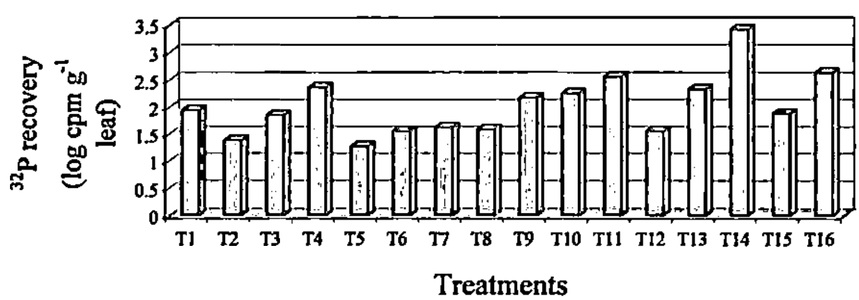


Fig. 20. ^{32}P recovery from standards at 45 days after application

after application of ^{32}P, all the treatments except T_1, T_7 and T_{10} were on par with T_{17} (Fig. 19. When recovery of ^{32}P by standards was considered, lower quantity of ^{32}P was recovered by standards *viz.* *Ailanthus*, arecanut, *Artocarpus*, *Caesalpinia*, coconut and *Grevillea* at 30 days after application (Fig. 18) and *Acacia*, *Ailanthus*, arecanut, *Azadirachta*, *Bombax*, *Caesalpinia*, coconut, *Grevillea and Pajanelia* at 45 days after application (Fig. 20). This means that these standards are expected to exert least effect of competition with pepper.

In a polyculture system where black pepper is trailed on live standards either a complimentary or competitive interaction can be expected. In order to have a better understanding on such an interaction, the percentage distribution of ^{32}P uptake by pepper and standard in each combination was worked out and compared (Table 14). During both periods (30 and 45 days after application) pepper recovered more ^{32}P than the corresponding standard when trailed on *Ailanthus*, arecanut, coconut and *Grevillea*. Higher recovery of ^{32}P by pepper vine than the corresponding standard was also observed for T_4 (*Artocarpus*) at 30 days after application and neem (92.10 per cent), *Bombax* (71.52 per cent) and *Pajanelia* (58.60 per cent) at 45 days after application.

The standards like *Ailanthus*, arecanut, coconut and *Grevillea* are thus concluded to have a complementary interaction with the pepper vine associated with them with respect to ^{32}P uptake. *Artocarpus*, *Azadirachta*, *Bombax* and *Pajanelia* can also be expected to exert a similar effect on pepper vine but to a lesser extent. The other standards were obviously expected to have a competitive influence through root competition for below ground resources like water and nutrients. This may be due to the interlocking of tree roots through root grafts and/or micorrhizal connections as well documented by earlier workers (Kozlowski and Cooley, 1961; Kramer and Kozlowski, 1979). The lesser competition for ^{32}P uptake with pepper vine by a few standards mentioned earlier may be due to the presence of deep root system which reduces the overlapping of root system in the effective foraging zone of black pepper as defined by Wahid (2000) as L30/D40 (lateral distance of 30 cm and depth of 40 cm from the vine). The differential uptake of ^{32}P by pepper vines when trailed on different standards can also be attributed to the qualitative and quantitative differences in the chemical and microbiological composition of the rhizosphere of the vine when associated with different standards.

Jamaludheen (1994) noticed a deep tap root system and low lateral spread for *Ailanthus triphysa* in the excavation studies. About 41 to 59 per cent of the physiologically active roots of *Ailanthus* were distributed within 40 cm lateral distance from the tree trunk and the remainder is presumably outside this range. Thomas *et al.* (1998) reported that presence or absence of *Ailanthus* did not substantially alter the uptake pattern of ^{32}P applied to ginger grown between *Ailanthus* trees. This would mean that if the crop component of *Ailanthus* based cropping systems are adequately fertilized, competitive influences from the tree component are negligible. According to Caldwell (1987) if a little overlap of neighbouring root systems is apparent, or if moisture or nutrients are drawn from distinctly different soil zones by neighbouring plants, there will be little competition between individual roots of neighbouring plants.

Anilkumar and Wahid (1988) found that in Kerala, regular opening and closing of soil basin of coconut for fertilizer application might discourage the proliferation of roots in the disturbed surface layer. Over 80 per cent of the active roots of coconut are found in the 30-60 cm soil layer within a lateral distance of 2 m from the palm. But the effective foraging zone of black pepper lie at a lateral distance of 30 cm and depth of 40cm from the vine. Results obtained in the present study also confirm the minimum root competition exerted by coconut on black pepper which can be considered as a mixed cropping system resulting in crop advantage.

Jamaludheen *et al.* (1997) while studying the root activity of *Artocarpus hirsutus* (wild jack) found that 39.5 per cent of physiologically active roots are at 75 cm from the base at a depth of 30 cm whereas more than 99 per cent of active roots of black pepper are distributed within a zone of 60 cm from the base at a depth of 30 cm (Sankar, 1985).

The competitive effect of multipurpose trees like *Erythrina*, *Gliricidia* etc. can be explained based on their root activity pattern. Sankar *et al.* (1988) reported that over 80 per cent of the feeder roots of *Erythrina* are lying within the active root zone area of pepper suggesting that *Erythrina* has a more extensive root system than the vine and that black pepper and *Erythrina* explore to almost same extent of the various soil layers. The root activity pattern of *Gliricidia* as studied by Vasu *et al.* (1994) points out that 30-35 per cent of the active roots are distributed within 50 cm from the plant, 30 per cent over 50-100 cm and 35 per cent beyond 100cm.The vertical distribution of active roots was more or less uniform (23-28 per cent) upto 120cm soil depth. This indicates that eventhough *Gliricidia* is not as competitive as *Erythrina* when used as the standard for pepper, it can also adversely affect the nutrient uptake by pepper vine associated with it considerably.

Interspecific root interactions based on relative absorption of ^{32}P have also been studied earlier by many workers. Asokan *et al.* (1988) reported both complimentary as well as competitive interactions in ^{32}P uptake involving cassava, banana and elephant foot yam. Lai and Lawton (1962) observed that in a corn-field bean system, corn competed more vigorously for labeled P.

George *et al.* (1996) while studying the competition for applied ^{32}P between trees and herbaceous components noticed that none of the grass species when grown in association with tree components affected the absorption of ^{32}P by trees. Of the tree species *Casuarina* and *Ailanthus* exerted a complementary effect on grass species and *Acacia* and *Leucaena* adversely affected ^{32}P uptake by grass species. Interspecific competition between rubber and interplanted banana was reported by Joseph (1999).

In the present study, based on the uptake pattern of ^{32}P by pepper and standards, *Artocarpus heterophyllus, Ailanthus triphysa,* coconut, arecanut and *Grevillea robusta* were found to exert least competition with pepper vines for nutrients. Selection of tree species with low root competition and / or trees with complementary root interaction is more important for efficient utilization of below ground resources from the various strata of the soil profile (Wahid, 2000).

5.3 EXPERIMENT III

SHOOT LEVEL INTERACTION BETWEEN BLACK PEPPER AND STANDARD

5.3.1 Growth characters of pepper

The effect of different standards on growth characters of black pepper was studied in detail (Table 15). One of the important characters studied was height of bearing column of pepper, which significantly varied among different treatments. Maximum height was observed when pepper was trailed on coconut (Fig. 21). Except T_7 and T_{17} all the treatments were statistically on par with coconut. Minimum height was observed when *Caesalpinia* (T_7) was used as the standard. Mathew *et al.* (1996) observed that pepper vine trailed on *Garuga pinnata* recorded higher value for height of the vine compared to other standards like *Erythrina indica, E. stricta, E. lithosperma, Gliricidia sepium, Moringa oleifa* and *Thespesia populnea.* But Kurien *et al.* (1985) obtained maximum height of the vine when trailed on dead teak pole, which was significantly superior to the live standards used in the study *viz. Erythrina indica* and *Garuga pinnata.* Factors influencing height of bearing column of pepper were observed to be height of the standard as well as nature of bark of the standard. Pepper had a lower bearing column when trailed on *Caesalpinia* because of the lower height of the standard as well as branching at a lower height. Height of bearing column was also low when trailed on teak pole because of the smooth surface of teak pole which makes clinging of roots and climbing of the vine difficult.

Maximum spread of pepper at chest height was observed when trailed on *Artocarpus* followed by coconut, *Erythrina* and *Gliricidia* (Fig. 22). Minimum spread was observed when trailed on *Caesalpinia* as in the case of height of bearing column. It is generally expected that spread of pepper is dependent on the girth of support tree because it gets more space to grow and spread. However, in the present study, it was observed that on standards like *Acacia*, which has more girth, the spread of pepper was poor. Probably there are some limiting factors in pepper – *Acacia* combination which does not support luxuriant growth of pepper. However, detailed studies are

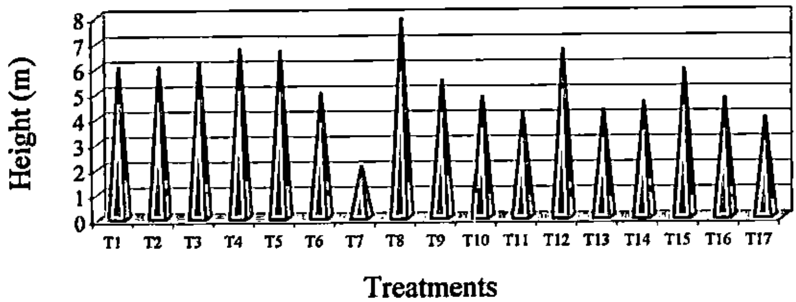


Fig. 21. Height of bearing column of pepper trailed on different standards

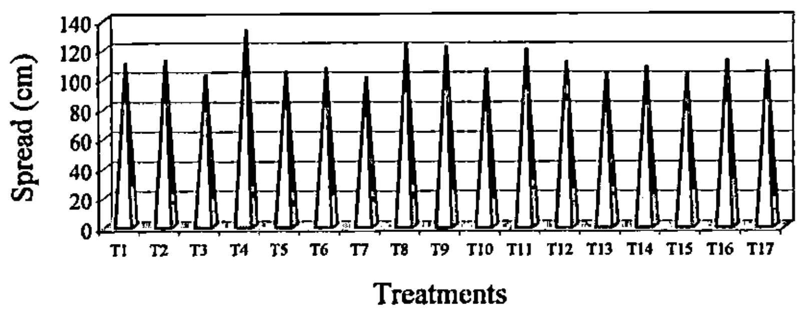


Fig. 22. Spread of pepper trailed on different standards

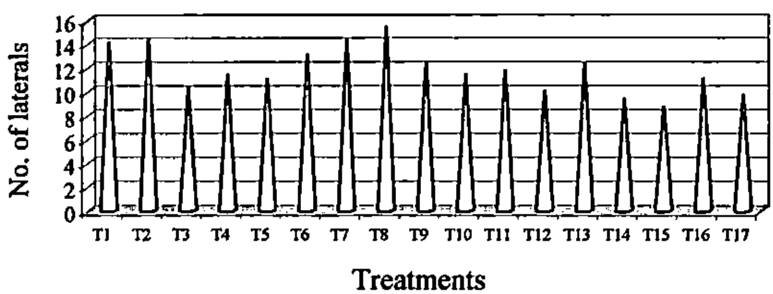


Fig. 23. No. of laterals of pepper trailed on different standards

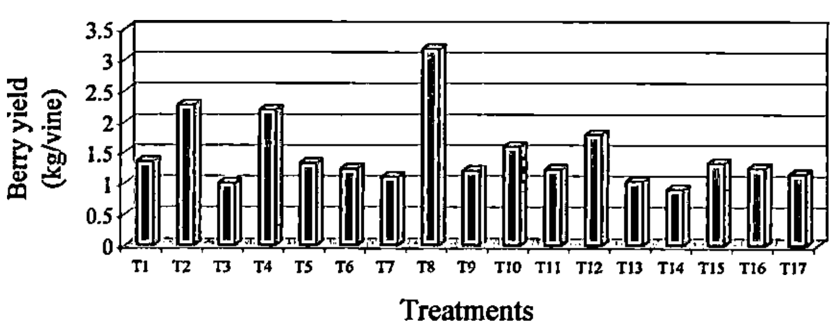


Fig. 24. Dry berry yield of pepper trailed on different standards

required before arriving at a conclusion. According to Kurien *et al.* (1985), dead teak pole was found superior to the live standards *viz. Erythrina indica* and *Garuga pinnata* with respect to spread of the vine.

Number of laterals per 0.25 m^2 varied significantly among various treatments (Fig. 23). Maximum value was recorded for T_8, which was on par with T_1, T_2, T_6, T_7, T_9, T_{11} and T_{13}. In pepper, laterals are the inflorescence bearing branches and number of laterals in a unit area influences the yield of crop. Support trees, which can influence the production of more number of laterals, can definitely improve the yield of pepper trailed on it. In the present study, standard with maximum lateral production (T_8) gave maximum yield of pepper. However there are standards with more laterals per unit area with poor yield like *Caesalpinia* which shows that yield is a combined effect of other factors like height of bearing column, spread of plant etc. which are also important and not the number of laterals per unit area alone.

Number of spikes per 0.25 m^2 also varied significantly where maximum value was recorded in pepper vines trailed on *Acacia*. Other treatments with significantly more number of spikes were T_1; T_2, T_3, T_5, T_6, T_8, T_9, T_{13}, T_{16} and T_{17}, which were on par. Number of spikes is generally considered as a factor influencing the yield of pepper. However, in the present study, there was no definite relationship between number of spikes at chest height and yield of pepper. For example, *Artocarpus* and *Grevillea*, which were second and fourth in yield of pepper trailed, had lesser number of spikes per 0.25 m^2 whereas pepper on arecanut and *Leucaena* which were poor yielders had more number of spikes per 0.25 m^2. This probably indicates that when pepper is trailed on different types of standards, number of spikes at a particular height (chest height) cannot be taken as an indication of total yield of pepper which is contradictory to the report of Prabhakaran (1994) who found that one of the factors influencing the yield of pepper was number of spikes per 0.25 m^2 at chest height. Mathew *et al.* (1996) obtained maximum number of spikes from pepper trailed on Garuga *pinnata* followed by *Thespesia populnea*. Pepper trailed on other standards like *Erythrina indica, E. stricta, E. lithosperma, Gliricidia sepium* and *Moringa oleifera* recorded lower values for number of spikes. In contrast to our study, Kurien *et al.* (1985) observed maximum number of spikes when pepper was trailed on teak pole followed by *Erythrina indica* and *Garuga pinnata*.

Length of spike of pepper vines trailed on different standards ranged from 15.30 to 17.20 cm and the variation was statistically significant. Maximum length was observed in T_6 and minimum in T_{11}. The treatments T_3, T_4, T_5, T_7, T_8, T_{12}, T_{14}, T_{15} and T_{17} also had significantly higher values for spike length. Even though length of spike is primarily a varietal character, spike to spike variations in length is generally observed which could be due to the influence of several environmental factors like soil nutrition, soil moisture, availability of light in the particular site, number of berries set, pest and disease incidence etc. Kurien *et al.* (1985) observed maximum length of spike in pepper when trailed on teak pole.

Number of berries per spike did not vary significantly among various treatments. The values ranged from 49.30 to 76.33 with T_8 (coconut) recording the highest and T_2 (*Ailanthus*), the lowest values. As number of berries per spike is primarily a varietal character no variation was observed among treatments as generally expected. There was significant variation in the number of pinheads per spike in the study. Minimum value was recorded in T_{17}, which was on par with T_4, T_5, T_{11}, T_{12} T_{14}, T_{15} and T_{16}. Under developed berries (pinheads) are formed due to insufficient pollination or poor pollen quality or loss of stigma receptivity before pollination or stigma damage or a combination of these factors. Panniyur 1 is a variety in which very high variation in number of berries and number of pinheads has been noticed which is primarily attributed to environmental factors like availability of light, amount and distribution of rainfall during flowering and fruit set. A detailed study in this regard is likely to explain the actual role of these environmental factors and standards used for trailing pepper in berry set and development especially in Panniyur 1.

Hundred berry weight in different treatments varied significantly which ranged from 12.40 to 17.20g. T_4 recorded the maximum value, which was on par with T_5, T_8, T_9, T_{14}, T_{16} and T_{17}. Hundred berry weight is primarily a varietal character. It can also be influenced by environmental factors, probably because of the small size of the fruit, not much attention has been paid in this regard. More detailed studies are likely to give interesting results. Hundred berry volume did not show significant variation among different treatments and the values ranged from 11.00cc to 14.00cc. Spike compactness varied from 3.10 to 4.50 no. cm^{-1} in different treatments with T_8 recording the highest value and T_6, the lowest. However, the variation was not significant. Different treatments varied significantly regarding pedicel length of the spike with T_{17} recording the minimum value. All the treatments except T_2, T_7 and T_{14} were on par with T_{17}. Study indicates that pedicel length also is a character which can be influenced by environment.

All the above characters contribute to the yield of pepper in one way or the other. Coconut (T_8) was superior to all other standards with respect to the growth characters of pepper like height of bearing column, number of laterals per 0.25 m^2, number of berries per spike and spike compactness and recorded lower values for pedicel length. The treatment also expressed higher values for spread at chest height, number of spikes per 0.25 m^2 and spike length.

T_4 (*Artocarpus*) also had significantly higher values for height of bearing column of pepper, spread at chest height, spike length, hundred berry weight and lower values for number of pinheads per spike and pedicel length.

5.3.2 Yield of pepper

The ultimate objective of any cropping system is to obtain maximum productivity. In the present study, pepper trailed on coconut was superior in yield followed by *Artocarpus* and *Ailanthus* whereas *Moringa* recorded the lowest yield of pepper followed by arecanut and *Leucaena* (Fig. 24). Apart from green berry yield, there was significant variation in dry recovery also. Here again, coconut recorded the maximum dry recovery (34.3 per cent) followed by arecanut. The treatments T_1, T_4, T_{11} and T_{16} were on par with coconut. Minimum dry recovery was recorded in *Leucaena*. Dry berry yield is a function of green berry yield and dry recovery. There was significant variation in the dry berry yield also which indicates the influence of various standards on different yield attributes of pepper (Table 16).

The pepper vines trailed on different standards were divided into three yield groups based on the criterion suggested by Davee *et al.* (1986) using mean and standard deviation (SD). High yield group (HYG) was constituted by plants having dry berry yield equal to or exceeding 1.88 kg/vine (mean + SD) and low yield group (LYG) having berry yield equal to or below 1.06 kg/vine (mean - SD) where mean dry yield was 1.47 and standard deviation was 0.41. The vines yielding dry berry yield between 1.06 and 1.88 kg/vine were considered to belong to medium yield group (MYG) (Table 35).

Based on the yield of pepper trailed on, the standards were grouped as follows.

Table 35. Grouping of standards based on yield of pepper trailed

HYG (>1.88 kg/vine)	MYG (1.06 - 1.88 kg/vine)	LYG (<1.06 kg/vine)
Coconut, jack *Ailanthus*	*Acacia, Azadirachta, Bombax, Caesalpinia, Erythrina, Garuga, Gliricidia, Grevillea, Pajanelia, Thespesia,* teak pole	Arecanut, *Leucaena, Moringa*

The results obtained indicated the superiority of standards namely coconut, jack and multipurpose trees like *Ailanthus* in terms of yield of pepper trailed on it.

Variation in yield attributes of pepper vine when trailed on different types of standards was reported by earlier workers. Mathew *et al.* (1996) observed that maximum yield of pepper was obtained when trailed on *Garuga pinnata* (122.9 kg/ha) followed by *Thespesia populnea* (104.9 kg/ha) and *Erythrina indica* (96.5 kg/ha). Minimum yield was recorded when trailed on *Gliricidia sepium* (38.8 kg/ha). The yield of pepper trailed on other standards of pepper like *Moringa oleifera, Erythrina stricta* and *E. lithosperma* were 80.2, 72.1 and 58.0 kg/ha respectively.

George (2005) observed significant variation in the yield of pepper when trailed on different standards. *Acacia* (2.56 t/ha) and *Artocarpus* (1.91 t/ha) were foremost in terms of dry berry yield. *Macaranga* and *Ailanthus* had the lowest yield of pepper trailed on them.

Rajagopalan and Mammootty (1996) compared the living supports of pepper and recorded a higher green berry yield (2.84 kg/vine) of pepper when trailed on *Ailanthus malabaricum* compared to subabul (0.83 kg), *Gliricidia* (1.88 kg), *Garuga pinnata* (1.11 kg) and *Erythrina* (1.5 kg). Kandiannan *et al.* (1999) suggested *Ailanthus malabaricum* as an ideal living support to establish pure monocrop of black pepper plantation as well as pepper at homestead agroforestry based on the observations made at Indian Institute of Spices Research Experimental Farm. The yield of black pepper vines (Panniyur 1) was maximum in vines trailed on *Terminalia bellerica* followed by *Grevillea robusta, Ficus glomerata* and *Erythrina lithosperma* according to a study conducted by Korikanthimath and Ankegowda (1999).

In contrast to these studies, Kurien *et al.* (1985) obtained low yield of pepper when trailed on *Garuga pinnata* and *Erythrina indica* compared to that on teak pole. But when the two live standards were compared, *Garuga* was superior to *Erythrina.* Superiority of dead standards like teak poles, reinforced concrete posts, granite pillars etc. to live standards was also reported by many other workers. (Jayakrishnakumar *et al.*, 1991; Cheeran *et al.*, 1992). However, poor growth and productivity were observed on concrete poles by Wahid and Sitepu (1987). During summer, concrete poles and stone pillars absorb heat and become hot resulting in drying of clinging roots and poor growth of black pepper vines under exposed situations.

In the current study, most of the live standards were superior to teak pole in yield of pepper. Only standards like arecanut, *Caesalpinia, Leucaena* and *Moringa* were inferior to teak pole with respect to yield of pepper.

5.3.3 Quality attributes

The quality attributes studied *viz.* essential oil, oleoresin and piperine content varied among different treatments studied (Table 17). However, a specific trend could not be observed with respect to these parameters. Essential oil content varied from 1.70 to 2.85 per cent. It was maximum when pepper was trailed on *Garuga* (2.85 per cent) followed by *Grevillea* (2.69 per cent) which were on par.

Minimum oil content was obtained in T_6. Oleoresin content of various treatments ranged from 9.36 to 13.43 per cent with T_{13} recording the maximum value (13.43 per cent). Other treatments which gave better recovery of oleoresin were T_3, T_5, T_6, T_{12}, T_{15} and T_{17} which were on par with T_{13}. Minimum oleoresin recovery was found in T_{11}. Significant variation was also observed for piperine content. T_{15} recorded the highest value (6.31 per cent) and T_3, the lowest (4.48 per cent). Treatments which recorded significantly higher content of piperine were T_1, T_5, T_7, T_8, T_{10}, T_{11} and T_{12} which were on par with T_{15}.

Though the quality aspects of a spice crop is primarily governed by the genotype of the cultivars, the environmental conditions during growth can also contribute some amount of variability (Purseglove *et al.*, 1981). Various external factors like soil nutrient status, light, moisture availability etc. were found to influence the quality of black pepper. Nitrogen and phosphorus levels had significant effect on volatile oil and oleoresin contents in black pepper (Devadas and Chandini, 2000).

Quality of black pepper was found to be enhanced by the application of 0.5 kg Mo per ha (Hamza and Sadanandan, 2005) and composted coir pith, NPK and *Azospirillium* (Srinivasan *et al.*, 2005).

In turmeric, curcumin content decreased with increase in the levels of N, P and K fertilization (Rao *et al.*, 1975), whereas it improved significantly with graded doses of potassium (Mohanbabu and Muthuswamy, 1984; Ahmedshah *et al.*, 1988). A higher curcumin content was obtained in turmeric (Jena and Das, 1997) and essential oil yield in ginger (Chengat, 1997) by the dual inoculation of nitrogen fixing bacteria like *Azotobacter* and *Azospirillum*. Application of farmyard manure and organic cakes could increase the rhizome and oleoresin yield turmeric (Rao *et al.*, 2005), Kaempferia (Maheswarappa *et al.*, 2000) and mango ginger (Mridula and Jayachandran, 2001).

Effect of shade on the quality of different spice crops was reported by many workers. Quality of bush pepper was not found to be significantly influenced by varying light levels (Devadas and Chandini, 2000). Open condition was found to increase the oleoresin content in ginger (Varughese, 1989), oil content and oil yield in clocimum (Pillai, 1990) and volatile oil content in kacholam (Sureshkumar, 1997). But the quality of ginger was reported to be higher when grown under shade by Ravisankar and Muthuswamy (1987) and George (1992). Latha (1994) and Thomas (1996) could not find any influence of shade on the quality of kacholam and ginger respectively.

5.3.4 Foliar nutrient analysis

5.3.4.1 Pepper

Significant variation in the nutrient content of leaves of pepper was noticed for all the elements studied except P, Cu and Zn. (Table 18). Maximum nitrogen content was recorded when *Erythrina* was used as standard (2.35 per cent) followed by *Pajanelia* and *Grevillea* (2.08 and 1.91 per cent respectively). The nitrogen content of pepper was found minimum when arecanut was used as the standard (1.08 per cent) followed by coconut (Table 18). Available P content of pepper leaves varied from 0.10 to 0.46 per cent in various treatments. Maximum content was noticed when *Garuga* was used as the standard followed by *Moringa* and *Pajanelia*. However, the variation was not significant. There was significant variation in the potassium content of pepper leaves in various treatments. It ranged from 1.10 to 2.63 per cent. Maximum content was recorded in T_2 and T_5, which were on par with T_3, T_4, T_{11}, T_{12}, T_{13} and T_{15}. Treatments with lower content of potassium were T_1, T_6, T_8, T_{10}, T_{16} and T_{17}. Sodium content varied significantly among different treatments. Treatments with higher content of sodium were T_5, T_6, T_7, T_8, T_9, T_{11}, T_{13}, T_{15}, T_{16} and T_{17}. Maximum value was recorded in T_9 (0.37 per cent) and minimum in T_3 (0.11 per cent).

Calcium content varied from 0.49 to 1.24 per cent in various treatments and the variation was statistically significant. Maximum calcium content was recorded in leaves of pepper trailed on *Pajanelia* (T_1), which was statistically on par with T_{16}. All other treatments had a comparatively lower content of calcium. Foliar content of magnesium in pepper ranged from 0.12 to 0.84 per cent with T_1 recording the maximum and T_4 the minimum value. Except T_1, all other treatments were statistically on par.

Among the micronutrients, Fe and Mn significantly varied among different treatments. Iron content varied from 150.00 to 368.33 mg kg^{-1} (Table 18). T_6 and T_7 had significantly higher content of iron in the pepper leaves. T_3 and T_{10} recorded the minimum iron content (150.00 mg kg^{-1})

Foliar manganese content was maximum in T_{13} (775.00 mg kg^{-1}) followed by T_8 (666.67mg kg^{-1}) (Table 18). All the treatments except T_{17} were statistically on par. Foliar copper content varied from 2.50 to 12.50 mg kg^{-1} and zinc content from 1.17 to 15.00 mg kg^{-1}. Conditions like variety, age of pepper, cultural and manurial practices being uniform, the differential nutrient content of pepper trailed on different standards could have arisen due to two reasons – one is the differential uptake of macro and micronutrients from a relatively uniform rhizosphere soil modified by the nutrient uptake and recycling pattern of different standards used in the study and the other due to the difference in the feeding zones of various standards which had influenced the uptake of nutrients by pepper.

Sadanandan and Rajagopal (1989) reported the foliar nutrient status of pepper as 1.98 to 2.96 per cent N, 0.06 to 0.18 per cent P, 0.95 to 1.75 per cent K and 0.09 to 2.13 per cent Ca. Stephen (2002) obtained variation in the foliar nutrient status of pepper employing various treatments like organic and inorganic fertilizers including biofertilizers which could modify the rhizosphere soil nutrient status. The study recorded the foliar nutrient status of black pepper as 1.22 to 1.83 per cent N, 0.12 to 0.17 per cent P, 1.8 to 2.2 per cent K, 1.69 to 2.1 per cent Ca, 0.36 to 0.54 per cent Mg, 335 to 496 ppm Fe, 436 to 555 ppm Mn, 17.3 to 30 ppm Cu and 14 to 19.3 ppm Zn in various treatments.

According to Sivakumar (1992), foliar nutrient status as well as biomass production of pepper vines was affected by the application of leaves of *Erythrina*, *Garuga*, silver oak and coffee. Foliar N content ranged from 2.05 to 2.75 per cent, P content ranged from 0.14 to 0.19 per cent, K - 3.99 to 4.28 per cent, Ca - 1.37 to 1.55 per cent, Mg - 0.197 to 0.272 per cent, Fe - 103 to 164 ppm and Mn - 434 to 506 ppm.

5.3.4.2 Standard

The nutrient content of leaves of the standards was analysed which can give an indication of their ability to ameliorate soil fertility through litter fall and decomposition of loppings or pruned branches as a practice for shade regulation (Table 24).

Leucaena leucocephala possessed the maximum nitrogen content of 3.45 per cent followed by *Gliricidia* (2.87 per cent) (Fig.26). Both being nitrogen fixing trees, a higher foliar N is expected. The other leguminous trees like *Acacia* and *Caesalpinia* also had significantly higher nitrogen content in their leaves (2.31 and 2.37 per cent respectively) which was on par with *Leucaena* together with *Azadirachta* (2.16 per cent) and *Moringa* (2.50 per cent). Minimum nitrogen content was noticed in arecanut (0.83 per cent). Phosphorus content of loppings of standards varied from 0.06 to 0.40 per cent with maximum content in *Moringa* and minimum in coconut (Fig. 27). Potassium content was maximum in *Thespesia* (1.97 per cent) followed by *Gliricidia* (1.92 per cent) and *Azadirachta* (1.80 per cent) (Fig. 28). The maximum sodium content was recorded in *Thespesia* (0.45 per cent) and minimum in *Artocarpus* (0.07 per cent) (Fig. 29). The calcium content did not vary significantly among various standards which varied from 0.62 to 1.20 per cent (Fig. 30). Foliar magnesium content was highest in *Gliricidia* and *Pajanelia* (0.27 per cent) and lowest in *Caesalpinia*, *Garuga* and *Thespesia* (0.16 per cent) (Fig. 31).

The different standards varied significantly in the foliar micronutrient status except for Fe. The mean iron content of various standards was 232.81 mg kg^{-1} (Fig. 32). Standards with high manganese content were *Grevillea* (766.67 mg kg^{-1}), coconut (766.67 mg kg^{-1}), arecanut (433.33 mg kg^{-1}), *Thespesia* (375.00 mg kg^{-1}) and *Artocarpus* (316.67 mg kg^{-1}) (Fig. 33). The copper content was highest in *Caesalpinia* (16.67 mg kg^{-1}), followed by *Leucaena* 15.83 mg kg^{-1}, *Acacia* (14.17 mg kg^{-1}) and *Thespesia* (14.17 mg kg^{-1}) (Fig. 34). Standards with high zinc content were *Pajanelia* (27.5 mg kg^{-1}), *Erythrina* (24.17 mg kg^{-1}), *Bombax* (15.83 mg kg^{-1}), coconut (14.17 mg kg^{-1}), *Leucaena* (15.00 mg kg^{-1}) and *Thespesia* (20.00 mg kg^{-1}) (Fig. 35).

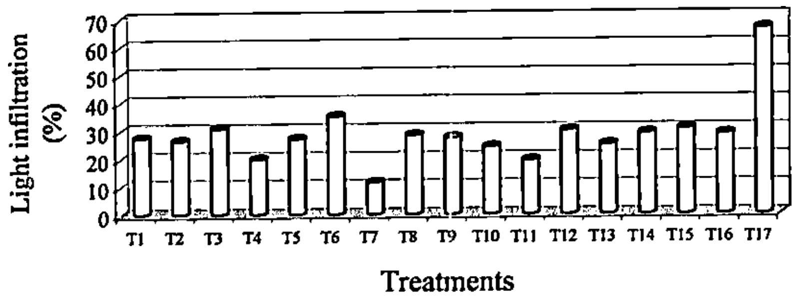


Fig. 25. Percentage of light infiltration through different standards

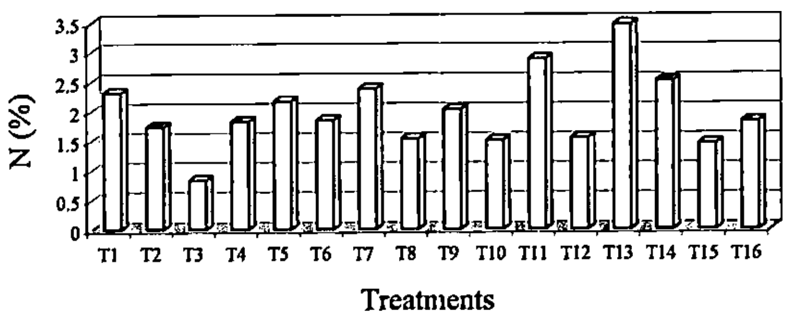


Fig. 26. Foliar nitrogen content of different standards

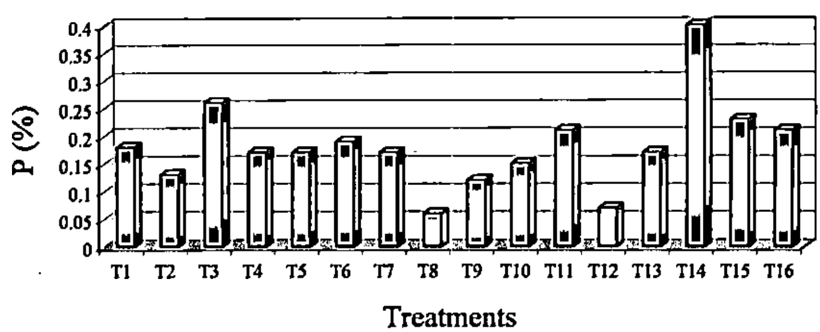


Fig. 27. Foliar phosphorus content of different standards

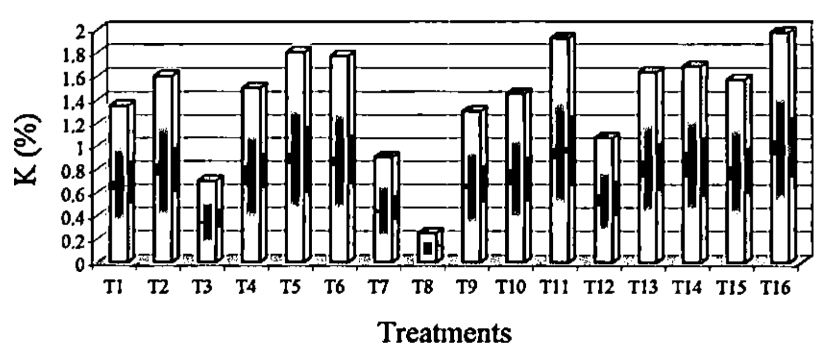


Fig. 28. Foliar potassium content of different standards

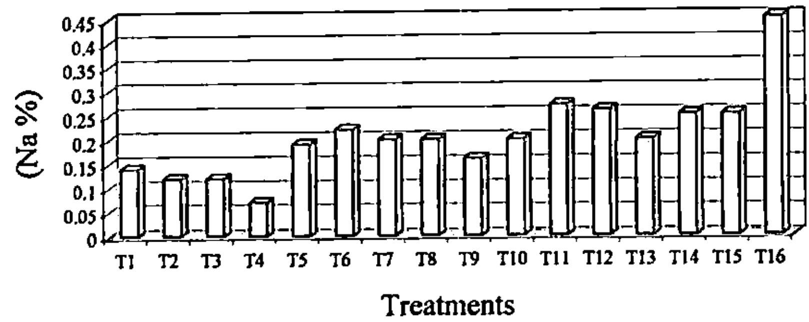


Fig. 29. Foliar sodium content of different standards

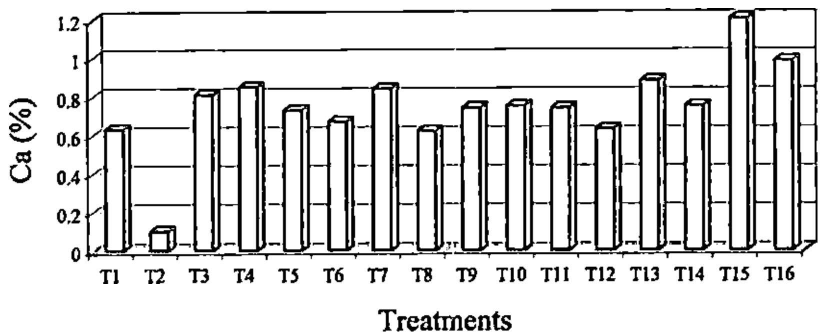


Fig. 30. Foliar calcium content of different standards

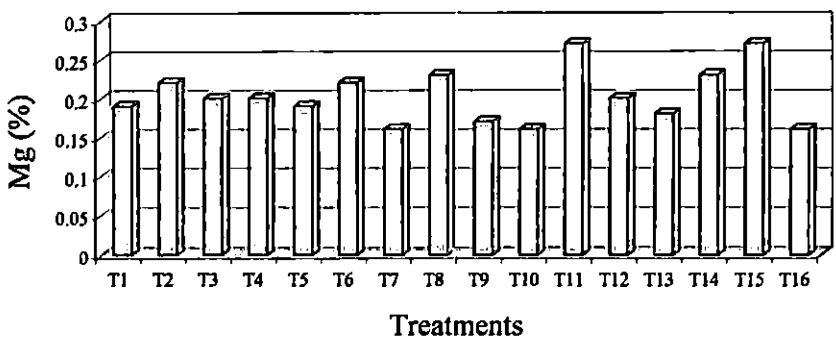


Fig. 31. Foliar magnesium content of different standards

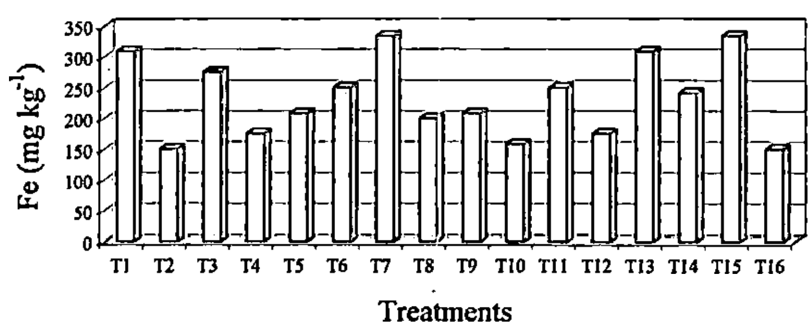


Fig. 32. Foliar iron content of different standards

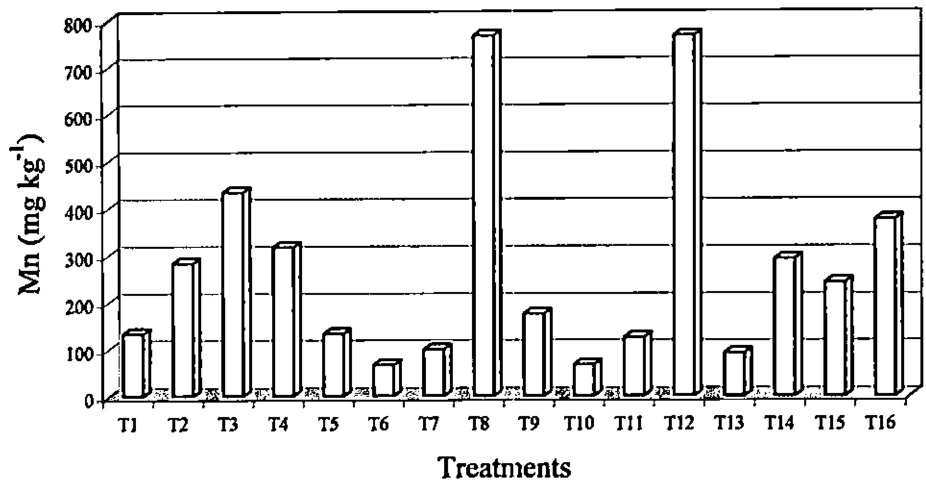


Fig. 33. Foliar manganese content of different standards

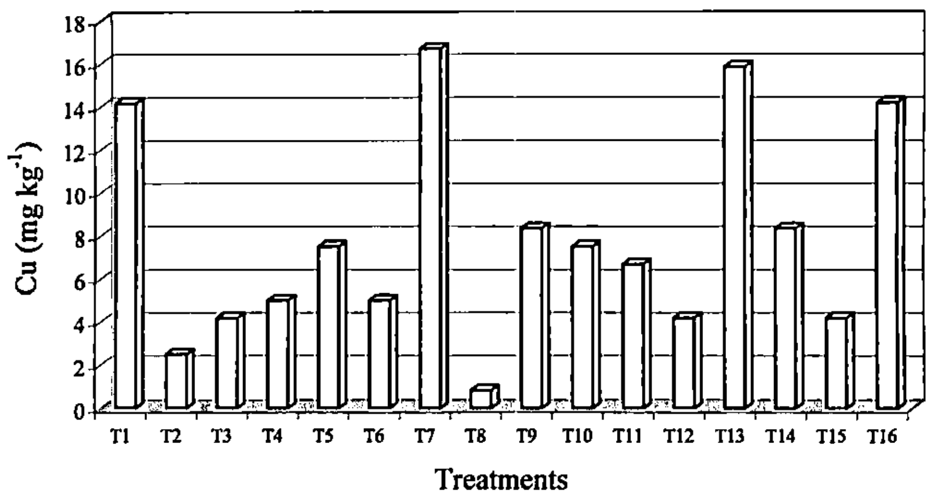


Fig. 34. Foliar copper content of different standards

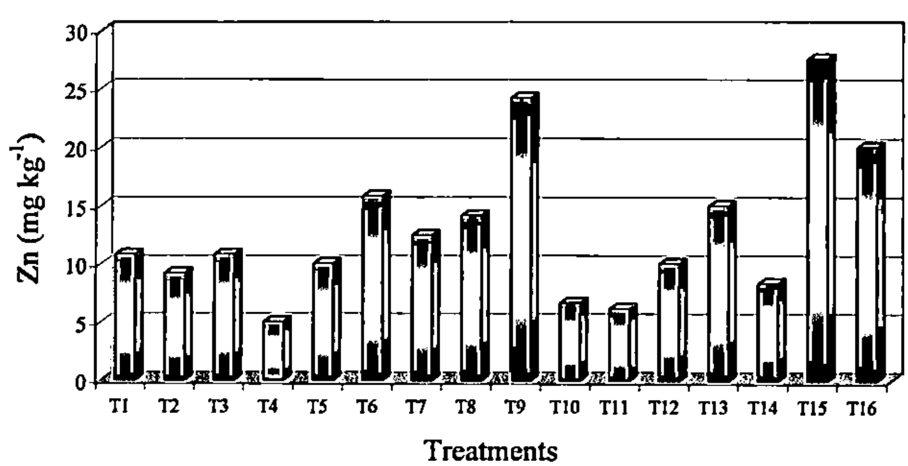


Fig. 35. Foliar zinc content of different standards

The study revealed the fact that in almost all cases there existed significant inter-specific differences in the foliar nutrient content (except for calcium and iron). A knowledge on the nutrient content along with the dry matter production of loppings and amount of litter addition from each species can give a picture on the potential of each plant species to recycle the nutrients to soil and mine soil nutrient resources. Budelman (1989) suggested leaf biomass as an important agricultural resource when modern industrially produced inputs are absent or too expensive. The value of leaf biomass depends on the intrinsic properties of the material collected, nutrient content, the amino acid composition of its protein, digestibility, resistance to decomposition and its use.

The information on leaf nutrient composition in tropical multipurpose trees is scarce and incomplete. Majority of the records does not give proper description of the parts of the plant sampled, the age of the material, the analysis technique used, nor environmental information on ambient climatic and soil conditions. The nutrient content of the leaves of *Leucaena leucocephala* was reported as 3.8 to 4.4 per cent N, 0.15 to 0.21 per cent P, 1.5 to 2.1 per cent K, 0.5 to 0.66 per cent Ca and 0.17 to 0.31 per cent Mg (Jones, 1979). In the present study also, nutrient content of *Leucaena* was found to lie in this range (3.45 % N, 0.17% P, 1.63% K, 0.88% Ca and 0.18% Mg). There are also other reports on nutrient content of *Leucaena* all of which do not have conformity to the results obtained in the present study (3.2 per cent N, 0.27 per cent P, 2.91 per cent K, 0.84 per cent Ca and 0.29 per cent Mg, Kang *et al.*, 1981; 3.12 per cent N, 0.16 per cent P, 2.0 per cent K, 2.0 per cent Ca and 0.40 per cent Mg, Chandhokar, 1982; 2.95 to 3.67 per cent N, 0.22 per cent P, 1.52 per cent K, 0.92 per cent Ca and 0.31 to 0.37 per cent Mg, Budelman, 1989 etc.). Reports on nutrient content of *Gliricidia sepium* also showed significant variation with location and age of the plant. Results obtained in the present study indicate a lower value for foliar nutrient content of *Gliricidia* (2.87% N, 0.21%P, 1.92% K, 0.74% Ca and 0.27% Mg) compared to other reports (4.21 per cent N, 0.29 per cent P, 3.43 per cent K, 1.40 per cent Ca and 0.40 per cent Mg, Vearasilp, 1981; 3.63 per cent N, 0.17 per cent P, 2.35 per cent K, 2.44 per cent Ca and 0.58 per cent Mg, Chadhokar, 1982; 4.0 per cent N, 0.28 per cent P, 3.33 per cent K, 1.60 per cent Ca and 0.42 per cent Mg, IITA, 1982) etc.

Variation in leaf nutrient content among species was due to the differences in soil nutrient resources, nitrogen fixation pattern, inherent ability of the plant in the uptake and assimilation of different nutrients which depend upon the root distribution pattern, rhizosphere soil characters etc. In all cases the better part of the nutrients of leaf biomass originates from the nutrient pool in the soil, and that the value of the perennials lies in making the nutrients available for primary production processes.

A comparison of the foliar nutrient content of a few multipurpose trees was attempted with the available reports. N, P, K, Ca, Mg, Fe, Mn, Cu and Zn content of *Azadirachta* was obtained as 2.16%, 0.17% p, 1.80% K, 0.73% Ca, 0.19% Mg, 208 ppm Fe, 133 ppm Mn, 7.5 ppm Cu and 10 ppm Zn respectively which was almost similar to the reports by Drechsel *et al.* (1991) in the case of N (2.05%), K (1.89 %), Cu (8ppm) and Zn (10 ppm) but differ for P (0.41%), Ca (2.74%), Mg (0.60%), Fe (160 ppm) and Mn (54 ppm). Gowda (2002) reported the foliar nutrient status of *Ailanthus triphysa* as 1.85 to 1.93 percent N, 0.09 to 0.11 per cent P and 0.81 to 0.96 per cent K which is comparable to the results obtained in the present study (1.73% N and 0.13% P) except for K (1.60%). He also reported the foliar nutrient content of *Grevillea robusta* as 1.56 to 2.0 per cent N, 0.09 to 0.13 per cent P and 1.03 to 1.13 per cent K which are in conformity to our results (1.54% N, 0.07% P and 10.7% K).

Foliar nutrient ratios of both pepper and standards were computed and compared. In pepper, the ratios N/P, P/K and P/Fe+Mn gave significant treatment variation (Table 19). Highest N/P ratio was recorded in pepper leaves when *Erythrina* was used as the standard followed by *Grevillea* and *Bombax* due to the higher foliar N content. Higher P/K ratio was observed when Acacia was used as the standard followed by *Garuga,* arecanut, *Azadirachta, Gliricidia and Grevillea.* The high P/Fe + Mn ratio in pepper leaves when teak pole was used as the standard may be due to the low foliar Mn content even though the leaves had good amount of P and Fe.

In the case of standards, significant variation was observed in the foliar nutrient ratios *viz.* N/P, N/K, P/K and P/Fe+Mn (Table 25). Coconut leaves possessed the highest N/P and N/K ratio due to high N and low P and K content in the leaves. P/K ratio was found maximum in the leaves of *Moringa* as it is the largest accumulator of P compared to other species.

The variation in the available nutrients as well as nutrient ratios in the leaves of pepper and different standards is the effect of differential uptake and accumulation of nutrients from the rhizosphere soil among the various tree species and difference in the intrinsic properties of the plant. Information on such aspects helps to determine the utility range of different biomass, which includes options such as supplementary feeding of cattle or poultry, mulching for soil protection or green manuring to improve soil fertility.

5.3.4.2.1 Addition of foliar biomass and nutrients from loppings

Loppings of standards on decomposition can enrich the rhizosphere soil of pepper with all the essential nutrients needed for the growth and development of pepper. The degree of soil enrichment varied with the quantity of foliar biomass added through loppings as well as their nutrient content. In the present study, it was observed that coconut and arecanut yielded the maximum foliar biomass considering the average annual leaf fall from a palm. This is realized when the fallen leaves are not removed from the field, but are added to the base of the palm itself. Among the other standards, *Ailanthus*, jack and *Gliricidia* were superior with respect to weight of loppings added.

When addition of nutrients from loppings of different standards was compared, significant variation was observed for N, P, K, Na, Ca, Mg, Fe, Mn and Zn. Addition of nitrogen was significantly higher from coconut which was on par with *Ailanthus, Gliricidia,* jack and *Leucaena.* Addition of P was also maximum from coconut followed by arecanut. Among the other multipurpose trees, jack and *Gliricidia* added significantly high amount of P through loppings. Maximum addition of K was recorded from coconut, which was on par with jack, *Ailanthus* and

Gliricidia. Minimum addition of potassium was observed from loppings of *Moringa.* Addition of calcium ranged from 2.30 to 217.19 g/yr with coconut significantly superior to all other treatments. Other standards, which added high amount of calcium, were arecanut and *Artocarpus.* Coconut was significantly superior to all other treatments regarding addition of magnesium also. Other standards, which added high amount of magnesium, were *Ailanthus*, arecanut, *Artocarpus* and *Gliricidia.* Addition of sodium was significantly high from coconut. All other treatments were on par.

Among the micronutrients studied, significant variation was obtained in the addition of Fe, Mn and Zn with coconut significantly superior to all other treatments. *Moringa* recorded the minimum addition of iron and zinc and *Bombax* added minimum amount of manganese through their loppings.

The results of the study indicate that coconut was significantly superior to all other standards regarding addition of all major and minor nutrients studied except for copper. This was partly due to the maximum quantity of recycling possible through heavy coconut leaves. A high nutrient addition can be realized when the leaves of the palm are added to its base itself and making nutrient recycling be possible. Among the other standards, arecanut, *Artocarpus, Ailanthus* and *Grevillea* could add comparatively higher amount of nutrients which was due to the greater amount of foliar biomass obtained through loppings. More nutrients could be available in the rhizophere soil of pepper when these standards are used for trailing pepper.

When George (2005) in a comparative evaluation on the addition of nutrients from loppings of six multipurpose trees *viz. Casuarina equisettifolia, Macaranga peltata, Ailanthus triphysa, Artocarpus heterophyllus, Acacia auriculiformis* and *Grevillea robusta*, used as the standards for pepper found that absolute amount of N, P and K added through loppings was maximum from *Artocarpus* and *Acacia* and *Grevillea* turned out to be the poorest supplier of all the nutrients.

5.3.5 Light infiltration through standards

The solar radiation available to pepper is a function of plant density, canopy shape, size and leaf area index. In the selection of standards for black pepper, tree species which can infiltrate a high proportion of available light and adequately expose the maximum number of fruiting sites is expected to give a good yield of pepper. This is especially important in Panniyur 1 which is relatively less shade tolerant than other popular varieties. The dry berry yield of black pepper was only 1.15 kg when trailed on teak pole which was low compared to those on all live standards except arecanut (1.0 kg), *Caesalpinia* (1.10 kg), *Leucaena* (1.03 kg) and *Moringa* (0.90 kg). One of the reasons for this may be the effect of high irradiance experienced by vines trailed on teak pole which resulted in high rate of transpiration. This result in internal deficiencies of water and a consequent retardation of cell division or cell elongation. Light was highly limiting under the canopy of *Caesalpinia* (11.50 per cent) due to wide spread canopy at a lower height and under *Gliricidia* (19.30 per cent) and *Artocarpus* (19.80 per cent) due to the greater spread of canopy (Fig.23). In spite of the higher shade effect of *Artocarpus*, pepper vines trailed on it gave a high yield of 2.19 kg per vine. Although light is only one of the growth limiting factors in pepper, excessive shade and excessive light deleteriously affected the productivity of the vine. Excessive shade reduces transpiration, metabolism, growth and the demand for soil nutrients in addition to the reduction in photosynthesis. This was better explained by Mathew *et al.* (1996) who observed that the profuse branching, increased height and highest foliage observed in *Gliricidia sepium* have induced excessive shade for pepper vine trained on it which have affected deleteriously the photosynthetic efficiency of pepper which in turn reduced the yield. The different multipurpose trees studied differed substantially in terms of height, crown size, canopy spread and leaf morphology which facilitated different levels of infiltration of solar radiation and photosynthetically active radiation (PAR) reaching the canopy profiles of pepper vine thus influencing the photosynthetic efficiency and productivity. Mathai (1983) had reported that a check in the availability of solar radiation due to the wide spread foliage of the live standards can possibly affect the productivity character of pepper vines trailed on them.

5.4 CORRELATION STUDIES

Inorder to realize the effect of various factors like growth characters of pepper, soil chemical properties, plant nutrient availability and availability of light on dry berry yield of pepper, correlation studies were conducted.

5.4.1 Morphological characters and yield

The results of the correlation studies revealed that the characters of the vines such as height of bearing column and number of spike bearing laterals per 0.25 m^2 recorded significant positive correlation with dry berry yield in pepper (Table 27). Positive correlation was also observed with spread at chest height, number of spikes per 0.25 m^2, spike length, pedicel length, number of berries per spike and spike compactness and dry berry yield of pepper. The results support the findings of Stephen (2002) who got significant positive correlation for characters like height of bearing column, spread at chest height, number of laterals and number of spikes per 0.25m^2, length of spike and number of berries per spike with dry yield of pepper. Similar results were also obtained by Satheesan (2000) and Thanuja (2003). The results also support the findings of Ibrahim *et al.* (1985) who reported that number of spikes per vine, length of spike and number of developed berries per spike were the most important characters influencing yield in black pepper. Sujatha (1991) and Sujatha and Namboodiri (1995) also reported that characters such as number of spikes per vine, length of spike and number of developed berries per spike registered high positive correlation with yield. Positive direct effect of height of bearing column on nut yield of cashew had been reported earlier (Bhaskar, 1993 and Nalini, 1997).

5.4.2 Available soil nutrients and yield

Among the rhizosphere soil characteristics studied organic carbon, available P, available Ca and available Mg in the surface soil were found positively correlated with yield (Table 28). On the other hand, available K, available Na and all the micronutrients i.e., Fe, Mn, Cu and Zn were negatively correlated with the dry berry yield. In the subsurface samples also a similar trend was noticed for micronutrients. Among all the available nutrients studied, available Mn had a significant negative influence on dry berry yield in both layers of soil(r = -0.384** in surface and -0.484** in subsurface soil respectively) and copper in surface soil (r = -0.319*). The negative influence of micronutrients like manganese and copper in the rhizosphere soil on dry berry yield of black pepper indicates the fact that these soils are excess in Cu and Mn and these nutrients should be managed restrictively to sustain a higher level of crop production.

Mathew *et al.* (1995) reported that in black pepper, a positive correlation was observed between yield and soil pH, organic carbon, available and exchangeable Ca and available and exchangeable Mg. Significant correlations existing among these soil parameters indicate that Ca and Mg saturation of the exchange sites was responsible for increasing the soil pH. In the present study also, a positive correlation was obtained for organic carbon, available Ca and Mg in the surface soil with yield of pepper.

Sreekumaran (1998) in his study on rhizosphere soil of black pepper observed that the negative relationship of P and K with yield may be due to the continued application of same level of fertilizers to all plants irrespective of the yield. While Zn had a positive effect, Mn had a negative effect, which indicate that yield analysis based on major nutrients alone is incomplete. The results of the present study is in conformity to these reports in the case of effect of manganese on yield of pepper, where a significant negative correlation was obtained.

5.4.3 Available plant nutrients and yield

When nutrient content of pepper leaves was correlated with yield of black pepper, no significant influence of any of the nutrients in the pepper leaves on dry berry yield of black pepper was noticed (Table 29). But the foliar nutrient content of standards had a significant and negative effect on yield for P, Fe and Cu (r = -0.498**, -0.427** and -0.478** respectively) whereas there was a positive effect for Mn (r = 0.459**). Except for Mg and Mn all the nutrients in the leaves of standards had a negative effect on dry yield of black pepper.

Sushama *et al.* (1984) observed significant positive correlation of yield of black pepper with P and K content of pepper leaves where as N content failed to establish a significant correlation with yield. Nybe *et al.* (1989) observed that nutrient element P, K, Ca, Mg and S were found to exert direct and indirect effect on yield of green pepper. Of these P and K were found to be of greater importance in enhancing the yield. Sadanandan and Rajagopal (1989) found that the P indices (P/N+P+K+Ca) of both the youngest matured and next matured leaves gave significant correlation with yield. Mathew (1995) obtained significant correlation between foliar nutrients and yield of black pepper. While the correlations between yield and the concentrations of S, P and K were negative, for other nutrients it was positive. The highest positive correlation was found between leaf N and yield. In the present study, none of the foliar nutrients of pepper was significantly correlated with yield. This shows that even though the nutrient content of pepper leaves was influenced by the different standards used, its effect on the yield of pepper was not significant.

5.4.4 Available soil nutrient and plant nutrient

When available nutrient status of soil was correlated with foliar nutrient content of pepper, significant negative correlation was observed between organic carbon content of surface soil and foliar N content of pepper as well as available sodium content of subsurface soil and sodium content of pepper (Table 30). Although nonsignificant, negative correlation was also observed between the soil and plant samples of pepper for P, K and Fe in both layers of soil, Ca, Mg and Zn for subsurface samples and Mn and Cu for surface samples. However, Mathew (1993) observed a direct relation between soil organic matter content and leaf N content in black pepper. Such a trend was not obtained for P whereas ammonium acetate extractable K and Ca showed a positive correlation with the corresponding leaf nutrient.

In the standard, potassium in the subsurface soil had a negative correlation with that in the leaves (Table 31). Significant negative correlation was also obtained between sodium content of both soil layers and foliar nutrient status of sodium in standards. A positive correlation of organic carbon, available Ca, Mg and Cu in the rhizosphere soil with N, Ca, Mg and Cu content in the foliar samples of standard indicates that the foliar nutrient status of standards is a better indication of the available nutrient content in the rhizosphere soil at least for the above nutrients. A negative correlation of available P, K, Fe and Mn in the rhizosphere with the corresponding elements in the standard reveals the fact that the soil in the experiment field is abundant in those nutrients and a higher content in the soil cannot make considerable effect on the uptake by different standards.

OVERALL PERFORMANCE OF PEPPER TRAILED ON DIFFERENT STANDARDS

Inherent low fertility and its further deterioration are recognized as the major constraints to agricultural production under humid tropical environment. Both scientific research and farmer's observations clearly point to the need to improve current farming practices with respect to their ability to improve and sustain soil fertility and productivity. Trees with their numerous beneficial effects on soil fertility play an important role in this strategy.

In an attempt to evaluate the performance of pepper trailed on different live standards and a dead standard, both below ground and above ground interactions between the crop and the standards were analysed. The most important criterion for selection of suitable standard is invariably the yield of pepper trailed on it. Based on dry berry yield of pepper, standards were grouped into high yield, medium yield and low yield groups (Table 34). The different factors contributing to yield in each group were critically evaluated to make the selection of standards more reliable.

High yield group

Coconut followed by jack and *Ailanthus* were the superior standards with respect to yield of pepper and belonged to the high yield group.

Kerala homesteads are predominantly coconut based and trailing pepper on coconut gives an additional income to the farmer. Although trailing pepper on coconut has been an age-old practice in the homesteads of Kerala, the system has not been widely practiced on an intensive scale among farmers. Pepper gave the maximum average yield of 9.25 kg fresh yield per vine and a dry yield of 3.17 kg/vine when trailed on coconut. Pepper also recorded the maximum height of bearing column, number of laterals per 0.25 m^2, number of berries per spike and spike compactness in this treatment. Spread of pepper vine around the trunk, number of spikes per 0.25 m^2 and spike length were also higher when trailed on coconut. When root level interactions between pepper and standards were studied, it was observed that pepper absorbed more ^{32}P applied than coconut at 30 days as well as 45 days after application. This indicates that coconut does not compete for water and nutrients with pepper in its feeding zone. Earlier reports also suggest that the effective foraging space (EFS) of pepper and coconut are not the same (Anilkumar and Wahid, 1988 and Sankar *et al.*, 1988). In the present study, yield of pepper was found adversely affected by the higher micronutrient status of Mn and Cu in the rhizosphere soil. In this aspect also, trailing pepper on coconut was advantageous because the rhizosphere soil of pepper trailed on coconut was found to be comparatively low in the levels of the above nutrients. Also, the biomass addition and thereby nutrient cycling were found the maximum from coconut if the fallen leaves were recycled back to the palm base. This advantage for trailing pepper is in addition to the diverse products obtained from coconut - the Kalpavriksha - which makes the pepper - coconut mixed cropping system more productive and economically viable.

Next to coconut, jack gave the highest fresh yield of 7.14 kg/vine and a dry berry yield of 2.27 kg/vine. As in the case of coconut, pepper had a tall and well-spread bearing column when trailed on jack. Pepper absorbed more ^{32}P than jack at 30 days after application indicating a low level of root competition for below ground resources. Foliage biomass addition through loppings was also high from jack, which on decomposition can enrich the rhizosphere soil. One of the disadvantages on using jack as the standard for pepper was the intense shade effect of the tree, which can be reduced by proper pruning of side branches. In addition to being an excellent standard for pepper, jack is a versatile tree species yielding good quality timber, which is fairly strong and durable with high timber value of around Rs. 14000 per m^3. Fruits also have varied uses such as in culinary purpose and confectionaries like halwa, chips etc.

Another tree found promising as the standard for pepper was *Ailanthus triphysa*, which is a commonly seen multipurpose tree in the homesteads of Kerala. Pepper gave a fresh yield of 6.83 kg/vine and a dry yield of 2.27 kg/vine when trailed on *Ailanthus*. It had a tall bearing column and more number of laterals as well as spikes per 0.25 m^2. The root competition for water and nutrients was also less when *Ailanthus* was used as the standard as evidenced from the ^{32}P studies. Deep tap root system of *Ailanthus triphysa* had been reported earlier (Jamaludheen, 1994). Nutrient addition through loppings of *Ailanthus* was also high. The level of micronutrients (Mn and Cu) adversely affecting the yield of pepper was low in the rhizosphere soil of pepper trailed on *Ailanthus*. Other advantages of *Ailanthus* are its strong stem, evergreen nature and suitability for packing cases, match boxes, paper pulp etc. Based on the present study, *Ailanthus* has been proven to be an ideal standard for trailing pepper.

Medium yield group

In this group, pepper trailed on *Grevillea* recorded the maximum yield of 6.24 kg fresh yield per vine. Eventhough height of bearing column was more for *Grevillea*, number of laterals as well as number of spikes per 0.25 m^2 were less. The root level competition as measured by ^{32}P uptake was low. *Grevillea* is used as a shade tree in tea and coffee plantations. Performance of pepper on *Grevillea* under such situations was reported to be good (Pugalendhi *et al.*, 1997). Eventhough *Grevillea* was found to grow tall in the experimental garden, its vigour was poor unlike those in the mild weather situations of coffee and tea plantations. This could be the reasons for the relatively poor performance of pepper on *Grevillea* compared to coconut, jack and *Ailanthus*.

Pepper when trailed on *Garuga pinnata* yielded 5.25 kg fresh yield/vine. Severe root competition exerted by *Garuga* on the pepper vine trailed on it was indicated by a higher uptake of ^{32}P by *Garuga* than the pepper trailed on it. This may be due to the overlapping of feeding zones of pepper and *Garuga*. However, among standards propagated through stem cuttings, pepper on *Garuga* recorded highest yield.

For quick establishment of a new pepper garden either as a pure crop or in the interspaces of coconut on separate standards, *Garuga* may be considered as the ideal standard. Moreover the deciduous nature of the plant permits maximum solar radiation for pepper during its period of high light demand.

Pajanelia followed *Garuga* with respect to yield of pepper trailed on it, with a fresh yield of 4.30 kg/vine. Although the height of bearing column of pepper was more (5.81 m) when tailed on *Pajanelia*, number of laterals as well as spikes per 0.25 m^2 area was less. Also, competition for below ground resources was high as evidenced by the higher uptake of ^{32}P by standard than pepper. A high level of micronutrient status especially for Fe and Mn was observed in the rhizosphere soil which also must have negatively influenced the yield of pepper. Although *Pajanelia* is a fast growing multipurpose tree it is prone to wind damage. All these factors makes *Pajanelia* a less promising standard for pepper.

Pepper yielded a mean fresh yield of 4.21 kg/vine when trailed on *Azadirachta indica*. Although pepper had a tall bearing column when trailed on *Azadirachta*, spread at chest height, number of laterals and spikes per 0.25 m^2 were low compared to other standards. A high competition for applied ^{32}P was observed between pepper and standard. Another disadvantage of neem when used as the standard of pepper was its sensitivity to pruning and susceptibility to die back and also the slow rate of growth as neem is propagated through seedlings. Many neem trees in the experimental field were dried up resulting from die back of branches.

Another standard falling in the medium yield group was *Acacia mangium* on which pepper gave a fresh yield of 4.05 kg/vine. Inspite of the tall bearing column, more number of laterals and spikes per 0.25 m^2, a high yield could not be realized by pepper trailed on *Acacia*. A main reason could be the high level of root competition between the pepper and standard which was indicated by the higher uptake of ^{32}P (at 30 and 45 DAA) by *Acacia* compared to pepper. Also a higher micronutrient status was reported in the rhizosphere soil of pepper - *Acacia* combinations. *Acacia mangium* does not have a deep root system and is reported to be sensitive to drought

(Animon *et al.*, 1995). Die back of mangium resulting in total damage of the tree was found occasionally in the field.

Bombax malabaricum as a standard for pepper was evaluated and pepper yielded only 3.93 kg fresh berries per vine on it. Pepper had a low height of bearing column, lesser spread at chest height, lesser number of laterals and spikes per 0.25 m^2. Moreover *Bombax* exerted a competitive effect on pepper with respect to ^{32}P uptake at 30 DAA. So, *Bombax* could not prove to be a desirable standard for pepper.

Performance of pepper on *Thespesia populnea* was not satisfactory, where a mean fresh yield of only 3.74 kg/vine was obtained. Pepper experienced severe root competition from *Thespesia* as indicated by a higher ^{32}P uptake by *Thespesia* than pepper. The tree was also slow growing and not found to be suitable as standard for pepper.

Erythrina, a popular standard of pepper could not give a high yield of pepper when trailed on it. A fresh yield of only 3.70 kg/vine was obtained from the pepper trailed on *Erythrina*. A high level of competition at the feeding zone of pepper was indicated by the higher uptake of ^{32}P by *Erythrina* than pepper trailed on it. Reports on overlapping of effective foraging space of pepper and *Erythrina* (Sankar *et al.*, 1988) was confirmed by the results of the present study. This must have resulted in the low yield of pepper. During recent times, severe infestation of stem borer *viz. Terestia meticulosalis* causing extensive foliar damage has been reported in *Erythrina*. This makes the farmers reluctant to use *Erythrina* as standard in pure pepper gardens. Probably because of the easiness in multiplication, *Erythrina* became a popular standard for pepper in the past.

Gliricidia sepium, another popular standard for pepper, could not perform well in the present study. Various reasons attributed to the low yield of pepper were low height of bearing column, lesser number of laterals and spikes per 0.25 m^2 etc. Root level competition, with respect to ^{32}P uptake pattern, was also high. Vasu *et al.* (1994) had reported earlier the zone of maximum root activity of *Gliricidia* based on ^{32}P uptake which was found to lie in the effective foraging space of black pepper as explained by Wahid (2000). Although *Gliricidia* is easy to establish, fast growing, yield good amount of biomass on lopping, it could not be recommended as an ideal standard for pepper.

The least performance of unconventional species used as the standard for pepper was by *Caesalpinia sappan*. The low yield of pepper (3.52 kg/vine) was due to the low height of bearing column, relatively weak stem, minimum spread of vine around the stem of standard, excessive branching which cause excessive shade under the canopy, high competition for nutrients in the rhizosphere soil, poor ability to withstand lopping etc. Due to these reasons, *Caesalpinia* could not be recommended as a good standard for pepper in a mixed cropping situation like that in homesteads.

Eventhough there are earlier reports of superiority of teak pole to *Erythrina*, a common standard of pepper, in the present study performance of teak pole as a standard was not on par with many live supports. A fresh yield of only 3.68 kg/vine could be obtained in the present study. The growth of pepper was in general poor with low height of bearing column, lesser number of laterals per 0.25 m^2. Eventhough no competition for below ground resources was experienced by the vine from the standard, a high yield could not be obtained. There are several drawbacks observed in using dead standards to trail pepper. On a long term basis, growth of pepper is poor probably due to exposure to hot dry weather during the drought period, which stretches for over five months. Smooth surface of teak pole does not provide an ideal texture for the growth of pepper. Pepper on teak pole can probably give satisfactory results only when managed under ideal conditions.

Low yield group

The standards found inferior with respect to yield of pepper were arecanut, *Leucaena* and *Moringa*.

Eventhough arecanut is a conventional standard for pepper and had a tall bearing column of pepper trailed on it, growth of pepper on arecanut was not luxuriant. Yield was low due to the lesser spread of vine around the palm and lesser number of laterals per 0.25 m^2.

Support trees like *Leucaena* and *Moringa* also showed a poor performance of pepper trailed on it with very low yield and stiff competition in the feeding zone.

Laterite soils of Kerala are generally reported to be high in Fe, Al and Mn. A general observation of the study was that the experimental field had a higher level to the tune of toxicity of micronutrient status especially copper and manganese, which could adversely affect the yield of pepper. This should be given due importance while planning nutrient strategies for improvement of production in pepper. A high copper content of soil observed could be due to regular prophylactic drenching and spraying of copper fungicides in the field.

Complimentary interaction between support tree and pepper has a major role in improving the yield of pepper. Results of the present study points to the superiority of coconut, jack and *Ailanthus* as supports of pepper. Such intensive integration of diverse but compatible cropping models will open up multiple sources of income and employment besides strengthening the ecological base of farming. For quick establishment of pepper gardens in plains, either as a pure crop or in the interspaces of coconut, *Garuga* could be recommended as a support tree which is fast growing, easy to propagate through cuttings and gives a medium yield of pepper.

Summary

SUMMARY

Black pepper is a small holder's crop in most pepper producing countries and more than one million farmers depend on it for their livelihood. In India, 95 per cent of production is from homesteads with promiscuous planting of black pepper along with perennials. Providing ideal support plays an important role in successful establishment of pepper holdings.

The present investigation on "Crop-standard interactions in black pepper (*Piper nigrum* L.)" was carried out at the Department of Plantation Crops and Spices, College of Horticulture with the main objective of selecting ideal standard(s) or supports for trailing pepper. Salient findings of the study are summarized as follows:

1. Characterisation of rhizosphere soil of black pepper trailed on different standards

i) Electrochemical and available nutrient status of rhizosphere soil of pepper trailed on different standards

a) Rhizosphere soil of pepper vines trailed on the dead standard had higher pH compared to other standards.

b) No significant variation was observed in the organic carbon, available P, K, Ca, Mg and Fe in surface samples and organic carbon, available P, K, Fe, Mn and Zn in subsurface samples.

c) When nutrient ratio, P/Fe + Mn was computed and compared among various treatments, those with *Bombax*, coconut and *Gliricidia* as standards recorded the maximum ratio in surface samples and those with *Thespesia*, coconut and *Pajanelia* as standards recorded higher ratio in subsurface samples.

d) Variation in the nutrient ratio, K/Ca + Mg + Fe + Mn was not significant in both soil layers.

e) Rhizosphere soil of pepper trailed on coconut had the least availability of manganese in both surface and subsurface samples.

f) Copper content of rhizosphere soil of pepper trailed on teak pole was the highest in surface and subsurface samples followed by *Acacia* and *Grevillea*. The treatment with coconut as the standard recorded the least availability of copper in both soil layers.

g) Cation exchange capacity (CEC) of soil differed significantly in the surface soil. Maximum CEC was recorded in the rhizosphere soil of pepper-coconut combination followed by *Leucaena, Acacia* and *Caesalpinia*.

h) Exchange complex was dominated by calcium followed by magnesium, sodium and potassium in surface soils and calcium followed by sodium, magnesium and potassium in subsurface soil. In both layers of soil, highest exchangeable Ca was observed under rhizosphere soil of pepper trailed on coconut.

ii) Soil biological properties of rhizosphere soil

a) Population of fungi, bacteria, actinomycetes, nitrogen fixing bacteria and phosphate solubilising bacteria varied significantly in the rhizosphere soil of different pepper-standard combinations.

b) Population of nitrogen fixing bacteria and phosphate solubilising bacteria was higher in the rhizosphere soil of pepper vines trailed on *Artocarpus* and *Garuga* and lower in *Ailanthus* and *Erythrina*.

c) No significant variation was observed among various treatments with regard to dehydrogenase and phosphatase activity of rhizosphere soil.

2. Root level interaction between pepper and standard employing radiotracer technique

a) Absorption pattern of ^{32}P varied substantially among various standards used as well as with the period of sampling.

b) Pepper vines trailed on *Acacia, Artocarpus, Caesalpinia, Erythrina, Gliricidia, Grevillea* and teak pole recovered maximum ^{32}P at 30 days after application whereas those on *Ailanthus, Azadirachta, Bombax, Garuga, Leucaena, Moringa, Pajanelia* and *Thespesia* absorbed maximum ^{32}P at 45 days after application, thereafter declined.

c) When arecanut and coconut were used as standards, absorption of ^{32}P was maximum at 15 days after application and thereafter declined.

d) Considerable variability existed among various standards in influencing the uptake of ^{32}P by the pepper vines trailed on them.

e) Maximum absorption of ^{32}P by the pepper vines occurred when teak pole was used as the standard which can be considered as a monoculture system.

f) When percentage distribution of ^{32}P uptake by pepper and standard in each combination was compared, it was noticed that pepper recovered more ^{32}P than the corresponding standard when trailed on *Ailanthus*, arecanut, coconut and *Grevillea*. These standards are thus expected to have a complementary interaction with the pepper vine with respect to ^{32}P uptake.

g) *Artocarpus, Azadirachta, Bombax* and *Pajanelia* were also expected to exert a complimentary effect on pepper vine as the ^{32}P uptake by pepper was more than the corresponding standard either at 30 or 45 days after application.

h) Standards like *Acacia, Bombax, Caesalpinia, Erythrina, Garuga, Gliricidia, Leucaena, Pajanelia* and *Thespesia* were found to have a competitive influence on the pepper trailed on them with respect to ^{32}P uptake.

3. Shoot level interaction between pepper and standard

i) Growth characters of pepper as influenced by standards

a) There was significant variation in the height of bearing column of pepper, spread at chest height, number of laterals per 0.25 m^2, number of spikes per 0.25 m^2, spike length, pedicel length, number of pinheads per spike and hundred berry weight among various treatments.

b) Height of bearing column of pepper was maximum (7.83 m) when trailed on coconut followed by *Artocarpus* (6.67 m). It was also more when *Acacia*, arecanut, *Azadirachta, Grevillea* and *Pajanelia* were used as the standards.

c) Coconut was superior to all other standards with respect to other growth characters like number of laterals per 0.25 m^2, number of berries per spike and spike compactness and had higher values for spread at chest height, number of spikes per 0.25 m^2 and spike length.

ii) Influence of standards on yield of pepper

a) Highest yield of pepper was obtained when trailed on coconut with a fresh yield of 9.25 kg followed by *Artocarpus* (7.14 kg), *Ailanthus* (6.83 kg) and *Grevillea* (6.24 kg).

b) Grouping of standards was done based on the dry berry yield of pepper trailed

1) High yield group – Coconut, *Ailanthus and Artocarpus*

2) Medium yield group – *Grevillea, Garuga, Acacia, Azadirachta, Pajanelia, Thespesia, Bombax, Gliricidia, Erythrina, Caesalpinia* and teak pole

3) Low yield group – *Leucaena,* arecanut and *Moringa*

c) Pepper trailed on teak pole, the dead standard, yielded only 3.68 kg/vine, which is lower than all other treatments except arecanut, *Caesalpinia, Leucaena* and *Moringa.*

iii) Influence of standards on quality of pepper

a) Quality attributes of pepper viz. oil, oleoresin and piperine significantly varied among various treatments.

b) Essential oil content was maximum (2.85 per cent) when pepper was trailed on *Garuga* and minimum (1.70 per cent) when trailed on *Bombax.*

c) Oleoresin content ranged from 9.36 to 13.43 per cent with T_{13} recording the maximum value and T_{11}, the minimum.

d) Piperine content was found maximum in T_{15} (6.31 per cent) and minimum in T_3 (4.48 per cent).

iv) Variation in foliar nutrient status of pepper as influenced by standards

a) Significant variation in the nutrient content of leaves of pepper was observed for all the nutrients except P, Cu and Zn.

b) Nitrogen content of pepper leaves ranged from 1.08 to 2.35 per cent, phosphorus content from 0.10 to 0.46 per cent, potassium content from 1.10 to 2.63 per cent, sodium content from 0.11 to 0.37 per cent, calcium content from 0.49 to 1.24 per cent, magnesium content from 0.12 to 0.84 per cent, iron content from 150.00 to 368.33 mg kg^{-1}, manganese content from 108.33 to 775.00 mg kg^{-1}, copper content from 2.50 to 12.50 mg kg^{-1} and zinc content from 1.17 to 15.00 mg kg^{-1}.

v) Foliar nutrient status of standards

a) Different standards varied significantly with respect to foliar nutrient status for all the nutrients analysed except for Ca and Fe.

b) Nitrogen content was maximum in *Leucana* followed by *Gliricidia.*

c) Phosphorus content of leaves of standards ranged from 0.06 to 0.40 percent and potassium content from 0.25 to 1.97 per cent.

d) Foliar magnesium content was highest in *Gliricidia* and *Pajanelia* (0.27 per cent) and lowest in *Caesalpinia*, *Garuga* and *Thespesia* (0.16 per cent). Sodium content ranged from 0.07 to 0.45 per cent.

e) Foliar iron content varied from 150.00 to 333.33 mg kg^{-1}.

f) Manganese content varied significantly among various treatments and ranged from 66.67 to 766.67 mg kg^{-1}.

g) Copper content was highest in *Caesalpinia* (16.67 mg kg^{-1}) and minimum in coconut (0.83 mg kg^{-1}).

h) Zinc content varied from 5.00 to 27.00 mg kg^{-1}.

i) When foliar nutrient ratios in pepper were compared among the treatments, the ratio N/P, P/K and P/Fe+Mn gave significant treatment variation.

j) Highest N/P ratio was recorded when *Erythrina* was used as the standard and P/K ratio when *Acacia* was used as the standard. Leaves of pepper trailed on teak pole recorded highest P/Fe+Mn ratio.

k) In the standards, significant variation was observed in the foliar nutrient ratios viz. N/P, N/K, P/K and P/Fe+Mn.

l) Coconut leaves possessed the highest N/P and N/K ratio due to high N and low P and K content in the leaves. P/K ratio was found maximum in the leaves of *Moringa*.

vi) Addition of foliar biomass through loppings of standards

a) Maximum amount of foliar biomass was added from coconut followed by arecanut taking annual leaf fall of these palms into consideration.

b) Among the standards other than coconut and arecanut, weight of loppings was high from *Ailanthus, Artocarpus* and *Gliricidia.*

vii) Nutrient addition from loppings of standards

a) Significant variation was observed in the amount of nutrients added through loppings of standards for all the elements studied except for Cu.

b) Coconut was significantly superior to all other treatments regarding addition of all major and minor nutrients.

c) Besides coconut, *Ailanthus, Artocarpus, Gliricidia* and *Leucaena* recorded higher addition of N.

d) Addition of phosphorus was high from loppings of *Artocarpus* and *Gliricidia.* Standards which recorded significantly higher addition of K were *Ailanthus, Artocarpus, Garuga* and *Gliricidia* besides coconut.

e) Addition of calcium was high from arecanut and *Artocarpus* and magnesium from *Ailanthus,* arecanut, *Artocarpus* and *Gliricidia* besides coconut.

viii) Light interception by pepper vines trailed on different standards

a) Maximum amount of light was intercepted when teak pole, the dead standard, was used which can be considered as a monocrop situation.

b) Light was very low under the canopy of *Caesalpinia* (11.00 per cent), *Gliricidia* (19.30 per cent) and *Artocarpus* (19.80 per cent).

c) Standards which infiltered comparatively more quantum of sunlight were *Bombax* (35.07 per cent), arecanut (30.80 per cent) and *Pajanelia* (30.40 per cent).

ix) Correlation studies

a) Among the different growth characters of pepper studied, height of bearing column and number of spike bearing laterals per 0.25 m^2. recorded significant positive correlation with dry berry yield of pepper.

b) Positive correlation was also observed for spread at chest height, number of spikes per 0.25 m^2, spike length, pedicel length, number of berries per spike and spike compactness with dry yield of pepper.

c) Among the rhizosphere soil nutrients studied, organic carbon, available P, Ca and Mg in the surface soil were found positively correlated with yield and all other nutrients studied viz. K, Na, Fe, Mn, Cu and Zn had a negative correlation with yield.

d) Available Mn and Cu had a significant negative correlation with yield of pepper which indicates the presence of these native elements in excess in the experimental field.

e) None of the foliar nutrients of pepper had a significant correlation with yield of pepper.

f) Foliar nutrient content of P, Fe and Cu in standards had a significant negative correlation and Mn had a significant positive correlation with yield of pepper.

g) When different nutrient elements in soil and plant were correlated, significant negative correlation was observed between organic carbon content of surface soil and foliar N content of pepper as well as available sodium content of subsurface soil and sodium content of pepper.

h) In standard, potassium in the subsurface soil had a significant negative correlation with that in leaves.

i) Significant negative correlation was also obtained between sodium content of both layers of soil and sodium content of leaves of standards.

From the present study, it could be concluded that the most ideal standard for trailing pepper is coconut followed by jack and *Ailanthus*. For quick establishment *Garuga* could be recommended as the standard.

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Appendices

APPENDIX I

Description of multipurpose trees used in the study

1. *Acacia mangium* Willd. (Family - Mimosaceae)

Acacia mangium is an evergreen, leguminous tropical tree popular for its rapid early growth. It generally grows to a height of 25-35 m with straight bole which may be over half of the total height with a diameter at breast height of over 60 cm. The sapwood is white and sharply defined from the darker brown heartwood. The wood makes attractive furniture, doorframes, window parts, cabinets and is useful in paper and pulp manufacture. The value of its wood is about Rs.2500 m^{-3}.

2. *Ailanthus triphysa* (Dennst.) Alston (Family – Simaroubaceae)

Ailanthus triphysa is a medium sized deciduous tree with cylindrical bole and narrow crown reaching a maximum heightof 30 m. The tree is a strong light demander especially during the initial stages of growth. *Ailanthus* is a dominant woody perennial component in the homesteads of Kerala. It is used in matchwood, packing case, paper and pulp industries and the wood value is about Rs.3000 m^{-3}.

3. *Areca catechu* L. (Family – Palmae)

A tall slender palm with a smooth whitish stem reaching a height of 40-60'. The palms require a moist tropical climate for luxuriant growth and are very sensitive to drought. It is a shade loving plant and is generally grown as a mixed crop with fruit trees, coconut etc. It thrives on a variety of soils such as laterite soils, alluvial soils, dark fertile clayey loams etc. Arecanut is used as a masticatory throughout India, Burma, Sri Lanka and Malaysia. The stem is used in various ways in house construction, pillars, reapers etc. Leaf sheaths are commonly used as packing materials. Spathe, which is tough and impervious to water, is used in the manufacture of disposable cups and plates.

4. *Artocarpus heterophyllus* Lamk. (Family - Moraceae)

It is a large evergreen tree with a short thick bole and a dense round crown of dark green foliage. The bark of the tree is dark brown and rough. Jack tree is one of the most common species in the home gardens of Kerala. The tree is a good shade bearer, drought and frost sensitive. Unripe jackfruit is used as a vegetable while the ripe one is eaten fresh or preserved in syrup. The wood is of medium weight, fairly strong, durable and not attacked by fungi or white ants. It is of excellent quality, suitable for general carpentry work, plain furniture, brush backs, inlay works and turnery. The wood fetches a high price of about Rs.13800 m^{-3}.

5. *Azadirachta indica* A. Juss. (Family - Meliaceae)

A large evergreen tree attaining a maximum height of 18 m and girth of 24 m with a straight bole and long spreading branches forming a broad crown commonly found throughout the greater part of India and often cultivated. Bark is dark grey with longitudinal or oblique furrows on the outer surface and rough. The timber seasons well and are durable even in exposed situations and not attacked by white ants. It is recommended for general construction, door shutter, furniture, tool handles, railway sleepers and general-purpose pallets. Almost every part of the tree is bitter and has found application in indigenous medicine. The seed oil is used in skin diseases, applied in cases of rheumatism and is reputed to possess anthelmintic and insecticidal properties. The bark is a good bitter tonic, astringent and antiperiodic and regarded as beneficial in malarial fever. The softwood of neem is now becoming popular for the manufacture of interior furnitures because of its insect repellant property. The wood values about Rs.4000 m^{-3}.

6. *Bombax malabaricum* DC. (Family - Bombacaceae)

A lofty, deciduous tree up to 40 m in height and 6 m or more in girth with a clear bole of 24-30 m, widely distributed throughout India. Branches horizontally spreading, more or less in whorls; young stems and branches covered with stought hard prickles; bark rough with vertical cracks. It is eminently suited for afforestation of new ground and of grasslands in the riverain tracts and for controlling soil erosion. The tree is a strong light demander and is affected by severe frost but is fairly drought resistant. The tree is fast growing and requires little weeding. The timber values about Rs.2900 to 3500 m^{-3} and is most widely used in the match industry for match boxes, suitable for the manufacture of cheap grade light plywood for tea-chests, packing cases, canoes, toys, musical instruments, pencils, frames, coffins etc. The young fruits are employed as expectorant, stimulant and diuretic.

7. *Caesalpinia sappan* L. (Family - Caesalpiniaceae)

Caesalpinia sappan (Sappan wood) is a small to medium sized thorny spreading tree, grows up to 10 m in height and the wood reaches 15-30 cm in diameter. The plant reaches a height of 3-5 m within a year's time. It is a multi purpose tree used as a source of medicine and dye. The tree is a native to India and Malaysia and presently found growing throughout Eastern and Western Peninsula. The heartwood yields a red dye called "brazilin" which is oxidized to "brazilein" by atmospheric oxygen. The dye is used for facials, which are resistant to light, heat, water and non-irritant. The natural dye extracted from heartwood is used in colouring leather, silk, cotton, cool fibres, calico-printing, furniture, floors, medicines, foreign liquors and several handicrafts.

8. *Cocos nucifera* L. (Family – Palmae)

A tall and stately palm growing to a height of 20m or more when fully mature, bearing a crown of large, pinnate leaves and the trunk is straight or gently curved. The palm thrives best within the tropic zone. Coconut is a major oilseed crop of the tropics and due to its diverse uses it is considered as the "Ḳalpavriksha". Inter cropping a wide spectrum of annual, biennial and perennial crops are feasible in coconut plantations. The combination of coconut + cocoa + black pepper + pineapple is a widely accepted multi storied crop combination in several coconut growing regions. The palm yields a large variety of products among which ripe coconuts, copra, coconut oil and coir are important. Coconut oil is used for edible and industrial purposes. Coconut cake forms a valuable feeding stuff for cattle. Coconut shells are commonly used as fuel and are used for making drinking bowls, handicrafts etc.

9. *Erythrina indica* (Lamk.) (Family – Leguminosae)

It is a medium sized deciduous tree with straight trunk and reaches a maximum height of 18 m. The bark is smooth, yellowish, shining with dark coloured conical prickles. They are cultivated in India for their showy flowers, grown in plantations as shade trees and for green manure. The plant is well adapted for live fences and hedges and used as supports for betel, pepper, grape, jasmine and other climbers. The leaves are valued as cattle fodder. The plant yields heavy green foliage and leaves are laxative, diuretic, anthelmintic, galactagogue and emmenagogue. The bark is astringent and used as febrifuge, antibilious and anthelmintic. The wood of this species fetches a low price (Rs.2750 m^{-3}) and is used for rafts, floats, canoes and catamarans and suitable for paper pulp.

10. *Garuga pinnata* Roxb. (Family – Burseraceae)

A medium sized tree, up to 50 feet high, distributed almost throughout India. It has a straight cylindrical bole, sometimes 20-25 ft high and 6 ft in girth. The tree is a strong light demander, is sensitive to frost and drought, but fire resistant. It coppices well and produces root suckers. The heartwood is suitable for furniture and the sapwood after seasoning and treatment can be used for boarding. The timber is used for canoes, boxes, drums, cabinetwork and house building and values about Rs.2050 m^{-3}. The leaves and shoots are used as fodder.

11. *Gliricidia sepium* (Jack.) Kunth (Family- Leguminosae)

A small or medium sized tree with a short bole introduced into India primarily as a shade tree in plantations. It is valued as a source of green manure and used as a hedge plant. The tree is quick growing and is fairly free from pests and diseases. Leaves are shed in dry weather when flowers appear in profusion covering the greater part of the branches. The tree is valued for the large quantity of green material it produces. The yield of green material per acre is high and the plant stands harder lopping. The economic life of the tree is estimated to be 8-20 years. The loppings are rich in nitrogen. The wood is durable and is used for house posts, fences, stakes and railway crosses ties. The wood value of *Gliricidia* is estimated to be around Rs.5000 m^{-3}. The tree is considered poisonous to rats and other rodents. Powdered seeds, leaves and bark are used as bait for destruction of pests.

12. *Grevillea robusta* A.Cunn (Family-Proteaceae)

An evergreen tree with a long conical crown reported to attain a height of about 150 ft in its native habit but growing to a moderate size in India. The tree is grown nearly throughout India at elevations of 2000-6000 ft and reproduces itself naturally from seeds. It grows rapidly and reaches maturity at an early age. It is resistant to drought and fairly resistant to frost but is rather brittle and should not be grown in situations exposed to high winds. It is cultivated as a shade tree in tea and coffee plantations and is commonly planted in gardens and avenues. The wood is hard, light, reddish brown, elastic and durable and requires careful seasoning and fetches around Rs.4200 m^{-3}. It can be used for cabinet work, ornamental paneling, furniture, toys, plywood etc.

13. *Leucaena leucocephala* (Lamk.) de Wit (Family- Mimosaceae)

This is a small evergreen tree up to 9 m in height and is a native of Mexico, but now found throughout the plains of India. The wood is hard, strong which works well for carpentry, flooring and wood pulp makes better quality newsprint and values about Rs.3200 m^{-3}. *Leucaena* can provide an important protein supplement for ruminant livestock such as cattle and goats. It is a reasonably good firewood and produce good quality charcoal. *Leucaena* is a preferred leguminous species for afforestation, farm forestry, windbreaks and ornamental planting.

14. *Moringa oleifera* Lamk (Family- Moringaceae)

A small or medium sized tree, about 10m high, cultivated all over the plains of India. It is often cultivated in hedges and home yards. It grows in all types of soils, except stiff clays and thrives best under the tropical climate of South India. The tree is valued mainly for the tender pods which are esteemed as vegetable. All parts of the tree are considered medicinal and used in the treatment of rheumatism, venomous bites and as cardiac and circulatory stimulants. The oils from the seeds are used locally for edible purposes, illumination and cosmetics. Any serious disease in India does not affect the tree.

15. *Pajanelia longifolia* (Willd) k.Schum (Family- Bignoniaceae)

A medium sized to large deciduous tree sometimes up to 27m in height and 2.7 m in girth, found in the hills of Assam, in Western Ghats from north Kanara to Travancore and in the Andaman islands. Bark is brown rough and fissured. The wood smells like teak when freshly cut and seems to be similarly immune to termites. It is used for canoes, catamarans, house building and planting. The value of the wood is estimated to be around Rs.2380 m^{-3}. The tree is much grown as a support in pepper plantations where it does not usually attain a height of more than 12 m. The leaves are externally used for enlarged spleen and their decoction against stomachache and rheumatism. The bark is used externally and the seeds internally in veterinary medicine.

16. *Thespesia populnea* Soland ex.Correa (Family -Malvaceae)

It is a compact quick growing evergreen tree having 18 m potential height and 1.2 in girth commonly found on the coasts of India and also grown in gardens and boundaries of agricultural field. The bark of the tree is grey to brown and 4 mm thick. The timber is tough, hard and heavy and suitable for making coats, wheel spokes, boats, agricultural implements and musical instruments. It can be grown everywhere including saline soils except in hilly areas and prefer warm situations for growth.

APPENDIX II

Composition of media used in the analysis of soil microflora

1. MARTIN'S ROSEBENGAL STREPTOMYCIN AGAR

Dextrose	: 10.0g
Peptone	: 5.0g
KH_2PO_4	: 1.0g
$MgSO_4$	: 0.5g
Rose Bengal	: 0.03g
Agar	: 20g
Distilled water	: 1000ml

2. THORNTON'S STANDARDISED AGAR

Mannitol	: 1.0g
Asparagine	: 0.5g
K_2HPO_4	: 1.0g
KNO_3	: 0.5g
$MgSO_4$	: 0.2g
$CaCl_2$	: 0.1g
NaCl	: 0.1g
$FeCl_3 . 6H_2O$	: 0.002g
Agar	: 20.0g
Distilled water	: 1000ml
pH	: 7.4

3. KENKNIGHT'S AGAR MEDIUM

Dextrose	: 1.0g
KH_2PO_4	: 0.1g
$NaNO_3$	: 0.1g
KCl	: 0.1g
$MgSO_4$	: 0.1g
Agar	: 20.0g
Distilled water	: 1000ml
pH	: 7.0

4. PIKOVSKAYA'S SOLID AGAR MEDIUM

Glucose	: 10.0g
$Ca_3(PO_4)_2$	: 5.0 g
$(NH_4)_2SO_4$	: 0.5g
KCl	: 0.2g
$MgSO_4.7H_2O$	: 0.1g
$MnSO_4$	: Trace
$FeSO_4$	: Trace
Yeast extract	: 0.5g
Agar	: 20g
Distilled water	: 1000ml

5. JENSEN'S MEDIUM

$CaHPO_4$	: 1.0g
K_2HPO_4	: 0.2g
$MgSO_4.7H_2O$	: 0.2g
NaCl	: 0.2g
$FeCl_3$	: 0.1g
Distilled water	: 1000ml

CROP - STANDARD INTERACTIONS IN BLACK PEPPER (*Piper nigrum* L.)

By
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ABSTRACT OF THE THESIS

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ABSTRACT

Black pepper, known as the King of Spices, is the most widely used spice in the world. Providing ideal support plays an important role in successful establishment of black pepper plantation. A study was carried out at the Department of Plantation Crops and Spices, College of Horticulture to unravel the interaction patterns of the Black pepper vines with different standards (supports) and to select the standard(s) ideal for trailing pepper.

Black pepper var. Panniyur 1 trailed on 17 different standards (16 live + one dead) served as the experimental material. Characterisation of rhizosphere soil of pepper and root and shoot level interactions between pepper and standards were studied.

Marked variations in the soil chemical and biological properties were noticed among the rhizosphere soil of different pepper-standard combinations. Significant variation was observed for pH, available Na, Mn, Cu and Zn in surface soil and available Na, Ca, Fe and Cu in subsurface soil. Available Mn and Cu had a significant negative influence on the dry yield of pepper. The rhizosphere region from which plants derive most of their nutrients are considered to be the seat of intense microbial activity. Variation in the microbial population of fungi, bacteria especially nitrogen fixing bacteria (NFB) and phosphate solubilising bacteria (PSB) and actinomycetes was significant in the rhizosphere soil of pepper trailed on different standards. Population of NFB and PSB was higher in the rhizosphere soil of pepper vines trailed on *Artocarpus* and *Garuga* and lower in *Ailanthus* and *Erythrina*. No significant variation was observed among various treatments with regard to dehydrogenase and phosphatase activities of rhizosphere soil.

To assess the extent of root competition between black pepper and standards on which they are trailed, ^{32}P soil injection technique was employed. Procedure involved applying ^{32}P at the effective foraging space (EFS) of black pepper followed by quantification of radioactivity absorbed by pepper and standards. The

standards viz. *Ailanthus*, arecanut, coconut and *Grevillea* had a complementary interaction with the pepper vine associated with them with respect to ^{32}P uptake. *Artocarpus*, *Azadirachta*, *Bombax* and *Pajanelia* also exerted a similar effect but to a lesser extent. The other standards had a competitive influence on pepper based on the uptake pattern of ^{32}P. For example, *Erythrina* had a more extensive root system than pepper and that pepper and *Erythrina* explore same extent of soil surface (Sankar *et al.*, 1988).

The effect of different standards on growth, yield and quality attributes of pepper was found to vary significantly in most of the characters studied. Coconut was superior to all other standards for growth characters of pepper like height of bearing column, number of laterals per 0.25 m^2, number of berries per spike and spike compactness and expressed higher values for spread at chest height, number of spikes per 0.25 m^2 and spike length. All these characters had a positive correlation with yield. Pepper gave high yield when trailed on coconut, *Ailanthus* and *Artocarpus* and medium yield when trailed on *Acacia, Azadirachta, Bombax, Caesalpinia, Erythrina, Garuga, Grevillea, Gliricidia, Pajanelia, Thespesia* and teak pole.

Foliar nutrient content of pepper was influenced by the standards used but had no significant correlation with yield of pepper. But the foliar nutrient status of standards had significant correlation with yield of pepper. Phosphorus, iron and copper had recorded a negative effect and Mn, a positive effect on yield.

Based on the present study, it could be concluded that the pepper production can be raised substantially by trailing it on suitable supports like coconut, jack and *Ailanthus*. For quick establishment of pepper gardens using standards propagated through stem cuttings, *Garuga* was found better compared to other standards propagated in a similar way.