RHIZOSPHERE MODULATION FOR HIGHER PRODUCTIVITY IN LONG PEPPER (*Piper longum* Linn.)

BIJILY KRISHNAN

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Department of Agronomy
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM 695 522

DECLARATION

I hereby declare that this thesis entitled **"Rhizosphere modulation for higher productivity in long pepper (*Piper longum* Linn.)"** 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, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
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BIJILY KRISHNAN
(2001-11-04)

CERTIFICATE

Certified that this thesis entitled **"Rhizosphere modulation for higher productivity in long pepper (*Piper longum* Linn.)"** is a record of research work done independently by Ms. Bijily Krishnan (2001-11-04) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellayani
17-10-2003

Dr. A. S. Anilkumar
(Chairman, Advisory Committee)
Assistant Professor (Agronomy)
Instructional Farm
College of Agriculture, Vellayani
Thiruvananthapuram

APPROVED BY

Chairman:

Dr. A. S. ANILKUMAR
(Chairman, Advisory Committee)
Assistant Professor (Agronomy),
Instructional Farm,
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522

Members:

Dr. S. JANARDHANAN PILLAI
Professor and Head,
Department of Agronomy,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

Dr. K. HARIKRISHNAN NAIR
Associate Professor and Head,
Instructional Farm,
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522

Dr. P. SIVAPRASAD
Associate Professor (Agricultural Microbiology)
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

EXTERNAL EXAMINER

Dr. M. OOMMEN
Professor of Agronomy (Retd.)
'Santha Bhavan'
Pattoor, Vanchiyoor (P.O)
Thiruvananthapuram

To

My Achan,

Amma

&

Sali....

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Introduction

1. INTRODUCTION

Medicinal plants provide raw materials for pharmaceutical, phytochemical, perfumery, food, flavour and cosmetic industries. There is a wide gap between the requirement and availability of medicinal plants in the state. It is estimated that in Kerala, people depend mainly on Ayurvedic system of medicine for treating common ailments. Ayurvedic preparations against common ailments can be easily made in the home utilizing medicinal plants. Hence strengthening the traditional health care system is of paramount importance to alleviate the sufferings of the rural folk. Increase in population, indiscriminate felling of trees, adoption of intensive integrated farming systems and over use of agricultural chemicals have already affected the survival and availability of medicinal plants. As people prefer plant based products, domestication of medicinal herbs is the only option today to meet the ever increasing demand.

Piper longum is popularly known as thippali or long pepper. It is a slender aromatic climber with perennial woody roots. Dried spike is the economic part commonly used in Ayurvedic and unani medicines. Apart from the spikes, the roots and thicker part of the stem are cut, dried and used as an important drug (Piplamool) in the above systems of medicines against diseases of respiratory tracts, cardiac and splenic disorders. It is a major constituent of the Ayurvedic drugs prescribed for increasing immunity against AIDS virus and it acts as immunostimulant. Long pepper is an integral component of 'Trikadu', an ayurvedic formulation, prescribed against several respiratory complaints. It is sometimes considered as a condiment because of its similar properties as that of black pepper.

Non-availability of quality planting material is one of the constraints for domestication of long pepper. Inoculation of cuttings with bio inoculants in the nursery may result in better activity of the bio inoculants in the main field. Nursery management for quality planting material production in long pepper can help a long way in ensuring the production of quality planting material.

Increasing demand of plant based raw materials to user industries has emphasised the need to promote commercial cultivation of many medicinal plants. Integration of mediculture with agriculture offers tremendous possibilities for improving crop productivity and profitability besides generation of employment. (Kumar and Patra, 2000).

Even though large quantities of dry spikes of long pepper is required every year for meeting the demand of Ayurvedic industries in Kerala, domestic production is quite insufficient to meet the ever increasing demand. Scope for sole cropping of long pepper is limited in Kerala due to high population density and intensive cultivation. The only option available is to introduce long pepper into the existing cropping systems. Introduction of long pepper in the coconut gardens as an intercrop is feasible and remunerative. It helps to augment income from coconut gardens. Developing an efficient nutrient management system involving organic manures, inorganic fertilizers and bio inoculants for intercropping long pepper in coconut garden may help to improve soil fertility and productivity. Such an approach in commercial mediculture may help for the maintenance of ecological balance and augmentation of biomass production besides bringing cost effectiveness.

Bio inoculants play an important role in integrated nutrient management. Rhizobium, Azospirillum, Azotobacter and Arbuscular Mycorrhizal Fungi are known for their specific functions. Studies have shown that other functions such as production of siderophores, hormones or antibiotics or increased nutrient uptake through increased root growth also help the host plant to increase the productivity (Wani, 1990; Wani and Lee, 1992). There are several reports about the beneficial effects of combined application of bio inoculants compared to single inoculation (Thimann, 1972; Bagyaraj, 1984 and Anilkumar, 1999). Even though many organisms work in synergistic way, their activity in the rhizosphere of medicinal plants under the influence of organic manures and inorganic fertilizers where the nature of rhizodeposition is expected to be different when compared to other cultivated plants, are yet to be studied. It is in this context that the present project is designed with the following objectives.

1. To standardise nursery management practices for quality planting material production
2. To manage the rhizosphere for maximising the yield of spikes and biochemical constituents in long pepper under partial shade.

Review of Literature

2. REVIEW OF LITERATURE

Long pepper is an economically important medicinal plant well adapted to the agro climatological situations prevailing in the state. It is ideally suited for intercropping in irrigated coconut gardens. Nutrient management is an important factor deciding the quality and yield of long pepper.

The investigation entitled "Rhizosphere modulation for higher productivity in long pepper (*Piper longum* Linn.)" was undertaken with the objective of developing an integrated nutrient management strategy involving organic manures, inorganic fertilizers and bio inoculants for long pepper intercropped in coconut gardens.

The relevant literature on the effect of nutrient sources including organic manures, inorganic fertilizers and bio inoculants on the growth, yield components, yield and quality of long pepper and related crops are reviewed here under.

2.1 THE CROP-LONG PEPPER

Long pepper grows wild in the West Coast and as an undergrowth in the evergreen forests of Western Ghats in well drained forest soils rich in organic matter (Aiyer and Kolammal, 1966). *Piper longum* is a creeper, the runners strike roots and branches at every node, the branches are erect (Rahiman *et al.*, 1979). The branchelets which bear the fruits are erect and leaves are sessile (Hooker, 1890). The leaves are simple, alternate, stipulate and petiolate or sessile according to their position on the plant. The roots of thippali are perennial, fleshy, crooked and knotted with many smaller rootlets branching from it (Dey, 1980). According to Viswanathan (1993a) about 95 per cent of roots are found within 20 cm depth and upto 10 cm laterally from the plants. Flowering takes place throughout the year. Inflorescence is a spike. It consists of a number of minute sessile fruits each being crowned with remains of stigma (Bentley and Triman, 1880).

The nearly ripened fruiting female spike is collected and dried in sunlight which form the long pepper of commerce for use in medicine. The male spikes are not of much economic value (Viswanathan, 1995)

Long pepper grows well under partial shade (25-50 %) in irrigated coconut gardens (Jessykutty and Kiran, 2001). Trials conducted to evaluate the performance of selected geographical races of long pepper resulted in the release of the variety, 'Viswam' for intercropping in irrigated coconut gardens (KAU, 1996).

2.2 NUTRIENT SOURCES

In order to get optimum yield of spikes, nutrients should be provided in adequate amounts through various sources. Long pepper gardens have to be continuously replenished through periodical application of organic manures, inorganic fertilizers and bio inoculants.

2.2.1 Organic manure

Organic matter content of a soil is intimately related to its productivity because it acts as a store house for nutrients, increases exchange capacity, provides energy for microbial activity, increases water holding capacity, improves soil structure, reduces crusting and increases infilteration, reduces effects of compaction and buffers the soil against changes in acidity, alkanity and salinity (Tisdale *et al.*, 1993). The efficacy of organic manures such as FYM, vermicompost, coirpith compost, neemcake and poultry manure have been listed in various crops and cropping systems.

2.2.1.1 Farm yard manure

The effect of FYM on growth, yield attributes, yield and biochemical constituents of long pepper have been studied. Long pepper requires heavy manuring (Deymock *et al.*, 1890). They stressed the importance of application of dried cowdung to long pepper twice a year. Since the crop gives economic yield for three years, manuring is to be done every year. During first year, FYM is applied in pits at the time of field planting and in subsequent years, manuring is done by spreading it in beds and covering with soil. Application of organic manure increases the water holding capacity of the soil (Viswanathan, 1995). Viswanathan (1993b) suggested the need for application of 15-25 t ha^{-1} FYM for growing long pepper.

The growth characters like plant height, number of branches, number of leaves and dry matter production and yield attributing characters like number of spikes and cumulative yield were significantly higher when FYM was applied @ 20 t ha^{-1} compared to no manure application (Sheela, 1996 and Ayisha, 1997). Levels of FYM had no significant effect on the length and diameter of spikes indicating that these were varietal characters. Similarly, FYM had no effect on crude alkaloid content of dry spikes. Application of FYM @ 20 t ha^{-1} increased the NPK uptake, organic carbon, available nitrogen, phosphorous and potassium in long pepper gardens. Higher rates of organic manure application resulted in higher net returns (Sheela, 1996 and Ayisha, 1997).

2.2.1.2 Vermicompost

Little information is available on the effect of vermicompost influencing the performance of long pepper intercropped in coconut gardens. However vermicompost is a potential organic manure, which can reduce the cost of cultivation substantially. Vermicompost has a definite advantage over other organic manures in respect of quality. Vermicompost contains significant quantities of available nutrients, beneficial microbial population and biologically active metabolites particularly gibberellins, cytokinins, auxins and group B vitamins. It can be applied alone or in combination with organic or inorganic fertilizers for better yield and quality of diverse crops (Gavrilov, 1962; Tomati *et al.*, 1983 and Bano *et al.*, 1987) Vermicompost contains major and minor nutrients in plant available forms, enzymes, vitamins and plant growth hormones (KAU, 2001). *Eudrillus* *euginae* has been identified as the best species of earthworms for vermitechnology under Kerala conditions. Kale *et al.* (1991) reported that the level of chemical fertilizers could be brought down to 25-50 per cent when applied with vermicompost. When vermicompost was applied as organic manure instead of FYM, the quantity of inorganic fertilizers was reduced to about half the recommended dose (KAU, 2001).

2.2.1.3 Coirpith compost

Corpith, a by-product of coir industry is one of the major industrial wastes of agricultural importance.

Coirpith has a surface area of 290 m^2 per gram and is lignocellulosic material which binds fibres (Idiculla, 1983). It has low bulk density of 0.49 g cc^{-1}, low thermal conductivity and a porosity of 76.77 per cent. It can absorb eight times its weight of water and release it slowly. Coirpith with about 30 per cent carbon and a C:N ratio of 112:1 which is presently available in abundance is a good source of carbon especially for tropical climates (Joseph, 1995). Nagarajan *et al.*, (1987) reported its suitability in rain water conservation and increasing yield by coirpith application.

2.2.1.4 Poultry manure

Poultry manure is a good source of nutrients for agricultural production. The nitrogen use efficiency of plants from poultry manure was found high when compared with other animal manures and NPK fertilizers . Poultry manure is a good source of humidified organic matter and can rapidly increase surface soil organic matter where soil productivity is threatened by erosion because of low solid organic matter level. It contains 3-4 per cent nitrogen, 2-3 per cent phosphorous and 1.5-2 per cent potassium. The nitrogen in the litter is highly variable due to the action of microbes on uric acid content in the droppings. Hence there is a continuous loss of nitrogen as ammonia, the loss is directly dependent on its pH value. In this 60 per cent nitrogen is present as uric acid, 30 per cent as more stable organic nitrogen forms and balance as mineral nitrogen (Srivastava, 1985).

2.2.1.5 Neemcake

Oil cakes of non-edible types like neemcake are widely used as organic manure. They are valued for their alkaloid content which inhibit the nitrification process in soil. Neemcake is a concentrated organic manure rich in plant nutrients. In addition to nutrients, it contains two alkaloids nimbin and nimbidin and certain sulphur compounds which effectively inhibit nitrification process. As a result, it acts like a slow releasing nitrogen fertilizer by inhibiting the nitrification process of soil. Neemcake is a rhizosphere acidifier which can solubilize insoluble micronutrients into available form.

2.3 INORGANIC FERTILIZERS

The importance of minerals in plant nutrition is recognised universally. It is also fully realised that an increase in crop yield per unit area of land depends upon mineral nutrition because the native soil fertility alone cannot be relied upon.

The growth characters like plant height, number of branches, number of leaves and dry matter production and yield attributes like number of spikes per plant, fresh and dry weight of spikes and cumulative yield were maximum when inorganic nutrients were applied @ 30:30:60 kg NPK ha^{-1} (Ayisha, 1997).

The nitrogen content of vegetative parts decreased where as phosphorus content increased with ageing. Potassium content in vegetative parts remained relatively stable during the entire growth period. The nitrogen content in spikes was much higher than vegetative parts. But P and K contents in vegetative parts and spikes were almost same. The NPK uptake was higher when it was applied @ 30:30:60 kg ha^{-1} compared to control and 60:60:120 kg ha^{-1}.

From the results of the long term fertilizer experiment in black pepper at Panniyur in Kerala, Nybe *et al.* (1989) concluded that the foliar levels of N, K, Ca and Mg increased when fertilizers were applied during rainy season. The nutrient elements, P, K, Ca, Mg and S were found to exert direct and indirect effect on the yield of green pepper. Of these P and K were found to have greater importance in enhancing the yield.

Sadanandan *et al.* (1991) observed significant positive correlation between yield and leaf N content in Panniyur-1 cultivar of black pepper. Geetha and Aravindakshan (1992) studied the influence of levels of NPK on growth and dry matter production in bush and vine pepper. Increasing levels of N, P and K resulted in significant increase in several growth parameters, dry matter, yield components and yield in both bush and vine pepper.

2.4 BIO INOCULANTS

In recent years, bio inoculants have emerged as a supplement to mineral fertilizers and hold a promise to improve the yield of crops. The biofertilizers were found to have positive contribution to soil fertility resulting in increase of crop yield without causing any type of environmental, water or soil hazards. Among the bio inoculants, Azospirillum, PSB, pseudomonads and AMF have a significant role in crop nutrition.

2.4.1 Azospirillum

Nitrogen use efficiency of long pepper cropping system is very low. Hence it is largely cultivated under nitrogen stress conditions. This environment is favourable for biological nitrogen fixation. Thus there is wide scope for efficient utilization of nitrogen fixing bacterial systems in long pepper cultivation. Among the different groups of nitrogen fixing bacteria, the species of Azospirillum are found to be effective in supplementing the nitrogen requirement of long pepper (Tien *et al.*, 1979).

2.4.1.1 Effect of Azospirillum on growth characters

Several workers reported better root development due to application of Azospirillum (Dobereiner and Day, 1975; Barea *et al.*, 1973 and Tien *et al.*, 1979). Root elongation was improved in a number of crops by Azospirillum inoculation both under green house and field conditions. Consequent to application, Azospirillum absorbs to and proliferates on the roots and apparently invades root internal parts (Patriquin *et al.*, 1983). Inside the roots, it promotes root hair development and branching (Kapulnik *et al.*, 1983). Azospirillum produced plant growth hormones in pure culture which in turn are responsible for growth response. Plant growth responses observed consequent to inoculation of Azospirillum was due to nitrogen fixation and hormone production by the bacteria (Tien *et al.*, 1979). Inoculation with Azospirillum increased root length particularly of root elongation zone. Increased cell division in the meristematic region of inoculated plants resulted in better root elongation. Moreover the inoculated plants showed increase in number of lateral roots with dense root hairs, root volume and root dry weight. Among all diazotrophs Azospirillum is known to produce significant quantities of plant growth hormones such as gibberellins, cytokinins and auxins like IAA. This will naturally result in better absorption of water and other nutrients from soil. The phytohormones induced root hair multiplication. Govindan and Chandy (1985) found that inoculation of the Azospirillum could induce rooting in pepper cuttings. It increases the number of roots per cutting, total length of roots and root dry weight as compared to zero values of control treatments. Eventhough IBA induced a greater number of roots, bacterial inoculation was found to be favourable for the production of more healthy and strong roots, a trait desirable for better establishment of rooted pepper cuttings. Nair and Peethambaran (2000) reported that Azospirillum can also be used for early root induction in many vegetatively propagated crops like pepper.

Okon *et al.* (1983) reported that initial growth response of Azospirillum inoculation might be more due to the secretion of growth promoting substances than biological nitrogen fixation. The major plant growth regulators produced by Azospirillum include IAA, IBA, Indole-3-ethanol, Indole-3-methanol, unidentified indole compounds, several gibberellins and cytokinins. They suggested that the presence of Azospirillum in the rhizosphere affects the metabolism of endogenous phytohormones in the plant.

The success of inoculation depends on many factors including the choice of the carrier and inoculum, the ability of the bacterium to establish itself and to compete with the native microflora, favourable soil chemical and physical conditions such as pH, aeration, available nutrients including nitrogen, climatic conditions and agricultural practices.

2.4.2 Fluorescent pseudomonads

Fluorescent pseudomonads have emerged as the most promising rhizobacteria which are predominantly rhizosphere inhabitants (Kloepper *et al.*, 1980). This rhizobacteria is being popularized as a potential plant growth promoting rhizobacteria (PGPR). The beneficial effect of this PGPR can be through plant growth promotion evidenced by seedling vigour, seedling weight, root system development and yield. Fluorescent pseudomonads may promote the plant growth by secreting plant hormones like gibberellic acid substances *i.e.*, A_9 like compounds (Katzenelson and Cole, 1965; Suslow, 1982; Lifshitz *et al.*, 1987, Schippers *et al.*, 1987 and Weller, 1988). Enhancement of plant growth has been attributed to the yellow green fluorescent siderophores produced by fluorescent pseudomonads (Kloepper *et al.*, 1980). Seed and root inoculation of rhizobacteria promote plant growth by producing phytohormones like auxins and gibberellins (Lopper and Schroth, 1986). Many rhizobacteria especially fluorescent pseudomonads are known to produce several growth hormones like auxins and cytokinins. This leads to certain morphological changes in plants like increased root growth, leaf expansion, shoot growth etc.(Garcia *et al.*, 2001). A study conducted by Sivaprasad *et al.* (2003) to explore the potential of fluorescent pseudomonads for the management of foot root of pepper revealed the superior performance of the isolates P_{22}, P_{13}, P_1 and P_{14} with respect to plant height and root length. Phyllosphere and rhizosphere population of pseudomonads were remarkably high in treated plants.

2.4.3 Arbuscular Mycorrhizal Fungi

Vesicular arbuscular mycorhizae are well known for their ability to absorb nutrients from the soil, particularly phosphorus. Their impact in tropical agriculture is greater than in temperate regions since phosphorous deficient soils are more wide spread in tropics.

Population of bacteria, actinomycetes, fungi and other microorganisms in rhizosphere of mycorrhizal roots are distinctly different form those of non-mycorrhizal roots. Bagyaraj and Menge (1978) showed that the vesicular arbuscular mycorrhizal fungus *Glomus fasciculatum* increased the population of azotobacter, general rhizosphere bacteria and actinomycetes around non-mycorrhizal roots. Moose (1973) revealed that mycorrhizal fungi increased nodulation in legumes, especially in low phosphate soils and mycorrhizal fungi in plant roots increased plant growth, seed yield, nodule number and weight and acetylene reduction rates over plants that had no mycorrhizal fungus present. He further demonstrated that most of this increase was due to the increase in phosphorus levels in mycorrhizal plants. Several hypothesis have been proposed to explain the improved nutrition of mycorrhizal plants. One hypothesis is that the mycorrhizal root surface is a more efficient nutrient absorber, that is physiological changes due to infection occur in the infected root causing it to more readily absorb soil nutrients. A second hypothesis is that mycorrhizal root systems are able to use nutrient sources that are unavailable or less available to non- mycorrhizal roots. A third hypothesis is that the soil network of hyphae is able to absorb nutrients from a larger soil volume and translocate them to the infected roots. A fourth possibility is that mycorrhizal root segments remain functional as nutrient absorbers longer than do non-mycorrhizal segments. The last hypothesis suggests that mycorrhizal infection alters root morphology to enable the entire root system to be larger and more efficient for nutrient absorption (Safir and Nelson , 1981)

The occurrence of arbuscular mycorrhizal association in black pepper was reported by Manjunath and Bagyaraj (1982). Bopaiah and Khader (1989) noticed the growth promotion of black pepper with AMF association. The enhanced root generation and nutrient uptake by AMF inoculated plants were reported by Anandaraj and Sarma (1994). Sivasankar and Iyer (1988) demonstrated the positive effect of AMF (*Glomus fasciculatum*) colonisation on the growth, phosphorus uptake and nitrate reductase activity in black pepper. Sivaprasad (1995) reported *Glomus monosporum* as the most promising arbuscular mycorrhizal fungus in promoting establishment and growth of black pepper under green house and field conditions. He also reported the improved growth of mycorrhizal black pepper cuttings through elevated uptake of phosphorus. Sivaprasad (1995) observed that the symbiotic association of arbuscular mycorrhizal fungi with plant root remarkably increased the nutrient uptake and resistance to root pathogens. Sarma *et al.* (1996) observed an enhanced rooting in black pepper cutting by different mycorrhizal fungi and suggested that mycorrhizal development compensated the root damage by foot rot pathogen.

Baylis (1959) reported an enhanced uptake of P by mycorrhizal plants. The mycorrhizal growth enhancement has been attributed to the increased nutrient uptake achieved by increasing the surface area of absorption, mobilizing sparingly available nutrient sources and secretion of ectoenzymes. Smith (1980) found that the positive influence of AM association on plant growth is due to increased partitioning of P between root and shoot system. This will result in better utilization of photosynthates by aerial parts. The plants with AM association are capable of mobilizing more of the available nutrients from the soil. This is because

AM can significantly modify the overall nutrient uptake properties of a plant root system through its external mycelium extending to several centimeters from root surface often beyond the rapidly developing nutrient depletion zone around an active root system (Hayman, 1982).

It is generally believed that the development of an extensive network of hyphae by the VAM in the soil surrounding the root, together with the capacity of the hyphae for nutrient absorption and transport to the cortical root cells results in modification of the nutrient uptake properties of a root system. VAM play a significant role in nutrient cycling in ecosystem. The external mycelium extends several centimeters from the root surface and it bypasses the depletion zone surrounding the root and exploits soil micro inhabitants beyond the nutrient depleted area where rootlets or root hairs cannot thrive. VAM have greater exploring ability than the root.

2.4.4 Dual inoculation of bio inoculants

Nagarajan *et al.* (1987) observed increase in plant height, shoot biomass and leaf weight due to combined inoculation of Azospirillum and VAM. It is reported that growth substances produced by Azospirillum are continuously released from root surface into the rhizosphere where Azospirillum grows with the photosynthates supplied by the host plants. The growth regulators might have enhanced the growth of root (Thimann, 1972). Govindan and Chandy (1985) reported increase in root formation, shoot and root biomass and dry matter of black pepper when inoculated with Azospirillum. In the dual combination, phosphobacteria + AMF was effective followed by Azospirillum + phosphobacteria. Among the individual inoculation of bio inoculants maximum growth was observed in VAM followed by phosphobacteria and Azospirillum. In general mycorrhizal inoculation together with diazotrophs gave better results than diazotrophic treatment alone. Application of AMF alone or together with Azospirillum has been found to benefit the crop growth and yield (Bopaiah and Khader, 1989). Karthikeyan *et al.* (1995) observed that combined inoculation of VAM fungi and phosphobacteria enhanced dry matter production, VAM colonisation and nutrient uptake over uninoculated control and individual inoculation. It was observed that Azospirillum in combination with mixed VAM culture resulted in higher mycorrhizal colonisation. Ashamisra and Sukla (1995) observed that growth parameters were significantly promoted by highest level of VAM with maximum time interval. Kandiannan *et al.* (2000) studied the growth and nutrient content of black pepper cuttings influenced by inoculation with biofertilizers *viz.*, Azospirillum, phosphobacteria and VAM. Black pepper cuttings responded well to combined inoculation. Plant height, leaf area, biomass, dry matter and nutrient contents were higher in inoculated plants.

Of the various microorganisms colonizing the rhizosphere, VAM fungi occupy an unique ecological position as they are partly inside and partly outside the host. The tripartite association of plants, VAM fungi and Nitrogen fixing bacteria has been well established. Nearly 25 genera of free living bacteria can fix atmospheric nitrogen. Species of Azospirillum are well known among these. Bagyaraj and Menge (1978) studied the interaction between *Azotobacter chroococcum* and the VAM fungus *Glomus fasciculatum* in tomato and found a synergistic effect on plant growth. Mycorrhizal colonisation increased the *A. chroococcum* population in the soil. Beneficial effect on plant growth from free living nitrogen fixing organisms was mainly due to the hormone production rather than or in addition to nitrogen fixation.

Bagyaraj (1984) and Linderman (1988) revealed that PSB survived for a longer period in the rhizosphere of mycorrhizal roots. The PSB rendered more P soluble, while VAM enhanced P uptake. Thus with combined inoculation, there was a synergistic effect on P supply and consequent plant growth. PSB also produced hormones and vitamins. The hormones and vitamins synthesised by these organisms might have contributed significantly to VAM development and plant growth.

2.4.5 Integrated Plant Nutrition System (IPNS)

In the integrated plant nutrition system (IPNS) the available organic and biological sources of nutrients which are renewable in nature, can be utilized along with mineral fertilizers in order to benefit from the positive interactions resulting from such integrated use. The objective is to achieve high yield through balanced plant nutrition without impairing soil health. As the IPNS involves the use of nutrients representing diverse sources, the optimum combination for deriving the maximum benefit have to be determined for different crops. The organic and or biological sources of nutrients utilized in the IPNS are those generated on the farm through *in situ* organic recycling as well as *the biomass and bio inoculants* transferred from outside.

The activity of rhizosphere microflora under the influence of organic manures and inorganic fertilizers where the nature of rhizo deposition is expected to be different varies widely. According to Hayman (1982) application of super phosphate beyond 0.01-0.02 mg ml^{-1} will diminish or eliminate the advantage of AM association by inhibiting the growth and activity of vegetative mycelium. Such an effect is also observed with high level of soil nitrogen. The benefits of Azospirillum inoculation is always more along with low doses of chemical fertilizer application (Tilak and Subbarao, 1987). Nitrate reductase activity of Azospirillum leading to increased absorption of NO_3^- by crop plants is also responsible for increased growth. Addition of organic manures will increase the beneficial effect of AM inoculation (Sieverding, 1991). The increased level of soluble P in soil is the determinant of mycorrhizal development in the root system (Barea, 1992). In tropical agriculture, the importance of mycorrhizal symbiosis is in phosphate nutrition of crop plants. This is because these soils are generally poor in available phosphorus. Under such situations, AM association will enable the host plant to absorb more P by greater exploration of soil resulting in better access to soil pool of available phosphorus (Tilak and Singh, 1996).

Materials and Methods

3.MATERIALS AND METHODS

Experiments were conducted at the College of Agriculture, Vellayani, during 2002-2003 to develop an efficient nutrient management strategy involving organic manures, inorganic fertilizers and bio inoculants for long pepper intercropped in coconut garden. Two trials *viz.*, "Nursery management for quality planting material production in long pepper" and "Nutritional management for long pepper under partial shade" were undertaken.

The materials utilized and the methodology followed for the experiments are presented in this chapter.

3.1 LOCATION

The experiment was conducted at the Instructional Farm attached to College of Agriculture, Vellayani. The farm is located at 8.5^0N latitude and 76.9^0E longitude at an altitude of 29 m above MSL.

3.2 SOIL

The soil of the experimental site is red sandy clay loam (Oxisol, Vellayani series). The mechanical composition, soil moisture characteristics and chemical properties of the soil are summerised in Table 1.

3.3 CLIMATE AND SEASON

The weather data recorded during the experimental period are given in Appendix and graphically presented in Fig. 1. Wet tropical climate prevailed in the experimental location. Abstract of the weather data during the experimental period is given in Table 2.

3.4 POT CULTURE

Nursery management for quality planting material production in long pepper.

Crop : *Piper longum* Linn.

Variety : Viswam

Table 1. Mechanical composition, soil moisture characteristics and chemical properties of soil

Particulars	Content	Method used
A. Mechanical composition		
Coarse sand, %	16.7	Bouyoucos Hydrometer method (Bouyoucos, 1962)
Fine sand, %	31.3	
Silt, %	25.5	
Clay, %	26.5	
B. Soil moisture characteristics		
Bulk density, g cc^{-1}	1.375	Core method (Gupta and Dakshinamoorthi, 1980)
Water holding capacity, %	21.5	
Porosity, %	32	
C. Chemical properties		
Organic carbon, %	0.43	Wakley and Black rapid titration method (Jackson, 1973)
Available nitrogen, kg ha^{-1}	100.2	Alkaline $KMnO_4$ method (Subbaih and Asija, 1956)
Available phosphorus, kg ha^{-1}	86.17	Bray's colorimetric method (Jackson, 1973)
Available potassium, kg ha^{-1}	58.05	Ammonium acetate method (Jackson, 1973)
Soil Reaction, pH	4.5	1:2.5 soil suspension using pH meter with glass electrode (Jackson, 1973)

Table 2. Abstract of the weather data during the experimental period (June2002-May2003)

Weather parameters	Range	Mean
Maximum temperature ^0C	29.9-32.8	31.1
Minimum temperature, ^0C	21.4-28.9	23.6
Annual rainfall, mm	--	1065.9
Relative Humidity, %	72.8-86.3	79.3
Monthly evaporation, mm	2.1-4.2	3.55

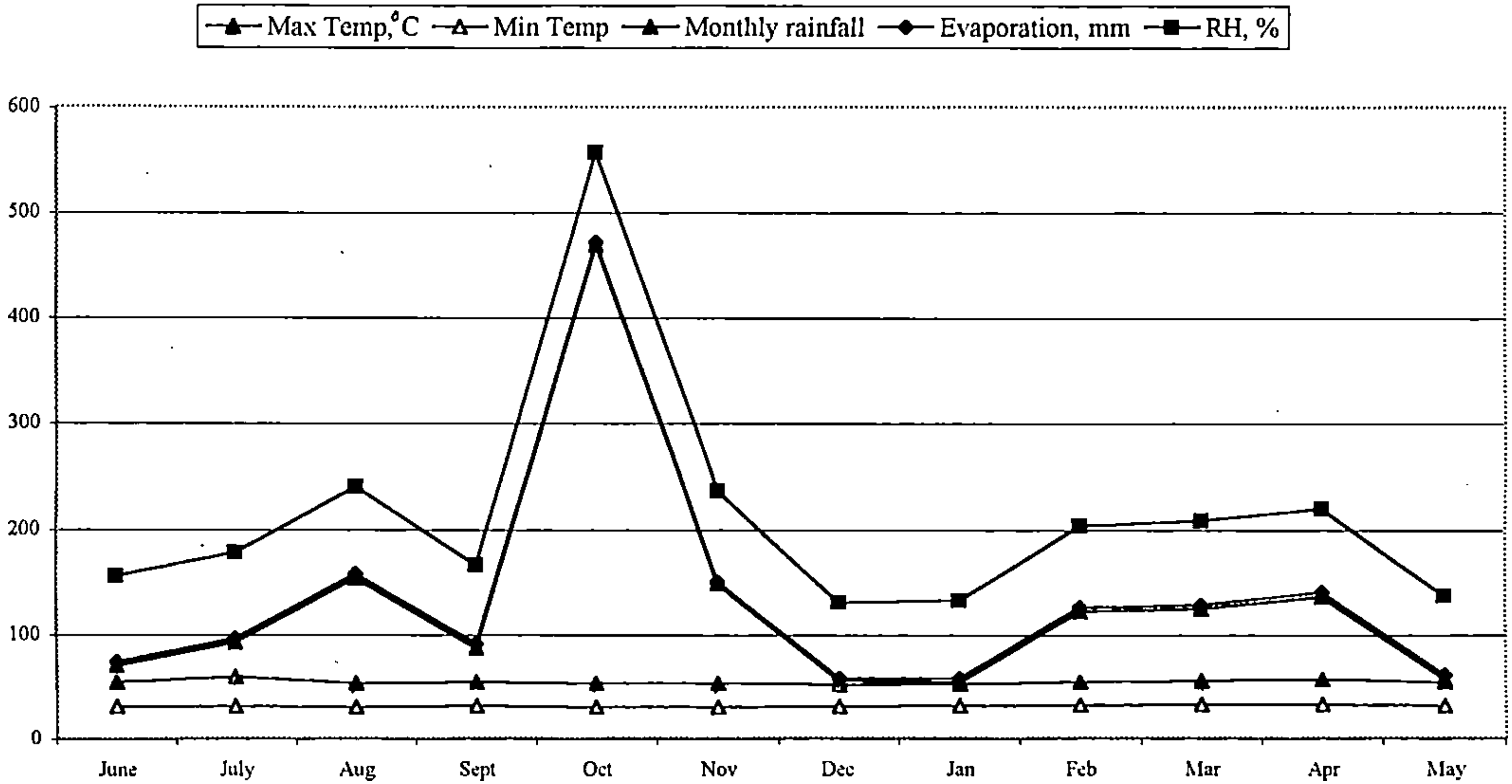


Fig. 1. Weather parameters during 2002-2003

Design : CRD

Replication : 3

3.4.1 Treatments

Factor A. Bioinoculants (8)

B_1 – Azospirillum

B_2 – Fluorescent pseudomonads

B_3 – Arbuscular Mycorrhizal Fungi (AMF)

B_4 – Azospirillum + Fluorescent pseudomonads

B_5 – Azospirillum + AMF

B_6 – Fluorescent pseudomonads + AMF

B_7 – Azospirillum + Fluorescent pseudomonads + AMF

B_0 – No inoculation

Factor B. Composition of rooting media (4)

R_1 – FYM : Sand : Soil (1:1:1)

R_2 – Vermicompost : Sand: Soil (1:1:1)

R_3 – Coirpith compost : Sand : Soil (1:1:1)

R_4 – Poultry manure : Sand : Soil (1:1:1)

3.4.2 Treatment combinations

T_1 – B_1R_1	T_9 – B_1R_2	T_{17} – B_1R_3	T_{25} – B_1R_4
T_2 – B_2R_1	T_{10} – B_2R_2	T_{18} – B_2R_3	T_{26} – B_2R_4
T_3 – B_3R_1	T_{11} – B_3R_2	T_{19} – B_3R_3	T_{27} – B_3R_4
T_4 – B_4R_1	T_{12} – B_4R_2	T_{20} – B_4R_3	T_{28} – B_4R_4
T_5 – B_5R_1	T_{13} – B_5R_2	T_{21} – B_5R_3	T_{29} – B_5R_4
T_6 – B_6R_1	T_{14} – B_6R_2	T_{22} – B_6R_3	T_{30} – B_6R_4
T_7 – B_7R_1	T_{15} – B_7R_2	T_{23} – B_7R_3	T_{31} – B_7R_4
T_8 – B_0R_1	T_{16} – B_0R_2	T_{24} – B_0R_3	T_{32} – B_0R_4

3.4.3 Layout

Layout plan of the pot culture experiment is given in Fig. 2.

REPLICATION I

T_1	T_8	T_6	T_3	T_5	T_7	T_2	T_4
T_9	T_{11}	T_{10}	T_{15}	T_{12}	T_{14}	T_{13}	T_{16}
T_{17}	T_{20}	T_{21}	T_{18}	T_{19}	T_{23}	T_{24}	T_{22}
T_{29}	T_{32}	T_{27}	T_{30}	T_{28}	T_{26}	T_{31}	T_{25}

REPLICATION II

T_4	T_2	T_7	T_5	T_3	T_6	T_8	T_1
T_{16}	T_{13}	T_{14}	T_{12}	T_{15}	T_{10}	T_{11}	T_9
T_{22}	T_{24}	T_{23}	T_{19}	T_{18}	T_{21}	T_{20}	T_{17}
T_{25}	T_{31}	T_{26}	T_{28}	T_{30}	T_{27}	T_{32}	T_{29}

REPLICATION III

T_3	T_6	T_8	T_1	T_4	T_2	T_7	T_5
T_{15}	T_{10}	T_{11}	T_9	T_{16}	T_{13}	T_{14}	T_{12}
T_{18}	T_{21}	T_{20}	T_{17}	T_{22}	T_{24}	T_{23}	T_{19}
T_{30}	T_{27}	T_{32}	T_{29}	T_{25}	T31	T_{26}	T_{28}

Fig. 2. Layout plan - nursery management for quality planting material production in long pepper

3.5 NURSERY DETAILS

3.5.1 Variety

Viswam, a high yielding selection from the geographical race, Cheemathippali, released from the Kerala Agricultural University, was used for the trail. The plant is glabrous, undershrub with erect and sub scandent nodose stem and slender branches. Branches creep or trail. Leaves simple, alternate, 5-7 nerved, stipulate and petiolate according to their position on the plant. Inflorescence is a spike with unisexual (dioecious) small or minute achlamydous closely packed green or dry grey berries. Spike length is 3-5 cm and diameter 2.5 cm. A plant produces 125 spike $year^{-1}$ after two years of growth. Average yield of the variety is 317 kg ha^{-1} of dry spike. The variety is recommended as a floor crop in irrigated coconut gardens.

3.5.2 Production of rooted long pepper cuttings

Six month old vines were cut into pieces of 20 cm length (3 nodes) and planted in polythene bags filled with potting mixture prepared as per the technical programme. The polythene bags were kept under partial shade for two months and irrigated once in two days. Saplings attained 6 –7 leaf stage at the time of planting (Plate 1).

3.5.3 Preparation of rooting media

Four different rooting media were prepared by substituting FYM with vermicompost, coirpith compost and poultry manure. The composition of the rooting media are furnished in the following table (Table 3).

Table 3. Composition of the rooting media

Treatments	Composition	Proportion
R_1	FYM : Sand : Soil	1:1:1
R_2	Vermicompost : Sand : Soil	1:1:1
R_3	Coirpith compost : Sand: Soil	1:1:1
R_4	Poultry manure : Sand: Soil	1:1:1

3.5.4 Bio inoculants

3.5.4.1 Inoculation of cuttings with Azospirillum

Fresh culture of *Azospirillum brasiliense* (acid tolerant strain) with an activity of 10^8 per gram of culture, obtained from the Department of Plant Pathology, College of Agriculture, Vellayani was thoroughly mixed with cowdung slurry and the long pepper cuttings were dipped in the slurry for 30 minutes and the saplings raised as explained earlier.

3.5.4.3 Inoculation of fluorescent pseudomonads

Fluorescent pseudomonads is a new strain of pseudomonads having root inducing property. Fresh culture of the same were obtained from the Department of Plant Pathology, College of Agriculture, Vellayani. It was thoroughly mixed with cowdung slurry and the cuttings were dipped in the slurry for 30 minutes before planting.

3.5.4.3 Inoculation of AMF at planting hole

Inoculation of AMF containing more than 15 spores per gram of air dried soil and infected root fragments of Guinea grass (*Panicum maximum*), was obtained from the College of Agriculture, Vellayani. The species used was *Glomus monosporum*. A planting hole of 5 cm depth and 2 cm width was made in the already filled in polythene bag and the inoculum was applied @ 5 g per hole and the cuttings were planted in such a way that the cut surface was in contact with the inoculum.

3.5.4.4 Combined application of Azospirillum, Fluorescent pseudomonads and AMF

Long pepper cuttings were inoculated with Azospirillum and fluorescent pseudomonads and then planted in planting hole treated with AMF as in single inoculation of AMF.

3.5.4.5 Control

Saplings were raised without inoculation with bio inoculants.

3.5.5 After care

Saplings were raised in the shade house (50 % shade) and irrigated as and when required.

3.5.6 Observations

Observations were taken after two months of planting when the saplings were ready for transplanting. The methods followed for recording of observations are given below.

3.5.6.1 Growth characters

3.5.6.1.1 Vine length

The length of the longest vine was taken from the base of the plant to the tip of the emerging leaf using a meter scale. It was expressed in centimeters.

3.5.6.1.2 Number of leaves

Total number of leaves on the vine was counted and recorded.

3.5.6.1.3 Leaf area

Leaf area was found out using graph paper method.

3.5.6.2 Root characters

Representative samples were uprooted two months after planting. They were thoroughly washed in running water to remove the adhering soil particles. The procedures described by Misra and Ahmed (1989) were followed for the estimation of root parameters.

i. Root number –The whole plant was uprooted and the total number of roots were counted.

ii. Root Weight – The roots were washed, cleaned and dried in an oven at 75^0C for about 10-20 hours and weighed.

iii. Root length – The roots were placed in a flat glass dish containing a small amount of water. Graph paper was placed under the dish. Roots were straightened by forceps so that they did not overlap and

Plate 1.Two months old saplings treated with bio inoculants ready for transplanting

Plate 2. Nursery management in long pepper

held in position by a glass plate. The length of the given roots or root segments were then estimated to the nearest segments by eye inspection. Branches were cut, joined end to end by gum, placed on a graph paper and length was measured.

iv. Root spread – Root spread was estimated using a graph paper.

3.5.6.3 Microbiological observations

3.6.6.3.1 Azospirillum

Colony count of Azospirillum was taken by pour plate method using nitrogen free malate medium.

One gram freshly collected soil sample was weighed. Water blanks of 99 ml each in conical flasks and nine ml each in test tubes were prepared and got sterilized. Weighed soil sample was suspended into 99 ml conical flask and shook it well. One ml of the suspension was transferred into nine ml blank in test tubes. This procedure was repeated till the dilution factor was 10^{-5}. Then one ml each was transferred into sterilized perti plates in three replications. Autoclaved medium was melted and poured into petri plates at optimum consistency. Rotated the plates in clockwise and anti-clockwise direction for uniform distribution. Counting of raised mucoid Azospirillum colonies were done after two days.

The total colony count was expressed by multiplying the number of colonies in the plate by dilution factor (reciprocal of dilution) and it was expressed in cfu g^{-1}.

3.6.6.3.2 Fluorescent pseudomonads

For taking the colony count of *Fluorescent pseudomonads*, the procedure followed for Azospirillum was used but the medium used was King's B medium (King *et al.*, 1954). After two days, observed for the fluorescent colonies (Johnson and Curl, 1972).

3.6.6.3.3 AMF

AMF staining was done according to the method described by Philips and Hayman (1970). FAA solution was prepared (Formaldehyde : Acetic acid: Ethanol @ 5:5:90). Long pepper roots were cut into pieces of one cm length and immersed in FAA solution and kept overnight. After draining this solution, poured ten per cent KOH solution into the root bits, autoclaved for 10 minutes to 1 hour for softening the roots to make it vulnerable for staining. After draining KOH solution roots were treated with one per cent HCl for ten minutes for neutralizing the effect of KOH.

Tripan blue dye was prepared in 0.05 per cent lacto phenol for staining mycorrhiza. Treated the roots with the dye for 1-5 minutes. Drained the dye, observed the root bits under microscope for mycelia, vesicles or arbuscules. At least 50 bits were examined for each treatment for better precision.

$$\text{AMF colonisation (\%)} = \frac{\text{No.of root bits positive for AMF colonisation}}{\text{Total no.of root bits observed}} \times 100$$

3.6 FIELD EXPERIMENT

Nutritional management for long pepper under partial shade

The objective of the experiment was to manage the rhizosphere for maximizing the yield of spikes and biochemical constituents in long pepper under partial shade.

This study commenced from July 2002 and continued upto May 2003.

Design	: Strip split plot
Replication	: 3
Spacing	: 40 x 40 cm
Gross plot size	: 2.4 x 2 m
Net plot size	: 1.6 x 1.2 m

3.6.1 Treatments

The different horizontal factors (organic manures), vertical factors (inorganic fertilizers) and intersection factors (bio inoculants) are furnished below:

Horizontal factors (organic manures)

M_1 – FYM

M_2 – Vermicompost

M_3 – Coirpith compost

M_4 – Neemcake

M_0 – No organic manure

Vertical Factors (inorganic fertilizers)

F_0 – No inorganic fertilizer

F_1 – 50 % of the recommended dose (30:30:60 kg ha^{-1} yr^{-1})

F_2 – 100 % of the recommended dose (60:60:120 kg ha^{-1} yr^{-1})

Intersection factors (Bio inoculants)

Based on the results of the nursery trail, "Nursery management for quality planting material production in long pepper" the following two treatment combinations were selected and compared with control.

B_1 – Azospirillum + Fluorescent pseudomonads + AMF

B_2 – Fluorescent pseudomonads + AMF

B_0 – No bio inoculant (Control)

3.6.2 Treatment combinations

The details of treatment combinations are listed in Table 4.

3.6.3 Imposition of treatments

Pits of size 25 x 25 x 25 cm were taken in the inter spaces of coconut palms at the spacing of 40 x 40 cm and organic manures were applied as per the technical programme. The land preparation was done in June 2002. Two month old rooted cuttings were planted on 1st July 2002.

N

REPLICATION I

T_{4}	T_{5}	T_{6}	T_{9}	T_{7}	T_{8}	T_{2}	T_{3}	T_{1}
T_{40}	T_{41}	T_{42}	T_{45}	T_{43}	T_{44}	T_{38}	T_{39}	T_{37}
T_{31}	T_{32}	T_{33}	T_{36}	T_{34}	T_{35}	T_{29}	T_{30}	T_{28}
T_{13}	T_{14}	T_{15}	T_{18}	T_{16}	T_{17}	T_{11}	T_{12}	T_{10}
T_{22}	T_{23}	T_{24}	T_{27}	T_{25}	T_{26}	T_{20}	T_{21}	T_{19}

REPLICATION II

T_{26}	T_{25}	T_{27}	T_{14}	T_{21}	T_{20}	T_{24}	T_{23}	T_{22}
T_{12}	T_{16}	T_{18}	T_{10}	T_{12}	T_{11}	T_{15}	T_{14}	T_{13}
T_{8}	T_{2}	T_{4}	T_{1}	T_{3}	T_{2}	T_{6}	T_{5}	T_{4}
T_{35}	T_{34}	T_{36}	T_{28}	T_{30}	T_{24}	T_{33}	T_{32}	T_{31}
T_{44}	T_{43}	T_{45}	T_{37}	T_{39}	T_{38}	T_{42}	T_{41}	T_{40}

REPLICATION III

T_{28}	T_{29}	T_{30}	T_{34}	T_{35}	T_{36}	T_{31}	T_{33}	T_{32}
T_{10}	$T_{1}7$	T_{12}	T_{16}	T_{17}	T_{18}	T_{13}	T_{15}	T_{14}
T_{19}	T_{20}	T_{21}	T_{25}	T_{26}	T_{27}	T_{22}	T_{24}	T_{23}
T_{37}	T_{38}	T_{39}	T_{43}	T_{44}	T_{45}	T_{40}	T_{42}	T_{41}
T_{1}	T_{2}	T_{3}	T_{7}	T_{8}	T_{9}	T_{4}	T_{6}	T_{5}

Fig. 3. Layout plan-nutritional management for long pepper under partial shade

Table 4. Treatment combinations

Treatment		Combinations
T1	$M_1F_0B_1$	FYM : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T2	$M_1F_0B_2$	FYM : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T3	$M_1F_0B_0$	FYM : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T4	$M_1F_1B_1$	FYM : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T5	$M_1F_1B_2$	FYM : 30:30:60 NPK kg $ha^{-1}yr^{-1}$ar : FP+AM
T6	$M_1F_1B_0$	FYM : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T7	$M_1F_2B_1$	FYM : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T8	$M_1F_2B_2$	FYM : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T9	$M1F_2B_0$	FYM : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T10	$M_2F_0B_1$	Vermicompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T11	$M_2F_0B_2$	Vermicompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T12	$M_2F_0B_0$	Vermicompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T13	$M_2F_1B_1$	Vermicompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T14	$M_2F_1B_2$	Vermicompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T15	$M_2F_1B_0$	Vermicompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T16	$M_2F_2B_1$	Vermicompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T17	$M_2F_2B_2$	Vermicompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T18	$M_2F_2B_0$	Vermicompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T19	$M_3F_0B_1$	Coirpithcompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T20	$M_3F_0B_2$	Coirpithcompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T21	$M_3F_0B_0$	Coirpithcompost : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T22	$M_3F_1B_1$	Coirpithcompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T23	$M_3F_1B_2$	Coirpithcompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T24	$M_3F_1B_0$	Coirpithcompost : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T25	M_3F2B_1	Coirpithcompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T26	$M_3F_2B_2$	Coirpithcompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T27	M_3F2B_0	Coirpithcompost : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T28	$M_4F_0B_1$	Neemcake : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM

Table 4. continued...

T29	$M_4F_0B_2$	Neemcake : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T30	$M_4F_0B_0$	Neemcake : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T31	$M_4F_1B_1$	Neemcake : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T32	$M_4F_1B_2$	Neemcake : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T33	$M_4F_1B_0$	Neemcake : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T34	$M_4F_2B_1$	Neemcake : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T35	M_4F_{2B2}	Neemcake : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T36	$M_4F_2B_0$	Neemcake : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T37	$M_0F_0B_1$	No organic manure : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T38	$M_0F_0B_2$	No organic manure : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T39	$M_0F_0B_0$	No organic manure : 0:0:0 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T40	$M_0F_1B_1$	No organic manure : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T41	$M_0F_1B_2$	No organic manure : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T42	$M_0F_1B_0$	No organic manure : 30:30:60 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants
T43	$M_0F_2B_1$	No organic manure : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: AZ+FP+AM
T44	$M_0F_2B_2$	No organic manure : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: FP+AM
T45	$M_0F_2B_0$	No organic manure : 60:60:120 NPK kg $ha^{-1}yr^{-1}$: no bio inoculants

Gap filling was done two weeks after planting. Layout plan of the experiment is shown in Fig. 3 (Plate 3).

3.6.3.1 Levels of organic manures

Organic manure was applied along with planting operation. Quantity of different organic manures was fixed on nitrogen equivalent basis. FYM @ 20 t ha^{-1}, vermicompost @ 6.25 t ha^{-1}, coirpith compost @ 7.8 t ha^{-1} and neemcake @ 1.88 t ha^{-1} were applied.

3.6.3.2 Inorganic fertilizers

Inorganic fertilizers were applied as per the technical programme. Urea (46 % N), Mussoriphos (16 % P_2O_5) and MOP (60 % K_20) were the nutrient sources. Nitrogen, phosphorus and potassium were applied in two equal splits.

3.6.3.3 Bioinoculants

Bioinoculant inoculated seedlings produced in the nursery described in section 3.5.4 were used for the trial.

3.6.4 After care

The crop was raised following the package of practices recommendations suggested by Viswanathan (1995).

3.6.5 Harvest

The plants started bearing from 5 MAP. First harvest was taken during the last week of February (7 MAP) and subsequent harvests at bimonthly intervals.

3.6.6 Observations

Five plants were selected at random for recording observations, unless otherwise specified. The methods followed for recording the observations are furnished below.

Plate 3. General view of the experimental field

Plate 4. Leaf development in long pepper

3.6.6.1 Growth characters

Growth characters like vine length, leaf number, leaf area, root spread, root number, root length, vine weight, root weight and DMP were recorded as described in section 3.5.6.1 and 3.5.6.2. from randomly selected plants from each plot.

3.6.6.2 Physiological characters

3.6.6.2.1 Leaf Area Index (LAI)

LAI was calculated by the following formula,

$$LAI = \frac{\text{Leaf area}}{\text{Land area}}$$

Leaf area was calculated as detailed below:

Leaves are grouped into small, medium and large and estimated the area by graph paper method. Total leaf area was found out by estimated leaf area multiplied by total number of leaves coming into respective group (Watson, 1958).

3.6.6.2.2 Net Assimilation Rate (NAR)

NAR is the amount of dry matter produced per unit leaf area per unit time. This can be calculated by the formula,

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Log}_e L_2 - \text{Log}_e L_1}{L_2 - L_1}$$

(William, 1946)

W_1, W_2 – Plant dry weight at t_1 and t_2 period in days.

L_1, L_2 – leaf area at t_1 and t_2 period in days.

3.6.6.2.3 Relative Growth Rate (RGR)

RGR is the amount of dry matter produced per unit amount of dry matter present in that. It can be calculated as:

$$RGR = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

(Blackman, 1919)

W_1, W_2 – Plant dry weight at t_1 and t_2 period in days.

3.6.6.2.4 Crop Growth Rate (CGR)

CGR is the dry mater accumulated per unit land area per unit time. It can be calculated as,

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{\text{Land area}}$$

(Watson, 1958 and Hunt, 1978)

W_1, W_2 – Plant dry weight at t_1 and t_2 period in days

3.6.6.3 Yield and yield attributing characters

3.6.6.3.1 Spike number

Total number of spikes per plant was counted from five random hills and mean was worked out. This was recorded before every harvest.

3.6.6.3.2 Fresh and dry spike yield

The fresh weight of spikes was recorded immediately after every harvest. The spikes were air dried for 1-2 weeks and dry weight recorded. Spike yield was expressed in kg ha^{-1}.

3.6.7 Laboratory analysis

3.6.7.1 Soil analysis

The composite soil samples collected prior to the commencement of field experiment and soil samples collected from individual plots after the completion of the third harvest were analysed for available nitrogen, phosphorus and potassium.

Available nitrogen in soil was determined by alkaline $KMn0_4$ method (Subaiah and Asija, 1956).

Available P_2O_5 in the soil was determined using Bray No.1 extractant by stannous chloride method in Spectrophotometer (Jackson, 1973).

Available K_20 in the soil was determined by Ammonium acetate method (Jackson, 1973).

3.6.7.2 Plant analysis

The plant samples were chopped and dried in a hot air oven at 70± 2^0C till constant weights were obtained. Samples were analysed for N, P and K by adopting standard procedures.

Nitrogen content was estimated using microkjeldahl method (Jackson, 1973). Phosphorus content using Vanado molybdo phosphoric yellow colour method (Jackson, 1973) and potassium content using flame photometer method (Piper, 1966).

Uptake of nitrogen, phosphorus and potassium by the crop in different intervals were computed by multiplying the nutrient content with dry matter production and expressed as the uptake of nutrients in kg ha^{-1}.

3.6.7.3 Biochemical analysis

The total alkaloid content in the spikes was determined using the Soxhlet extraction method (Harbone, 1973).

Five grams of finely powdered and dried samples of *Piper longum* was accurately weighed into the filter paper to hold the sample and the weight of sample with filter paper was recorded. The sample packet was then dropped into the extraction tube of Soxhlet apparatus. The bottom of the extraction tube was attached to the previously weighed Soxhlet flask. 100 ml of methanol was used as the solvent, which was poured through the sample into the flask. The top of the extraction tube was attached to the condenser. Extraction of the sample was carried out in water bath maintained at 80^0C till the solvent in the extraction tube turned colourless. The temperature of the water bath was regulated, so that the solvent is volatilized, condensed and dropped continuously upon the sample without any appreciable loss. At the end of the extraction period *ie*., when the previously colourless solvent in the flask turned dark coloured and solvent in the extraction tube turned colourless, the sample packet was removed from the extractor and most of the solvent was distilled off by allowing it to collect in the Soxhlet tube. The Soxhlet flask was dismantled and allowed to cool. The solvent was evaporated on a water bath. The Soxhlet flask along with the residue was weighed. The residue left in Soxhlet flask after complete evaporation of the solvent was weighed to get the total alkaloid extracted.

Weight of residue (g) = Weight of Soxhlet flask along with residue (g) – Weight of empty Soxhlet flask (g)

$$\text{Total alkaloid (\%)} = \frac{\text{Weight of residue (g)}}{\text{Weight of dried sample used for extraction}} \times 100$$

3.6.7.4 Microbiological analysis

Observations like AMF colonization, colony count of fluorescent pseudomonads, and Azospirillum were studied as explained in section 3.5.6.3.

3.6.7.4.1 Spore load

The extramatrical chlamydospores produced by the AMF were estimated following the wet sieving and decanting technique (Gerdemann and Nicolson, 1963).

Twenty five grams of soil was collected from the plots and made into a uniform suspension in 100 ml water by thoroughly stirring it. The suspension was then passed through a series of sieves ranging from 1000, 300, 250, 105 and 45µm kept one below the other in the same order. The contents of the bottom two sieves were made into a suspension in water and transferred to a nylon mesh (45 µm) placed in a petri dish. The petri dish containing the nylon mesh with the spores was observed under stereo microscope and the total AMF spore load was estimated.

3.6.7.5 Statistical analysis

The data were statistically analysed for analysis of variance as per the procedure outlined by Panse and Sukhatme (1995).

Results

4. RESULTS

An investigation entitled "Rhizosphere modulation for higher productivity in long pepper (*Piper longum* Linn.)" was undertaken at the College of Agriculture, Vellayani. The project comprised of the following two experiments.

Pot culture-Nursery management for quality planting material production in long pepper

Field Experiment-Nutritional management for long pepper under partial shade.

The project was carried out to evolve an integrated nutrient management strategy for achieving higher productivity in long pepper without sacrificing the quality. The results obtained from the study are summarised in the following sections.

4.1 POT CULTURE

Nursery management for quality planting material production in long pepper

Response of long pepper cuttings to single, dual and combined inoculation of bioinoculants *viz*, Azospirillum, Fluorescent pseudomonads, AMF, Azospirillum + Fluorescent pseudomonads, Azospirillum+AMF, Fluorescent pseudomonads + AMF, Azospirillum + Fluorescent pseudomonads + AMF and no inoculation and four rooting media *viz*., FYM : Sand : Soil (1:1:1), Vermicompost : Sand : Soil (1:1:1), Coirpith compost : Sand : Soil (1:1:1) and Poultry manure :Sand : Soil (1:1:1) were studied . Notations such as AZ, FP, AM and B_0 for Azospirillum, Fluorescent pseudomonads, AMF and no bio inoculants FY, VC, CC and PM for FYM : Sand : Soil (1:1:1), Vermicompost : Sand : soil (1:1:1), Coirpith compost :Sand : Soil (1:1:1) and Poultry manure : Sand : Soil (1:1:1) respectively, are conveniently used to express the treatment in the following sections. Inclusion of poultry manure in the rooting medium resulted in total failure of cuttings to strike roots. Hence no observations were recorded from the treatment combination involving poultry manure in the rooting media.

4.1.1 Vine Length

Data on vine length are given in Table 5.

Among the bio inoculants, FP+ AM recorded the maximum vine length (20.63 cm) which was on par with AZ+FP+AM (19.96 cm), FP (19.81 cm), AM (19.50 cm), and B_0 (19.28 cm). Composition of rooting media had no significant influence on vine length.

The interaction effect of bio inoculants and composition of rooting media was found to be significant (Table 6). However, vine length ranged from 14.63 cm (VC+AZ+FP) to 21.05 cm (FY+FP+AM). FY+FP+AM was on par with VC+FP+AM (20.83cm) and CC+FP (20.63).

4.1.2 Leaf number

The data on leaf number are furnished in Table 5.

FP+AM recorded maximum number of leaves (3.11) and it was on par with AZ+FP+AM (2.77). Similar to vine length, composition of rooting media had no significant effect on leaf number.

Leaf number ranged from 1.00 (VC+AZ+FP) to 3.66 (FY+FP+AM) and the interaction effect was significant (Table 6).

4.1.3 Leaf area

The data relating to leaf area are given in Table 5.

The superiority of FP+AM was well established in influencing the leaf area when compared to other bio inoculants. Combined inoculation of FP + AM resulted in 494.7 per cent increase in leaf area over no inoculation. Leaf area was not influenced by composition of rooting media.

The interaction effect of bio inoculants and composition of rooting media was significant. FY+ FP+ AM recorded the highest value (83.33

Table 5. Biometric characters, dry matter production and rhizosphere microflora as influenced by bio inoculants and rooting media

Treatments	Vine length, cm	Leaf number	Leaf area, cm^2	Vine weight, g	DMP g $plant^{-1}$	Root number	Root length, cm	Root spread, cm	Root weight, g	Rhizosphere Microflora		
										AZ, cfu g^{-1}	FP, cfu g^{-1}	AM, %
Bioinoculants												
B_1	17.17	2.00	23.61	2.05	3.23	8.88	8.12	2.66	0.22	8.77	5.55	31.00
B_2	19.81	2.33	18.78	2.72	4.69	9.33	9.58	3.51	0.39	1.22	20.66	27.33
B_3	19.50	2.22	13.33	2.30	4.26	8.11	11.24	3.34	0.34	2.22	2.11	74.00
B_4	17.20	1.44	23.67	1.90	3.37	9.55	10.01	3.06	0.38	11.22	12.22	37.00
B_5	17.84	1.67	35.00	2.45	4.41	11.00	6.79	3.86	0.42	12.33	1.78	80.33
B_6	20.63	3.11	60.78	3.03	5.40	12.00	8.07	3.81	0.56	4.11	17.89	88.66
B_7	19.96	2.77	34.89	3.09	5.61	12.56	9.66	4.19	0.49	10.11	17.00	88.66
B_0	19.28	2.33	10.22	2.14	3.74	6.78	6.29	2.35	0.38	1.44	1.11	43.00
SE	0.697	0.266	5.69	0.269	0.189	1.550	0.705	0.332	0.093	0.837	0.967	*
CD	1.980	0.757	16.18	0.765	0.512	4.430	2.000	0.945	0.265	2.370	2.748	*
Rooting media												
R_1	19.41	2.63	23.68	2.80	4.95	10.70	8.15	3.50	0.35	6.83	10.46	65.75
R_2	18.51	2.21	32.87	2.37	3.97	9.08	9.77	3.26	0.41	6.16	9.92	59.12
R_3	18.65	2.25	26.04	2.22	4.07	9.54	8.24	3.27	0.46	6.29	9.00	51.50
SE	0.427	0.163	3.48	0.164	0.084	0.955	0.432	0.203	0.057	0.512	0.592	*
CD	NS	NS	NS	0.468	0.250	NS	1.220	NS	NS	NS	NS	*

* data not analysed

cm^2). The leaf area ranged from 6.33 cm^2 (CC+B_0) to 83.33 cm^2 (FY + FP + AM) which was on par with VC+FP+AM (60.67 cm^2) (Table 6).

4.1.4 Vine weight

Data pertaining to vine weight are summarised in Table 5.

The highest vine weight was recorded by AZ+FP+AM (3.09 g $plant^{-1}$) which was on par with FP + AM (3.03 g $plant^{-1}$) and FP (2.72 g $plant^{-1}$) and AZ+AM (2.45 g $plant^{-1}$). The vine weight was increased to 3.09 g $plant^{-1}$ when AZ+ FP+AM were inoculated over control. The composition of rooting media had spectacular influence on vine weight unlike other parameters. FY was ranked first (2.8 g $plant^{-1}$) which was on par with VC (2.37 g $plant^{-1}$).

The interaction effect of bio inoculants and rooting media was found to be significant with regard to vine weight. It ranged from 1.23 g $plant^{-1}$ (VC+AZ) to 4.11 g $plant^{-1}$ (FY + FP + AM). FY+FP+AM was on par with VC + AZ + FP + AM, FY + AZ, VC + FP and FY + AZ + FP + AM (Table 6).

4.1.5 Dry matter accumulation

Data relating to total dry matter production are presented in Table 5.

AZ + FP + AM followed by FP + AM recorded higher DMP when compared to control (5.61 g and 5.40 g respectively). FP + AM and AZ + FP + AM showed 50.00 and 44.30 per cent improvement in dry matter accumulation over control. The effect of FYM was found to be superior in dry matter accumulation (4.95 g) followed by coirpith compost and vermicompost (Plate 2).

The interaction effect showed the superiority of the treatment combination, FY+FP+AM (7.14g) followed by VC +AZ+FP+AM (5.84g) (Table 6).

Table. 6. Biometric characters, dry matter production and rhizosphere microflora as influenced by interaction effect of bio inoculants and rooting media

Treatments	Vine length, cm	Leaf number	Leaf area, cm^2	Vine weight, g	DMP, g plant^{-1}	Root number	Root length, cm	Root spread, cm	Root weight, g	Rhizosphere microflora		
										AZ, cfu g^{-1}	FP, cfu g^{-1}	AM, %
B_1R_1	18.94	2.66	19.00	3.17	4.93	11.33	8.12	3.00	0.31	11.00	5.00	50.00
B_2R_1	18.96	2.66	32.88	2.90	5.55	10.33	9.68	4.66	0.35	1.33	24.30	37.00
B_3R_1	19.70	3.33	12.67	2.68	5.30	11.00	11.22	3.66	0.44	2.66	2.66	85.00
B_4R_1	18.76	2.00	11.67	1.67	3.19	9.33	11.22	3.66	0.27	12.00	14.00	37.00
B_5R_1	19.13	1.66	53.33	3.04	5.12	13.00	7.30	3.80	0.38	11.00	2.00	70.00
B_6R_1	21.05	3.66	83.33	4.11	7.14	11.66	6.30	3.73	0.42	4.33	16.33	90.00
B_7R_1	19.54	2.66	43.00	3.05	5.09	12.33	6.19	3.66	0.37	11.00	18.33	97.00
B_0R_1	19.20	2.33	7.66	1.77	3.10	6.66	5.40	1.91	0.21	1.33	1.00	60.00
B_1R_2	17.36	1.33	17.66	1.23	2.13	10.00	6.90	3.23	0.17	7.33	6.00	33.00
B_2R_2	19.83	2.33	14.00	3.12	4.93	9.00	9.15	2.86	0.56	1.33	20.33	20.00
B_3R_2	19.40	3.00	10.67	2.12	3.69	6.00	11.81	2.83	0.25	2.00	2.33	78.00
B_4R_2	14.63	1.00	27.67	1.82	3.06	8.33	11.81	3.00	0.30	10.00	14.33	38.00
B_5R_2	17.13	2.00	25.00	2.23	3.88	9.00	7.50	4.03	0.53	13.66	1.33	85.00
B_6R_2	20.83	3.00	60.67	2.44	4.53	11.00	9.91	3.83	0.40	3.00	19.33	89.00
B_7R_2	19.22	2.66	35.00	3.79	5.84	12.33	12.62	4.16	0.62	10.66	14.66	90.00
B_0R_2	19.66	2.33	16.66	2.17	3.63	7.00	8.47	2.13	0.40	1.33	1.00	40.00
B_1R_3	15.20	2.00	34.16	1.75	2.60	5.33	9.35	1.75	0.18	8.00	5.66	10.00
B_2R_3	20.63	2.00	10.00	2.16	3.56	8.66	9.89	3.05	0.28	1.00	17.33	25.00
B_3R_3	19.40	3.33	16.66	2.12	3.75	7.33	10.71	3.53	0.35	2.00	1.33	60.00
B_4R_3	18.20	1.33	31.66	2.20	3.63	11.00	7.01	2.50	0.58	11.66	8.33	36.00
B_5R_3	17.26	1.33	26.66	2.07	4.18	11.00	5.58	3.75	0.36	12.33	2.00	86.00
B_6R_3	19.99	2.66	37.33	2.54	4.61	13.33	8.29	3.85	0.35	5.00	18.00	87.00
B_7R_3	19.60	3.00	26.66	2.42	5.15	13.00	10.19	4.75	0.50	8.66	18.00	79.00
B_0R_3	18.96	2.33	6.33	2.47	4.45	6.66	4.92	3.00	0.52	1.66	1.33	29.00
SE	1.206	0.461	9.862	0.466	0.523	2.701	1.222	0.576	0.161	1.449	1.674	*
CD	3.430	1.311	28.030	1.325	1.526	NS	3.475	1.637	NS	4.121	4.761	*

* data not analysed

4.1.6 Root characters

Root characters *viz.*, root number, root length, root spread and root weight after two months of planting *i.e.*, at the time of transplanting are presented in Table 5.

Significant difference was observed among bio inoculants and AZ + FP + AM (12.56) followed by FP+AM (12.00) recorded maximum root number and the increase over control were 85.30 and 76.90 per cent respectively. Composition of rooting media had no significant effect on root number. However interaction effects were insignificant.

Maximum root length was observed when AM was inoculated (11.24cm) which was on par with AZ + FP (10.01 cm), AZ+FP+AM (9.66 cm) and FP (9.58 cm). AM recorded 78.70 per cent increase over no inoculation. VC in the rooting medium significantly increased root length (9.77 cm) when compared to CC and FY which were on par. The interaction effects of bio inoculants and rooting media had remarkable influence on root length. VC + AZ + FP + AM recorded the highest root length (12.62 cm) which was on par with VC+AM, VC+AZ+FP, FY+AM, FY+AZ+FP, CC+AM and CC+AZ+FP+AM (Table 6).

AZ + FP + AM recorded the highest root spread (4.19 cm) which was on par with AZ+AM (3.86 cm), FP+AM (3.81 cm), FP (3.51cm) and AM (3.34cm). FY showed the greatest value (3.50 cm) followed by CC and VC. Due to the interaction effect, CC+AZ+FP+AM recorded the maximum root spread (4.75 cm). The interaction effects had significant influence on the root spread.

With respect to root weight, FP+AM recorded the maximum (0.56 g). followed by AZ+FP+AM (0.49 g). The effect of rooting media was found to be non significant in influencing the root weight. Similarly the interaction effect was non significant.

4.1.7 Rhizosphere microflora

Data pertaining to colonisation of Azospirillum, Fluorescent pseudomonads and AMF are given in Table 5.

The combined application of Azospirillum and AMF resulted in significantly higher colonisation of Azospirilllum. However, no significant difference was observed with respect to composition of rooting media. The interaction effects were significant and combined application of VC+AZ+AM recorded the maximum colonization (Table 6).

Single inoculation of Fluorescent pseudomonads was found favourable for enhancing its colonization (20.66 cfu g^{-1}) when compared to combined inoculation with other bio inoculants and control. Dual inoculation of FP with AM and combined inoculation of FP with AM and AZ also recorded higher values, followed by dual inoculation of FP with AZ. However, when AZ was included in the treatment combination, there was considerable reduction in FP colonisation. Composition of rooting media exerted no significant influence on colonisation. Due to the interaction effect, FY+FP recorded the maximum colonisation and was on par with VC+FP which were significantly superior to other treatments.

There was improvement in per cent infection of AMF when it was inoculated either with FP or with AZ and FP and the increase was 19.80 per cent when compared to inoculation of AMF alone. Interaction effect of AZ+FP+AM and FY resulted in maximum per cent infection followed by VC +AZ+FP+AM and FY+FP+AM

4.2 FIELD EXPERIMENT

Nutritional management for long pepper under partial shade

Organic manures, *viz.*, FYM (M_1), vermicompost (M_2), coirpith compost (M_3) and neemcake (M_4) were tested against control (M_0). Inorganic fertilizers were tested at three levels *viz.*, no inorganic fertilizer (F_0) NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ (F_1) and NPK @ 60:60:120 kg $ha^{-1}yr^{-1}$ (F_2). The effect of bio inoculants were tested with the inoculation of

Table 7. Vine length (cm) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	53.04	141.26	194.29	228.26	245.45	259.11	269.41
M_2	66.22	133.26	188.74	207.41	219.56	236.89	247.52
M_3	51.15	103.44	138.19	148.81	167.78	178.93	189.59
M_4	54.96	124.00	149.44	150.11	167.85	175.59	184.63
M_0	53.88	82.11	92.44	99.44	111.44	118.41	125.48
SE	3.035	2.299	3.461	4.867	5.012	3.691	3.521
CD	9.898	7.498	11.288	15.871	16.347	12.037	11.484
Inorganic fertilizers							
F_0	54.78	117.04	154.64	167.58	189.25	200.27	210.22
F_1	63.60	124.04	162.44	171.07	185.44	196.89	206.22
F_2	49.18	109.36	140.78	161.78	172.56	184.20	193.53
SE	0.957	3.086	1.750	4.869	2.776	2.727	2.765
CD	3.758	12.117	6.872	19.115	10.900	10.706	10.856
Bio inoculants							
B_1	56.31	112.00	141.78	156.27	171.13	182.67	191.72
B_2	60.42	133.62	191.89	207.93	229.78	242.11	252.09
B_0	50.82	102.82	124.20	134.22	146.33	156.57	166.17
SE	1.833	3.247	2.640	3.225	2.174	2.203	2.062
CD	5.183	9.183	7.468	9.122	6.149	6.230	5.833

Table 8. Leaf number as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	21.26	32.52	40.93	48.74	54.85	59.70	66.07
M_2	22.11	32.26	40.22	46.70	52.29	57.41	63.07
M_3	17.78	26.04	34.52	40.22	45.74	50.22	56.45
M_4	20.07	29.07	36.33	41.26	46.33	50.96	57.04
M_0	17.11	23.89	27.93	33.26	37.30	41.33	46.18
SE	0.673	0.721	0.860	1.068	1.150	1.056	0.933
CD	2.195	2.351	2.804	3.482	3.752	3.444	3.043
Inorganic fertilizers							
F_0	18.91	28.29	36.64	42.93	48.16	52.78	58.87
F_1	20.36	29.69	35.31	41.09	45.96	50.56	56.09
F_2	19.73	28.29	36.00	42.09	47.80	52.45	58.33
SE	0.364	0.395	0.493	0.800	0.823	0.916	0.926
CD	NS	NS	NS	NS	NS	NS	NS
Bio inoculants							
B_1	17.51	25.60	35.53	39.35	44.27	48.96	55.22
B_2	25.87	37.18	45.56	52.51	58.42	63.45	68.76
B_0	15.62	23.49	28.87	34.25	39.22	43.38	49.31
SE	0.365	0.467	1.175	0.575	1.432	0.590	0.683
CD	1.033	1.320	3.523	1.626	4.293	1.670	1.951

MAP – Months After Planting

Table 9. LAI as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	0.93	1.41	1.78	2.13	2.39	2.61	2.89
M_2	0.97	1.41	1.76	2.04	2.29	2.51	2.76
M_3	0.78	1.14	1.58	1.76	2.00	2.19	2.48
M_4	0.88	1.27	1.58	1.81	2.03	2.23	2.49
M_0	0.75	1.03	1.22	1.45	1.63	1.81	2.02
SE	0.029	0.034	0.038	0.046	0.049	0.046	0.041
CD	0.096	0.112	0.124	0.152	0.163	0.151	0.134
Inorganic fertilizers							
F_0	0.82	1.24	1.60	1.88	2.10	2.31	2.58
F_1	0.89	1.29	1.54	1.79	2.00	2.21	2.46
F_2	0.86	1.22	1.58	1.84	2.09	2.29	2.55
SE	0.015	0.020	0.016	0.035	0.036	0.040	0.040
CD	0.060	NS	NS	NS	NS	NS	NS
Bio inoculants							
B_1	0.77	1.12	1.47	1.72	1.94	2.14	2.42
B_2	1.13	1.65	1.98	2.29	2.56	2.78	3.04
B_0	0.68	0.99	1.26	1.49	1.71	1.89	2.13
SE	0.015	0.022	0.024	0.025	0.026	0.026	0.030
CD	0.045	0.061	0.068	0.071	0.073	0.073	0.085

Table 10. NAR (mg cm^{-2} day^{-1}) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatment	6MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures						
M_1	0.007	0.007	0.011	0.014	0.017	0.002
M_2	0.01	0.013	0.014	0.02	0.02	0.02
M_3	0.004	0.003	0.005	0.005	0.008	0.009
M_4	0.005	0.005	0.006	0.005	0.008	0.01
M_0	0.006	0.006	0.008	0.008	0.009	0.008
SE	0.001	0.001	0.001	0.002	0.003	0.003
CD	0.003	0.002	0.004	0.004	0.005	0.004
Inorganic manures						
F_0	0.007	0.009	0.01	0.011	0.014	0.014
F_1	0.006	0.006	0.01	0.12	0.014	0.012
F_2	0.005	0.006	0.007	0.011	0.012	0.014
SE	0.001	0.002	0.002	0.002	0.003	0.004
CD	NS	NS	NS	NS	NS	NS
Bio inoculants						
B_1	0.007	0.016	0.008	0.009	0.009	0.011
B_2	0.007	0.008	0.002	0.016	0.021	0.02
B_0	0.005	0.007	0.008	0.008	0.011	0.011
SE	0.001	0.002	0.007	0.002	0.002	0.002
CD	0.003	NS	0.001	0.004	0.005	0.006

MAP- Months after planting

Table 11. RGR (mg g^{-1} day^{-1}) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatment	6MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures						
M_1	12.09	11.15	9.82	5.17	3.38	2.60
M_2	1036	8.39	7.65	5.05	3.62	2.8
M_3	7.18	6.14	5.00	3.84	3.22	2.34
M_4	6.84	5.01	4.50	3.77	3.29	2.43
M_0	5.39	4.91	4.25	3.83	3.13	2.26
SE	2.340	1.562	1.343	1.281	1.242	1.310
CD	2.431	1.932	1.878	1.563	NS	NS
Inorganic manures						
F_0	7.86	7.23	6.96	4.03	3.26	2.32
F_1	8.31	7.20	6.81	4.28	3.37	2.57
F_2	7.23	6.76	5.60	4.42	3.53	2.63
SE	2.011	1.346	1.118	1.138	1.002	1.001
CD	NS	NS	NS	NS	NS	NS
Bio inoculants						
B_1	8.36	7.23	6.31	4.41	3.28	2.30
B_2	9.17	8.68	6.85	4.52	3.51	2.61
B_0	7.28	6.26	5.62	4.40	3.35	2.51
SE	1.382	1.281	0.910	0.863	0.823	1.101
CD	1.560	1.388	1.100	NS	NS	NS

Table 12. CGR (g m^{-2} day^{-1}) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatment	6MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures						
M_1	0.24	0.26	0.28	0.32	0.34	0.36
M_2	0.23	0.29	0.31	0.34	0.35	0.39
M_3	0.18	0.17	0.21	0.23	0.24	0.28
M_4	0.13	0.19	0.23	0.26	0.26	0.3
M_0	0.18	0.14	0.16	0.17	0.19	0.21
SE	0.051	0.023	0.018	0.024	0.031	0.028
CD	0.093	0.081	0.071	0.063	0.058	0.046
Inorganic manures						
F_0	0.17	0.20	0.22	0.25	0.26	0.29
F_1	0.21	0.20	0.25	0.28	0.29	0.034
F_2	0.16	0.21	0.23	0.26	0.28	0.3
SE	0.027	0.038	0.041	0.031	0.021	0.047
CD	NS	NS	NS	NS	NS	NS
Bio inoculants						
B_1	0. 19	0.21	0.24	0.24	0.29	0.32
B_2	0.21	0.24	0.28	0.32	0.33	0.38
B_0	0.13	0.18	0.19	0.24	0.24	0.24
SE	0.031	0.047	0.023	0.039	0.028	0.021
CD	NS	NS	0.078	0.063	0.081	0.083

MAP- Months after Planting

Table 13. Root number as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	9.22	21.22	29.48	35.11	44.33	47.29	50.70
M_2	9.48	21.29	29.04	35.26	44.19	47.52	51.15
M_3	6.89	18.85	25.89	32.93	41.67	43.96	46.67
M_4	6.96	18.96	26.56	32.70	38.85	41.78	44.78
M_0	5.81	18.04	25.33	32.52	35.44	38.04	40.85
SE	0.478	0.244	0.334	0.546	0.634	0.796	0.593
CD	1.559	0.797	1.089	1.780	2.067	2.596	1.935
Inorganic fertilizers							
F_0	6.00	18.02	25.76	32.36	39.73	42.69	45.51
F_1	9.53	21.73	29.33	35.89	43.22	46.22	49.80
F_2	7.49	19.26	26.69	32.87	39.73	42.25	45.18
SE	0.366	0.470	0.637	0.620	0.567	0.545	0.413
CD	1.436	1.846	2.502	2.434	2.225	2.139	1.623
Bio inoculants							
B_1	11.96	24.04	33.29	40.93	48.51	51.82	55.67
B_2	7.67	19.16	28.18	35.11	42.62	45.40	48.40
B_0	4.00	15.82	20.31	25.62	31.56	33.93	36.42
SE	0.280	0.352	0.337	0.414	0.418	0.461	0.453
CD	0.793	0.995	0.952	1.172	0.183	1.305	1.283

Table 14. Root length (cm) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	7.20	12.31	17.18	19.11	21.81	23.67	25.67
M_2	8.67	14.11	18.94	21.45	23.06	25.35	26.93
M_3	6.18	10.93	14.37	16.76	19.17	20.43	21.87
M_4	5.26	9.74	12.81	15.04	17.33	18.50	19.19
M_0	5.74	9.44	11.57	14.39	16.76	18.65	19.24
SE	0.149	0.180	0.341	0.183	0.181	0.197	0.210
CD	0.487	0.586	1.112	0.597	0.589	0.641	0.685
Inorganic fertilizers							
F_0	5.81	10.18	14.56	16.66	18.99	21.06	22.17
F_1	7.33	12.43	15.47	17.96	20.37	21.70	23.04
F_2	6.69	11.31	14.91	17.43	19.52	21.20	22.52
SE	0.052	0.140	0.089	0.078	0.126	0.132	0.211
CD	0.205	0.549	0.347	0.307	0.495	0.519	0.827
Bio inoculants							
B_1	9.34	15.07	20.04	22.40	25.29	26.76	28.52
B_2	6.22	11.77	15.50	18.17	20.47	22.41	23.31
B_0	4.27	7.09	9.39	11.48	13.12	14.79	15.90
SE	0.131	0.163	0.311	0.276	0.177	0.134	0.215
CD	0.372	0.460	0.880	0.782	0.501	0.379	0.607

Table 15. Root spread (cm) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	6.72	10.19	13.19	16.56	19.28	21.85	23.54
M_2	6.96	10.81	13.89	16.35	18.90	21.06	22.56
M_3	6.74	8.63	11.33	14.24	16.89	19.22	20.63
M_4	7.50	9.44	13.12	15.74	18.07	19.96	21.57
M_0	6.40	7.57	9.38	12.20	14.91	16.46	17.94
SE	0.243	0.229	0.343	0.312	0.384	0.449	0.380
CD	0.793	0.747	1.118	1.016	1.254	1.463	1.241
Inorganic fertilizers							
F_0	7.32	9.88	12.99	15.77	18.63	21.02	22.43
F_1	6.68	9.30	11.44	14.73	17.40	19.58	21.09
F_2	6.60	9.11	12.12	14.56	16.80	18.53	20.22
SE	0.097	0.065	0.093	0.258	0.177	0.179	0.169
CD	0.379	0.254	0.367	1.011	0.694	0.705	0.662
Bio inoculants							
B_1	8.67	12.69	16.50	19.73	22.76	24.92	26.41
B_2	6.56	8.89	12.03	15.78	18.39	20.56	22.03
B_0	5.38	6.70	8.02	9.54	11.69	13.66	15.30
SE	0.183	0.240	0.239	0.313	0.317	0.332	0.327
CD	0.518	0.679	0.676	0.886	0.898	0.939	0.923

Table 16. Root weight (g) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
Organic manures							
M_1	0.94	2.33	2.88	3.05	3.37	3.59	3.91
M_2	0.86	2.31	2.89	3.01	3.20	3.39	3.56
M_3	0.49	0.82	1.28	1.47	1.73	1.91	2.19
M_4	0.44	0.61	0.98	1.28	1.48	1.59	1.93
M_0	0.40	0.60	0.88	1.08	1.27	1.29	1.69
SE	0.009	0.014	0.020	0.310	0.058	0.052	0.042
CD	0.031	0.046	0.064	0.100	0.191	0.169	0.137
Inorganic fertilizers							
F_0	0.55	1.26	1.62	1.83	2.09	2.28	2.54
F_1	0.70	1.43	1.89	2.07	2.33	2.47	2.77
F_2	0.62	1.31	1.83	2.03	2.21	2.31	2.66
SE	0.010	0.004	0.014	0.022	0.037	0.026	0.027
CD	0.039	0.016	0.056	0.086	0.145	0.103	0.107
Bio inoculants							
B_1	0.59	1.28	1.68	1.87	2.07	2.27	2.56
B_2	0.85	1.65	2.27	2.47	2.79	2.93	3.23
B_0	0.44	1.08	1.39	1.59	1.77	1.87	2.17
SE	0.008	0.007	0.010	0.015	0.029	0.032	0.024
CD	0.022	0.019	0.028	0.043	0.081	0.090	0.068

MAP-Months after planting

Azospirillium + Fluorescent pseudomonads +AMF (B_1), Fluorescent pseudomonads +AMF (B_2) and no bio inoculant (B_0). Notations such as M_1, M_2, M_3, M_4 and M_0 for organic manures, F_0, F_1 and F_2 for inorganic fertilizers and B_1, B_2, and B_0 for bio inoculants are conveniently used to express the treatments in the following sections.

4.2.1 Vine length

Data relating to mean vine length as influenced by organic manures, inorganic fertilizers, and bio inoculants recorded at 5, 6, 7, 8, 9, 10 and 11 MAP are presented in Table 7.

The effect of organic manures on vine length was evident through out the period of experiment. From 6 MAP, FYM (M_1) recorded the highest values followed by vermicompost (M_2) and its effect was spectacular and it differed significantly from all other treatments. When compared to control (M_0) the increase in vine length due to the application of FYM was 72.00, 110.54, 129.55, 120.25, 118.82, 114.70 per cent after 6, 7, 8, 9, 10 and 11 MAP respectively. Application of NPK@ 30:30:60 kg^{-1} ha^{-1} yr^{-1} (F_1) recorded maximum vine length upto 8 MAP and thereafter application of the highest dose. The application of FP+AM (B_2) showed the maximum vine length at all stages of growth and the per cent increase over no inoculation (B_0) were 18.80, 29.90, 54.50, 54.92, 57.02, 54.60 and 51.69 per cent respectively after 5, 6, 7, 8, 9, 10 and 11 months of planting

Application of $M_1F_0B_2$ resulted in longer wines (396.33 cm) compared to $M_0F_0B_0$ (96.33 cm) indicating the positive influence of FYM (M_1) on the performance of bio inoculants in the absence of inorganic fertilizers (F_0). When M_1B_2 was combined with F_1 and F_2 the per cent reduction in vine length were 21.10 and 20.90 per cent respectively after 11 months of planting (Table 17).

4.2.2 Leaf number

Data relating to the effect of treatments on mean leaf number at 5, 6, 7, 8, 9, 10 and 11 MAP are presented in Tables 8 and 17.

The significant influence of organic manures and bio inoculants were observed through out the period of growth. Application of FYM (M_1) and vermicompost (M_2) were on par and recorded higher values compared to all other treatments. There was a drastic reduction in leaf production when the crop was cultivated without the addition of organic manure (Plate 6). Inorganic fertilizers had no significant influence in leaf production. Among the bio inoculant treatment, B_2 was found to be superior at all stages and 65.60, 58.20, 57.80, 53.30, 48.95, 46.30 and 39.40 per cent increase in leaf number was recorded after 5^{th}, 6^{th}, 7^{th}, 8^{th} 9^{th}, 10^{th} and 11^{th} months of planting respectively when compared to no inoculation (B_0)

Among the treatment combinations $M_1F_1B_2$, $M_1F_2B_2$ followed by $M_2F_0B_2$ recorded higher values. The synergistic action of combined inoculation of bio inoculants *viz.*, FP + AM was evident when it was inoculated with vermicompost in the absence of inorganic fertilizers.

4.2.3 Root characters

The effect of treatments on root characters *viz.*, root number, root length, root spread and root weight recorded at 5, 6, 7, 8, 9, 10 and 11 MAP are given in Tables 13, 14, 15 and 16 respectively and the interaction effect after 11 MAP in Table 17.

The effects of FYM and vermicompost were spectacular on root number, root length, root spread and root weight throughout the period of investigation and that differed significantly from other treatments. When compared to M_0, M_1 and M_2 recorded 135.00 and 115.00 per cent, 288.30 and 285.00 per cent, 227.30 and 228.40 per cent, 182.40 and 178.70 per cent, 165.30 and 151.97 per cent, 178.30 and 162.70 per cent, 134.10 and

110.60 per cent higher root weight at 5, 6, 7, 8, 9, 10 and 11 MAP respectively (Table 16).

Application of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ recorded significantly higher root number at all growth stages. A similar trend was observed with respect to root length and root weight as well. The increase in root weight when 30:30:60 kg NPK $ha^{-1}yr^{-1}$ (F_1) was applied, were 27.30 13.50, 16.60 13.10, 11.50, 8.30 and 9.00 per cent higher over control (F_0) at 5, 6, 7, 8, 9, 10 and 11 MAP. However root spread was maximum when the crop was raised without the addition of inorganic fertilizers.

Among the bio inoculants, B_1 recorded significantly superior values with respect to root number, root length, and root spread at all stages of growth. However root weight was highest when B_2 was inoculated and the per cent increase over B_0 were 93.20, 52.70, 63.30 55.30, 57.60, 56.70 and 48.80 per cent at 5, 6, 7, 8, 9, 10 and 11 MAP respectively.

Interaction effect of organic manure X inorganic fertilizers X bio inoculants were significant and the treatment combination, $M_2F_1B_1$ recorded the maximum root number (69.67) which was on par with $M_1F_1B_1$ (67.00) after 11 months of planting and the per cent increase over control ($M_0F_0B_0$) was 115.40 and 107.20 per cent respectively. The maximum root length was obtained for $M_1F_1B_1$ (36.00 cm) and it was followed by $M_2F_1B_1$ (33.17 cm). The above treatment combinations recorded 195.80 and 172.50 per cent increase in root length compared to control ($M_0F_0B_0$). Root spread also varied widely from 12.83 cm to 31.17 cm. The treatment combinations $M_1F_0B_1$ and $M_1F_1B_1$ recorded the highest root spread (31.17 cm) and it was 142.90 per cent higher over control. They were on par with $M_2F_0B_1$ (30.17 cm). A variation of 366.00 per cent in root weight was observed due to interaction effects. The values ranged from 1.08 g ($M_0F_0B_0$) to 5.04 g ($M_1F_0B_2$). $M_1F_0B_2$ was on par with $M_1F_0B_1$ (4.97 g).

Table 17. Biometric characters, physiological parameters and root characters as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatment combination	Vine length, cm	Leaf number	LAI	NAR, mg cm^{-2} day^{-2}	RGR, mg g^{-1} day^{-1}	CGR, g m^{-2} day^{-1}	Root number	Root spread, cm	Root length, cm	Root weight, g
$M_1F_0B_1$	308.33	59.33	2.59	0.009	2.18	0.28	58.67	31.17	31.50	4.97
$M_1F_0B_2$	396.33	78.00	3.41	0.010	2.17	0.39	53.00	26.67	22.16	5.04
$M_1F_0B_0$	23.2.67	47.00	2.06	0.009	2.50	0.26	39.33	17.17	15.83	3.73
$M_1F_1B_1$	222.00	51.67	2.26	0.020	3.5	0.35	67.00	31.17	36.00	3.12
$M_1F_1B_2$	312.67	87.67	3.84	0.060	2.7	0.54	56.67	26.17	28.16	4.07
$M_1F_1B_0$	204.00	52.00	2.28	0.010	2.5	0.32	37.67	14.83	19.50	2.85
$M_1F_2B_1$	230.33	75.00	3.28	0.008	2.5	0.33	57.33	27.83	30.17	3.93
$M_1F_2B_2$	313.33	87.00	3.81	0.030	2.9	0.45	49.33	20.67	24.83	4.48
$M_1F_2B_0$	205.00	57.00	2.49	0.010	2.6	0.4	37.33	16.17	29.83	2.95
$M_2F_0B_1$	193.00	55.33	2.42	0.010	1.00	0.4	57.00	30.17	31.33	3.10
$M_2F_0B_2$	279.67	84.33	3.69	0.050	2.92	0.42	52.00	25.83	25.83	3.82
$M_2F_0B_0$	188.33	49.00	2.14	0.030	2.1	0.21	35.00	16.67	19.33	2.48
$M_2F_1B_1$	269.00	61.00	2.67	0.020	2.93	0.38	69.67	27.50	33.17	3.75
$M_2F_1B_2$	305.33	76.67	3.35	0.030	3.71	0.55	61.33	24.33	25.50	4.42
$M_2F_1B_0$	209.67	52.67	2.30	0.010	3.00	0.51	40.00	15.33	17.33	3.04
$M_2F_2B_1$	266.00	65.67	2.87	0.020	3.22	0.37	58.33	26.50	30.83	3.71
$M_2F_2B_2$	313.67	78.33	3.42	0.050	4.1	0.34	50.67	20.83	30.83	4.57
$M_2F_2B_0$	203.00	44.67	1.95	0.010	3.01	0.37	36.33	15.83	21.67	3.14
$M_3F_0B_1$	133.00	53.33	2.33	0.003	1.12	0.35	50.33	26.00	27.00	1.49
$M_3F_0B_2$	222.00	74.00	3.23	0.020	2.62	0.41	46.67	22.50	23.17	1.98
$M_3F_0B_0$	184.33	44.67	1.95	0.020	2.28	0.13	38.67	17.50	17.50	1.58

Table 17. continued...

$M_3F_1B_1$	175.67	52.00	2.83	0.004	2.83	0.23	58.33	22.83	31.50	2.81
$M_3F_1B_2$	216.33	62.00	2.71	0.010	1.9	0.37	49.33	17.00	25.33	3.84
$M_3F_1B_0$	165.33	46.00	2.06	0.005	3.33	0.06	37.33	14.33	13.67	2.38
$M_3F_2B_1$	186.67	53.33	2.33	0.005	2.41	0.48	51.00	27.00	25.00	1.71
$M_3F_2B_2$	290.33	70.67	3.09	0.010	2.7	0.43	49.67	21.83	21.17	2.32
$M_3F_2B_0$	132.67	52.00	2.88	0.004	2.14	0.11	38.67	16.67	12.50	1.64
$M_4F_0B_1$	172.67	63.33	2.77	0.010	2.42	0.21	52.67	27.17	25.00	1.54
$M_4F_0B_2$	286.33	68.57	3.00	0.005	3.57	0.41	46.00	24.83	22.17	2.28
$M_4F_0B_0$	181.67	51.67	2.26	0.005	3.08	0.22	36.67	13.67	12.83	1.63
$M_4F_1B_1$	211.67	56.67	2.48	0.002	2.05	0.33	58.00	27.17	26.33	1.98
$M_4F_1B_2$	264.00	50.33	2.64	0.020	2.24	0.40	47.00	24.17	19.00	1.96
$M_4F_1B_0$	143.00	60.33	2.20	0.010	2.82	0.34	37.67	18.67	12.81	1.58
$M_4F_2B_1$	129.67	48.67	2:13	0.020	2.31	0.40	51.00	27.50	21.17	2.08
$M_4F_2B_2$	155.67	59.67	2.61	0.010	1.12	0.41	41.67	18.33	17.83	2.91
$M_4F_2B_0$	117.00	54.00	2.36	0.008	2.43	0.01	32.33	12.67	15.50	1.37
$M_0F_0B_1$	127.67	49.67	2.17	0.009	1.2	0.33	45.67	22.17	24.33	1.42
$M_0F_0B_2$	151.00	56.67	2.48	0.010	2.91	0.42	38.67	22.17	22.33	1.88
$M_0F_0B_0$	96.33	48.00	2.10	0.010	2.94	0.05	32.33	12.83	12.17	1.08
$M_0F_1B_1$	126.67	42.67	1.87	0.009	2.26	0.27	51.67	20.33	23.50	1.08
$M_0F_1B_2$	150.00	49.67	2.17	0.010	1.11	0.17	41.00	18.67	21.00	2.55
$M_0F_1B_0$	118.00	40.00	1.75	0.010	1.9	0.28	34.33	13.83	12.83	2.07
$M_0F_2B_1$	123.33	40.67	1.78	0.010	3.38	0.09	48.33	21.67	21.50	1.69
$M_0F_2B_2$	124.67	47.67	2.08	0.010	2.71	0.01	43.00	16.50	20.33	2.28
$M_0F_2B_0$	111.67	40.67	1.78	0.008	2.27	0.33	62.67	13.33	15.17	1.09
SE	7.987	2.643	0.117	0.0014	0.187	0.001	1.756	0.832	1.265	0.093
CD	22.590	7.477	0.331	0.002	0.5	0.005	4.967	2.353	3.577	0.263

4.2.4 Physiological parameters

Physiological parameters *viz.*, LAI, NAR, RGR and CGR were estimated and the data are presented in Tables 9, 10, 11 and 12 respectively.

In general among the organic manures, FYM recorded the maximum LAI followed by vermicompost. The increase in LAI was 43.00 and 36.60 per cent respectively at 11 MAP. Among the inorganic fertilizers, upto 6 MAP, 30:30:60 kg NPK $ha^{-1}yr^{-1}$ recorded the maximum and there after F_0 performed better. The application of FP+AM recorded the maximum LAI throughout the period of experimentation followed by AZ+ FP + AM. $M_1F_1B_2$ recorded the highest LAI (3.84) which was on par with $M_1F_2B_2$ and $M_2F_0B_2$ (Table 17 and Plates 4 and 5).

NAR was significantly influenced by the effect of organic manures. Vermicompost on par with FYM was superior to other manures. Towards the later period of growth, FYM and vermicompost recorded the same NAR (0.02 mg cm^{-2} day^{-1}). The application of inorganic fertilizers had no significant influence on NAR. Among the bioinoculants, both B_1 and B_2 were on par up to 7 MAP. But after 9 months of planting the superiority of B_2 (FP+AM) was significantly evident.

The treatment combination $M_1F_1B_2$ recorded the highest NAR (0.06 mg $cm^{-2}day^{-1}$) and found significantly superior to other treatment combinations. $M_1F_1B_2$ was followed by $M_2F_0B_2$ and $M_2F_2B_2$ (0.05 mg cm^{-2} day^{-1}) (Table 17).

In the case of RGR, up to 6 MAP, FYM and vermicompost were on par, thereafter upto 9 MAP, FYM performed better than vermicompost. Towards the later period of growth the effect of organic manure was non significant. Similar to NAR, application of inorganic fertilizers had no significant influence on RGR. Among the bio inoculants, B_1 and B_2 were on par upto 8 MAP. Thereafter the effect was found to be non significant.

Plate 5.Spike formation consequent to leaf development in long pepper

Plate 6. Leaf shedding in long pepper-$M_0 F_1 B_0$

The treatment combination $M_2F_2B_2$ recorded the highest RGR (4.1 mg $g^{-1}day^{-1}$) followed by $M_2F_1B_2$ (3.71 mg $g^{-1}day^{-1}$) which were on par and followed by $M_1F_1B_1$ (3.5 mg $g^{-1}day^{-1}$) (Table 17).

With regard to CGR, among the organic manures, both FYM and vermicompost were on par when compared to others throughout the period of experimentation. Similar to NAR and RGR, CGR was also not significantly influenced by the inorganic fertilizers. The effect of bio inoculants had no significant influence on CGR upto 7 MAP. But 8 MAP onwards the bio inoculants had significant influence and B_1 and B_2 were found to be performing well and were on par.

Due to the interaction effect, the treatment combination $M_2F_1B_2$ recorded the highest CGR (0.55 g m^{-2} day^{-1}) and was followed by $M_1F_1B_2$ (0.54 g m^{-2} day^{-1}) and $M_2F_1B_0$ (0.51 g m^{-2} day^{-1}) (Table 17).

4.2.5 Total dry matter production

The data relating to total DMP estimated at 7, 9 and 11 MAP are presented in Table 18.

The total DMP was found to be influenced by organic manures, inorganic fertilizers and bio inoculants. Among the organic manures FYM was found to be superior with respect to total DMP at 9 MAP and 11 MAP (1360.38 kg ha^{-1} and 1524.15 kg ha^{-1}). At 7 MAP, vermicompost performed better than FYM. The per cent increase in total DMP by FYM and vermicompost at 11 MAP were 188.50 and 185.90 per cent respectively. The effect of inorganic fertilizers was also significant. F_1 recorded the maximum values *viz.*, 630.76, 922.52 and 1061.20 kg ha^{-1} at 7, 9 and 11 MAP respectively. The increase was 17.30 per cent at 11 MAP over F_0. Among the bio inoculants B_2 increased the total DMP significantly when compared to B_1 and B_0 at all stages.

The data on total DMP as influenced by the interaction effects of organic manures, inorganic fertilizers and bio inoculants are summarised in Table 19.

Table 18. Total dry matter production (kg ha^{-1}) and nutrient uptake (kg ha^{-1}) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	Total DMP, kg ha^{-1}			Nitrogen uptake, kg ha^{-1}			Phosphorus uptake, kg ha^{-1}			Potassium uptake, kg ha^{-1}		
	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP
Organic manures												
M_1	815.77	1360.38	1524.15	16.48	26.96	30.19	2.33	3.77	4.22	20.46	32.29	37.05
M_2	940.07	1340.50	1510.68	19.14	26.81	29.90	2.95	3.94	4.62	22.41	31.40	35.16
M_3	434.68	601.83	739.62	8.16	11.27	13.78	1.06	1.45	1.78	8.80	12.10	14.89
M_4	342.67	488.92	624.81	5.30	7.51	9.61	0.75	1.07	1.37	6.44	9.17	11.97
M_0	276.20	428.91	528.24	4.16	6.04	7.41	0.49	0.78	0.96	5.09	7.88	9.73
SE	9.083	5.103	26.220	0.228	0.270	0.669	0.046	0.129	0.113	0.231	0.677	0.681
CD	29.621	16.641	85.508	0.743	0.882	2.182	0.150	0.420	0.368	0.754	2.210	2.210
Inorganic fertilizers												
F_0	477.85	745.52	904.68	8.29	12.70	15.32	0.99	1.54	1.89	9.74	15.13	18.42
F_1	630.76	922.52	1061.20	12.89	18.44	20.95	2.08	2.89	3.39	15.34	22.31	25.52
F_2	577.03	864.28	990.62	10.75	16.01	18.15	1.47	2.17	2.48	12.84	18.27	21.34
SE	2.620	4.517	13.015	0.132	0.099	0.336	0.031	0.450	0.050	0.041	0.509	0.419
CD	10.287	17.732	51.093	0.519	0.390	1.319	0.123	0.176	0.195	0.162	2.000	1.644
Bio inoculants												
B_1	547.25	790.03	971.46	11.62	16.79	20.54	1.84	2.64	3.19	13.73	19.75	24.24
B_2	741.81	1056.01	1169.67	13.57	19.15	20.69	1.93	2.62	2.97	16.64	22.77	25.23
B_0	396.58	686.28	815.37	6.74	11.21	13.20	0.78	1.35	1.60	7.56	13.19	15.80
SE	5.601	5.333	14.670	0.136	0.178	0.330	0.027	0.075	0.061	0.128	0.570	0.484
CD	15.841	15.085	41.492	0.385	0.504	0.934	0.077	0.212	0.174	0.361	1.612	1.368

At 7 MAP, maximum total DMP was recorded by the treatment combination, $M_2F_1B_2$ (1646.66 kg ha^{-1}) and it was on par with $M_2F_2B_2$ (1484.09 kg ha^{-1}). Both the combinations differed significantly from $M_1F_0B_2$ (1072.98 kg ha^{-1}) and $M_1F_1B_1$ (1061.18 kg ha^{-1}). The lowest value was recorded by $M_0F_0B_0$ (207.50 kg ha^{-1}). After 9 months of planting the maximum total DMP was recorded by the combination $M_1F_2B_2$ (1955.25 kg ha^{-1}) which was significantly superior to others, followed by $M_1F_1B_2$ (1889.28 kg ha^{-1}), $M_2F_1B_2$ (1696.49 kg ha^{-1}). At 11 MAP, $M_1F_1B_2$ recorded the maximum total DMP (2093.38 kg ha^{-1}).

4.2.6 Uptake of Nutrients

4.2.6.1 Uptake of Nitrogen

Uptake of Nitrogen estimated at 7, 9 and 11 MAP are furnished in Table 18.

There was significant influence of organic manures, inorganic fertilizers and bio inoculants on the uptake of nitrogen. No significant variation was observed between FYM and vermicompost after 9 and 11 months of planting (26.96 and 26.81 kg ha^{-1}, 30.19 and 29.90 kg ha^{-1}). However at 7 MAP vermicompost showed maximum uptake (19.14 kg ha^{-1}) and differed significantly from all other sources. Among the inorganic fertilizers F_1 showed significantly higher values at 7, 9 and 11 MAP (12.89, 18.44 and 20.95 kg ha^{-1} respectively) followed by F_2. Nitrogen uptake was affected when inorganic fertilizers were not applied to long pepper. With respect to bio inoculants, B_2 showed superior values at all the three stages (13.57, 19.15 and 20.69 kg ha^{-1}).

Interaction effects were found significant. After seven months of planting the nitrogen uptake was the highest in $M_2F_1B_2$ (36.62 kg ha^{-1}) followed by $M_2F_2B_2$ (28.26 kg ha^{-1}) and $M_1F_1B_1$ (26.14 kg ha^{-1}). The lowest value was recorded by $M_0F_0B_0$ (2.69 kg ha^{-1}). At 9 MAP, the uptake ranged from 4.42 kg ha^{-1} to 39.98 kg ha^{-1}. The highest value was recorded by $M_2F_1B_2$ followed by $M_1F_1B_2$ (38.09 kg ha^{-1}) and $M_1F_1B_1$ (36.16 kg ha^{-1}) which were on par. $M_0F_2B_2$ recorded the lowest value. At 11 MAP

Table 19. Total DMP (kg ha^{-1}) and nutrient uptake (kg ha^{-1}) as influenced by the interaction effect of organic manures, inorganic fertilizers and bio inoculants

Treatments	Total DMP, kg ha^{-1}			Nitrogen uptake, kg ha^{-1}			Phosphorus uptake, kg ha^{-1}			Potassium uptake, kg ha^{-1}		
	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP
$M_1F_0B_1$	690.03	1139.86	1303.74	15.46	25.53	29.20	1.75	2.87	3.30	17.25	28.49	32.59
$M_1F_0B_2$	1072.98	1453.88	1711.13	18.02	24.43	28.75	2.30	3.12	3.69	24.14	32.71	38.50
$M_1F_0B_0$	520.91	965.37	1083.45	6.98	13.60	14.52	0.89	1.66	1.87	10.42	19.31	21.67
$M_1F_1B_1$	1061.18	1468.01	1623.12	26.14	36.17	40.67	5.45	7.54	8.34	31.45	44.04	48.70
$M_1F_1B_2$	994.07	1889.28	2093.38	20.04	38.09	41.20	3.26	6.19	6.87	26.34	50.07	55.47
$M_1F_1B_0$	691.76	1169.14	1331.87	13.56	23.25	26.10	1.41	2.39	2.72	17.29	29.23	33.29
$M_1F_2B_1$	922.66	1134.90	1316.67	22.36	27.36	31.80	2.87	3.54	4.11	23.99	29.51	34.23
$M_1F_2B_2$	869.98	1955.25	1997.93	15.10	34.63	34.01	2.06	4.63	4.73	21.28	33.23	40.78
$M_1F_2B_0$	518.36	1067.73	1256.01	10.53	19.66	23.91	0.99	2.04	2.37	11.66	24.02	28.26
$M_2F_0B_1$	721.74	1125.91	1577.78	15.77	25.59	35.13	1.87	2.92	4.17	17.32	27.02	38.19
$M_2F_0B_2$	895.70	1329.42	1512.84	16.55	24.90	27.96	2.11	3.12	3.55	17.91	26.59	30.26
$M_2F_0B_0$	505.21	1031.36	1105.77	6.32	11.55	12.38	0.99	1.99	2.16	8.59	17.53	18.80
$M_2F_1B_1$	970.89	1355.41	1613.98	23.38	33.30	38.84	4.69	6.56	7.80	26.69	37.27	44.36
$M_2F_1B_2$	1646.66	1818.93	1578.84	36.62	39.98	34.48	5.93	5.09	5.67	42.81	47.29	41.05
$M_2F_1B_0$	715.04	1213.63	1420.52	14.61	23.11	27.56	2.14	3.61	4.25	15.73	26.70	30.85
$M_2F_2B_1$	900.09	1358.31	1606.27	18.66	29.67	36.11	3.18	4.82	5.70	23.85	36.01	44.19
$M_2F_2B_2$	1484.09	1696.49	1884.72	28.26	32.30	33.39	4.33	4.96	5.49	36.36	41.56	41.63
$M_2F_2B_0$	621.19	1135.08	1296.36	12.14	20.98	23.28	1.35	2.46	2.80	12.42	22.70	27.15
$M_3F_0B_1$	361.13	562.74	659.93	7.34	11.07	12.86	1.01	1.58	1.85	8.13	12.66	14.85
$M_3F_0B_2$	490.85	657.83	810.60	9.46	11.79	15.19	1.11	1.49	1.84	9.32	12.49	15.40
$M_3F_0B_0$	278.19	456.79	570.33	5.18	7.49	9.93	0.45	0.72	0.91	4.17	6.85	8.55
$M_3F_1B_1$	457.25	610.38	864.31	8.97	11.63	17.61	1.38	1.83	2.59	11.20	14.99	21.17
$M_3F_1B_2$	666.08	823.98	915.92	12.68	16.02	18.10	1.73	2.14	2.38	13.98	17.30	19.23
$M_3F_1B_0$	260.68	459.33	620.27	5.19	8.64	10.77	0.51	0.88	1.18	4.43	7.81	10.54

Table 19. continued…

$M_3F_2B_1$	425.22	564.99	735.05	8.66	11.62	14.49	1.18	1.57	2.05	9.78	12.99	16.91
$M_3F_2B_2$	656.73	837.80	917.48	10.15	15.41	15.85	1.63	2.08	2.27	13.13	16.76	18.35
$M_3F_2B_0$	316.02	442.59	562.71	5.82	7.78	9.26	0.57	0.80	1.02	5.06	7.08	9.00
$M_4F_0B_1$	232.14	362.06	528.99	4.00	5.20	7.45	0.47	0.73	1.07	4.64	7.24	10.58
$M_4F_0B_2$	397.74	534.70	685.00	5.01	7.18	9.54	0.63	0.83	1.07	7.55	10.16	13.01
$M_4F_0B_0$	276.79	399.74	500.42	3.49	5.03	6.31	0.37	0.54	0.67	4.15	5.99	7.51
$M_4F_1B_1$	378.08	559.14	657.57	6.56	9.71	11.41	1.13	1.68	1.97	8.69	12.86	15.13
$M_4F_1B_2$	471.43	652.71	849.90	7.12	10.96	14.28	1.22	1.69	2.22	9.43	13.05	17.00
$M_4F_1B_0$	236.57	383.09	551.33	3.31	5.36	7.72	0.50	0.81	1.17	3.78	6.13	11.03
$M_4F_2B_1$	349.50	459.29	601.82	5.87	7.72	10.78	0.97	1.27	1.67	7.51	9.87	12.94
$M_4F_2B_2$	453.44	613.84	733.35	7.31	10.57	11.44	0.98	1.33	1.59	7.93	10.74	12.83
$M_4F_2B_0$	288.33	435.66	514.85	3.83	5.85	7.59	0.51	0.76	0.90	4.32	6.53	7.72
$M_0F_0B_1$	203.69	326.97	528.42	3.40	5.39	7.10	0.35	0.62	1.00	3.87	6.23	10.03
$M_0F_0B_2$	313.09	494.11	611.03	4.77	6.47	8.67	0.42	0.65	0.81	5.48	8.65	10.69
$M_0F_0B_0$	207.50	342.06	380.75	2.69	5.44	4.95	0.23	0.37	0.42	3.11	5.13	5.71
$M_0F_1B_1$	308.25	406.98	504.16	4.81	6.34	7.87	0.76	1.00	1.24	6.63	8.75	10.84
$M_0F_1B_2$	362.50	575.39	690.26	5.74	8.05	9.66	0.76	1.20	1.45	7.25	11.51	13.80
$M_0F_1B_0$	240.94	452.36	603.56	3.91	6.08	8.11	0.44	0.84	1.12	4.09	7.69	10.26
$M_0F_2B_1$	226.82	415.43	451.02	3.04	5.57	6.88	0.55	1.01	1.09	4.53	8.31	9.02
$M_0F_2B_2$	351.82	506.53	552.62	5.57	6.58	7.85	0.61	0.88	0.96	6.68	9.46	10.49
$M_0F_2B_0$	271.20	340.32	432.38	3.52	4.42	5.62	0.36	0.45	0.58	4.20	5.28	6.70
SE	21.691	20.656	56.815	0.527	0.690	1.279	0.105	0.290	0.238	0.495	2.208	1.873
CD	61.352	58.424	160.698	1.491	1.950	3.618	0.297	0.821	0.672	1.399	6.244	5.299

maximum nitrogen uptake was observed in $M_1F_1B_2$ (41.20 kg ha^{-1}) which was on par with $M_1F_1B_1$ (40.67 kg ha^{-1}). The least uptake was recorded by $M_0F_0B_0$ (4.95 kg ha^{-1}) (Table 19).

4.2.6.2 Uptake of phosphorus

The data on phosphorus uptake at 7, 9 and 11 MAP are furnished in Table 18.

Similar to nitrogen uptake, phosphorus uptake was also found to be influenced by organic manures, inorganic fertilizers and bio inoculants. Among the organic manures, vermicompost recorded the maximum values (2.95, 3.94 and 4.62 kg ha^{-1}) at 7, 9 and 11 MAP. The effect of bio inoculants on phosphorus uptake was evident and B_2 at 7 MAP, B_1 at 9 and 11 MAP followed by B_2 recorded higher phosphorus uptake.

Organic manure X inorganic fertilizers X bio inoculants interaction effect was significant on phosphorus uptake. The phosphorus uptake was comparatively low when compared to nitrogen uptake. At 7 MAP, the maximum phosphorus uptake was recorded by $M_2F_1B_2$ (5.93 kg ha^{-1}) followed by $M_1F_1B_1$ (5.45 kg ha^{-1}) $M_2F_1B_2$ (4.69 kg ha^{-1}) and $M_2F_2B_2$ (4.32 kg ha^{-1}). The uptake was as low as 0.23 kg ha^{-1} in $M_0F_0B_0$. After 9 months of planting, uptake ranged from 0.37 kg ha^{-1} to 7.53 kg ha^{-1}. The maximum was recorded by $M_1F_1B_1$ followed by $M_2F_1B_1$ (6.56 kg ha^{-1}) and $M_1F_1B_2$ (6.19 kg ha^{-1}) which were on par. After 11 months of planting phosphorus uptake increased to 8.34 kg ha^{-1} in $M_1F_1B_1$ which was on par with $M_2F_1B_1$ (7.80 kg ha^{-1}) followed by $M_1F_1B_2$ (6.87 kg ha^{-1}) (Table 19)

4.2.6.3 Uptake of Potassium

Potassium uptake estimated at 7, 9 and 11 MAP are furnished in Table 18.

Vermicompost at 7 MAP recorded significantly higher value (22.40 kg ha^{-1}). However it was on par with FYM and differed significantly from other sources. The effect of inorganic fertilizers on potassium uptake was similar to nitrogen and phosphorus uptake and F_1 recorded higher values

Table 20. Yield attributes, yield and biochemical constituents as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	Spike number plant^{-1}			Fresh spike yield, kg ha^{-1}				Dry spike yield, kg ha^{-1}				Alkaloid content, %	Total alkaloid production, kg ha^{-1}
Organic manures	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	Total	7 MAP	9 MAP	11 MAP	Total		
M_1	6.37	10.25	15.30	46.21	79.77	135.47	262.55	27.44	44.94	79.73	152.34	5.78	8.80
M_2	5.85	7.55	13.63	47.44	82.71	186.46	316.61	27.65	46.66	108.76	183.08	5.75	10.52
M_3	2.48	7.37	10.45	32.62	66.09	102.39	200.44	18.50	38.29	58.60	115.42	5.54	6.39
M_4	2.07	6.48	9.59	19.07	36.09	73.48	128.65	11.02	18.85	42.21	72.07	5.56	4.00
M_0	0.00	5.33	8.59	6.02	19.29	33.41	59.46	2.79	10.62	19.23	32.89	5.43	1.78
SE	0.287	0.431	0.487	0.791	1.663	2.963	2.487	0.641	1.164	1.973	1.690	*	*
CD	0.935	1.407	1.59	2.579	5.422	9.662	8.109	2.091	3.798	6.433	5.510	*	*
Inorganic fertilizers													
F_0	2.28	6.11	9.68	19.75	45.82	76.26	141.90	11.25	25.28	43.78	80.33	5.63	4.51
F_1	3.62	7.68	11.44	40.95	69.49	144.70	255.14	23.96	39.51	84.90	148.52	5.64	8.37
F_2	4.15	8.11	12.19	30.10	55.06	97.77	183.59	17.22	30.82	56.43	104.62	5.57	5.82
SE	0.054	0.361	0.429	0.735	0.828	1.918	3.188	0.559	0.423	1.214	1.384	*	*
CD	0.214	1.416	1.682	2.887	3.251	7.530	12.516	2.193	1.659	4.767	5.432	*	*
Bio inoculants													
B_1	5.45	11.24	17.45	46.84	78.14	145.14	270.15	28.10	44.14	84.37	156.62	5.64	8.83
B_2	3.00	7.62	10.37	30.85	55.63	106.51	193.07	17.83	31.56	61.98	111.52	5.59	6.23
B_0	1.62	4.82	8.00	13.12	36.59	67.07	117.40	6.51	19.93	38.77	65.34	5.61	3.66
SE	0.225	0.255	0.447	0.767	1.025	1.885	2.318	0.443	0.605	1.158	1.392	*	*
CD	0.635	0.721	1.263	2.168	2.898	5.330	6.555	1.253	1.711	3.270	3.938	*	*

* Data not analysed

MAP-Months after planting

throughout the period of experimentation (15.34, 22.31 and 25.52 kg ha^{-1}). B_2 at all stages recorded maximum uptake, *ie*., 16.64, 22.77 and 25.23 kg ha^{-1} respectively after 7 , 9 and 11 months of planting.

The interaction effects were significant and after 7 months of planting the highest uptake was recorded by $M_2F_1B_2$ (42.81 kg ha^{-1}) followed by $M_2F_2B_2$ (36.36 kg ha^{-1}) and $M_1F_1B_1$ (31.85 kg ha^{-1}). The lowest uptake was recorded by $M_0F_0B_0$ (3.11 kg ha^{-1}). At 9 MAP the uptake was increased to a maximum of 50.07 kg ha^{-1} in $M_1F_1B_2$ and was on par with $M_2F_1B_2$ (47.29 kg ha^{-1}) and $M_1F_1B_1$ (44.04 kg ha^{-1}). At 11 MAP, $M_1F_1B_2$ was found to be superior (55.47 kg ha^{-1}) followed by $M_1F_1B_1$ (48.70 kg ha^{-1}), $M_2F_1B_1$ (44.36 kg ha^{-1}) and $M_2F_2B_1$ (44.19 kg ha^{-1}) which were on par (Table 19).

4.2.7 Spike number plant^{-1}

Data on spike number per plant recorded at three harvests *viz.*, 7,9 and 11 MAP are furnished in Table 20.

The effect of organic manures on spike number was significant at all harvests and the superiority of FYM was evident at second and third harvests. No significant difference was observed between FYM and vermicompost at first harvest. When compared to control, FYM recorded 92.30 and 78.10 per cent increase in spike number at second and third harvests respectively. Inorganic fertilizers, F_1 and F_2 had significant influence on spike number at all harvests. A spectacular improvement in spike number was observed when B_1 was inoculated and there was 236.40, 133.20, 118.10 per cent increase over B_0 at 1st, 2nd and 3rd harvests respectively.

The effect of interaction among organic manures, inorganic fertilizers and bio inoculants was significant at all harvests. At first harvest, the spike number ranged from zero to 12.67. The higher spike number was recorded by $M_2F_1B_1$ followed by $M_1F_2B_1$ and $M_2F_2B_1$ which were on par (12.67, 11.00 and 11.00). There was no spike production in

$M_0F_2B_0$, $M_0F_2B_2$, $M_0F_2B_1$, $M_0F_1B_0$, $M_0F_1B_2$, $M_0F_1B_1$, $M_0F_0B_0$, $M_0F_0B_2$, $M_0F_0B_1$, $M_4F_0B_0$ and $M_3F_0B_0$ even after 7 MAP. After 9 months of planting spikes were observed in all the treatments and the highest number was recorded by $M_1F_0B_1$ which was followed by $M_2F_0B_1$ (16.33), $M_1F_1B_1$ (15.00) and $M_1F_2B_1$ (13.67). During the last harvest, the highest number was recorded by $M_1F_0B_1$ and it was significantly different from all other treatment combinations (Table 21).

4.2.8 Spike yield

The mean values of fresh spike yield and dry spike yield recorded at first, second and third harvests are summarised in Table 20.

Organic manures, inorganic fertilizers and bio inoculants had significant effect on fresh and dry spike yield. Among the organic manures, the superiority of vermicompost was evident with respect to total fresh and dry spike production and the increase over control were 432.50 and 456.60 per cent respectively. Vermicompost followed by FYM, coirpith compost and neemcake recorded higher yields. Drastic reduction in total yield was observed when long pepper was cultivated without the addition of organic manures. Almost a similar trend was observed with respect to individual harvests carried out at 7,9 and 11 MAP.

Among the inorganic fertilizers, application of NPK@ 30:30:60 kg $ha^{-1}yr^{-1}$ (F_1) recorded the maximum values at all harvests. A similar trend was observed with respect to total fresh and dry spike production (255.14 and 148.52 kg ha^{-1}). When compared to control the increase in yield in F_1 and F_2 were 107.30 and 52.40 per cent at 7 MAP, 51.60 and 20.20 per cent at 9 MAP, 89.70 and 28.20 per cent at 11 MAP. With respect to total fresh spike yield, it was 79.80 and 29.40 per cent. Increase in dry spike yield in F_1 and F_2 were 112.90 and 53.00 per cent at 7 MAP, 56.30 and 28.20 per cent at 9 MAP, 93.90 and 28.90 per cent at 11 MAP when compared to control.

Table. 21. Yield attributes, yield and quality as influenced by the interaction effect of organic manures, inorganic fertilizers and bio inoculants

Treatment Combination	Spike number plant^{-1}			Fresh spike yield, kg ha^{-1}				Dry spike yield, kg ha^{-1}				Alkaloid content, %	Total Alkaloid production, kg ha^{-1}
	7 MAP	9 MAP	11 MAP	7 MAP	9 MAP	11 MAP	Total	7 MAP	9 MAP	11 MAP	Total		
$M_1F_0B_1$	9.33	20.00	36.33	56.44	74.08	114.13	274.65	33.99	41.52	83.11	158.63	6.13	9.72
$M_1F_0B_2$	6.33	11.67	18.33	40.76	55.05	102.54	198.35	24.22	31.38	59.67	115.27	5.91	6.81
$M_1F_0B_0$	2.33	8.33	13.67	8.52	32.16	61.69	102.37	3.20	15.99	35.74	54.93	6.01	3.30
$M_1F_1B_1$	10.00	15.00	20.33	88.67	147.83	240.22	477.01	55.96	83.01	141.12	280.09	5.71	4.57
$M_1F_1B_2$	2.33	11.33	12.67	52.06	97.71	178.77	328.54	32.06	55.33	106.71	196.09	5.82	11.41
$M_1F_1B_0$	6.33	7.33	9.67	15.78	58.78	127.81	202.37	8.22	34.97	75.41	118.6	6.00	7.11
$M_1F_2B_1$	11.00	13.67	22.00	74.70	114.45	163.20	352.35	45.16	66.98	96.25	208.39	5.88	12.25
$M_1F_2B_2$	5.67	9.00	13.00	58.99	87.78	120.93	267.67	32.69	48.79	72.09	153.38	5.28	8.09
$M_1F_2B_0$	4.00	6.00	11.00	19.94	50.02	79.97	159.60	11.49	26.47	47.47	85.42	5.31	4.53
$M_2F_0B_1$	5.67	16.33	19.67	49.35	104.48	13.27	288.11	30.73	57.99	77.16	165.87	5.84	9.67
$M_2F_0B_2$	2.67	12.67	13.67	32.72	63.05	94.72	190.49	16.53	36.08	53.89	106.51	6.08	6.47
$M_2F_0B_0$	2.00	5.00	12.67	18.89	43.87	65.12	127.17	8.33	23.65	38.69	70.66	5.75	4.06
$M_2F_1B_1$	12.67	11.00	22.00	96.14	124.08	406.96	627.17	59.12	72.69	239.33	371.04	6.03	22.37
$M_2F_1B_2$	7.00	7.33	9.67	61.84	93.13	298.21	453.18	36.24	53.51	177.18	266.93	5.31	14.17
$M_2F_1B_0$	1.00	3.00	6.67	48.85	64.60	174.46	287.90	25.45	36.54	101.97	163.96	5.85	9.59
$M_2F_2B_1$	11.00	10.67	18.33	73.15	119.45	273.65	466.25	44.31	63.72	159.39	267.42	5.35	14.7
$M_2F_2B_2$	7.33	7.33	12.33	37.46	75.18	150.07	262.71	24.17	45.66	83.38	156.21	5.81	9.07
$M_2F_2B_0$	3.33	7.00	7.67	8.51	56.42	82.71	147.74	4.10	30.08	44.91	79.08	5.74	4.53
$M_3F_0B_1$	2.33	11.00	14.33	24.98	71.46	104.59	201.03	14.26	40.03	58.26	112.55	5.67	6.38
$M_3F_0B_2$	1.33	5.00	5.33	12.41	62.03	82.53	151.24	9.59	37.00	43.21	89.90	5.30	4.76
$M_3F_0B_0$	0.00	4.33	4.67	6.22	50.74	65.12	122.09	3.94	26.99	35.16	66.89	5.48	3.66
$M_3F_1B_1$	5.67	10.33	16.67	77.22	111.59	150.13	338.95	44.35	66.21	82.27	198.82	5.58	11.09
$M_3F_1B_2$	2.33	7.33	11.67	44.37	90.86	138.73	274.06	26.49	53.48	82.58	162.56	6.02	9.78
$M_3F_1B_0$	0.33	3.00	3.67	23.40	57.32	71.63	151.94	12.35	33.71	41.31	87.36	5.38	4.69

Table 21. continued…

$M_3F_2B_1$	4.33	11.00	18.00	44.90	69.45	128.14	242.48	25.42	40.41	72.16	138.79	5.41	7.50
$M_3F_2B_2$	4.00	8.00	11.67	36.65	47.57	104.77	188.58	19.44	26.97	61.24	107.64	5.68	6.11
$M_3F_2B_0$	2.00	6.33	8.00	23.99	33.74	75.89	133.61	10.69	19.89	43.54	74.23	5.36	3.97
$M_4F_0B_1$	1.33	6.67	10.67	19.34	42.34	76.25	138.13	11.93	22.92	44.19	79.02	5.30	4.18
$M_4F_0B_2$	1.00	4.67	7.00	16.66	32.30	70.75	119.72	8.15	14.91	39.17	62.22	5.82	3.62
$M_4F_0B_0$	0.00	3.67	3.33	1.84	15.12	46.25	63.21	0.53	7.03	28.13	35.69	5.32	1.89
$M_4F_1B_1$	3.67	11.00	15.00	39.72	59.18	107.36	206.26	23.70	33.72	62.16	119.57	5.75	6.87
$M_4F_1B_2$	1.33	5.00	7.00	27.81	40.39	86.79	154.97	15.80	19.58	49.07	84.44	5.03	4.24
$M_4F_1B_0$	1.67	3.00	6.67	10.00	29.65	61.11	100.78	5.11	12.88	34.46	52.45	5.80	3.04
$M_4F_2B_1$	4.67	10.33	14.00	30.14	51.01	89.27	170.42	18.66	26.79	50.77	96.22	5.72	5.54
$M_4F_2B_2$	3.67	8.33	13.66	21.24	33.90	80.65	135.80	13.44	20.51	47.72	81.76	5.31	4.34
$M_4F_2B_0$	1.33	5.67	9.00	4.83	20.94	42.83	68.6	1.87	11.29	24.23	37.23	5.98	2.26
$M_0F_0B_1$	0.00	5.00	9.33	7.40	19.23	64.15	90.78	3.27	11.14	37.79	52.23	5.42	2.83
$M_0F_0B_2$	0.00	2.67	2.66	0.69	11.61	23.31	43.28	0.17	6.82	15.80	22.79	5.34	1.21
$M_0F_0B_0$	0.00	1.33	7.00	0.02	9.74	9.46	19.22	0.00	5.81	5.97	11.76	5.08	0.56
$M_0F_1B_1$	0.00	9.00	14.33	14.72	33.24	65.82	113.80	7.92	19.27	37.49	64.80	5.18	3.35
$M_0F_1B_2$	0.00	6.00	9.67	9.09	20.36	37.23	66.68	4.58	11.01	21.72	37.31	5.81	2.16
$M_0F_1B_0$	0.00	5.67	6.67	4.56	13.56	25.29	43.42	2.19	6.73	14.81	23.73	5.35	1.26
$M_0F_2B_1$	0.00	7.67	10.67	5.67	30.19	30.99	68.85	2.86	15.63	17.27	35.77	5.73	2.04
$M_0F_2B_2$	0.00	8.00	7.33	10.59	23.45	26.75	60.79	3.89	12.36	13.24	29.50	5.28	1.55
$M_0F_2B_0$	0.00	2.67	9.67	1.40	12.22	16.72	30.34	0.16	6.77	9.04	18.11	5.72	1.03
SE	0.870	0.987	1.730	2.969	3.968	7.302	8.976	0.767	2.343	4.483	5.393	*	*
CD	2.461	2.792	4.892	8.398	11.225	20.654	25.389	2.170	6.628	12.681	15.253	*	*
Natural habitat	-	-	-	-	-	-	-	-	-	-	-	5.63	-

*data not analysed

MAP-Months after planting

Inoculation with B_1 was found significantly superior at all harvests followed by B_2. At all harvests B_1 recorded 257.00 and 331.00 per cent (7 MAP), 113.50 and 121.40 per cent (9 MAP) 116.40 and 117.60 per cent (11 MAP) increase in fresh and dry spike yield respectively over B_0. Increase in total fresh and dry spike production in B_1 and B_2 were 130.10 and 64.40 per cent, 139.70 and 70.60 per cent respectively over B_0.

The interaction effects of organic manures, inorganic fertilizers and bio inoculants were significant with respect to fresh and dry spike yield.

Fresh spike yield at first harvest showed wide variation *ie.*, from 0.02 kg ha^{-1} to 96.14 kg ha^{-1}. The highest yield was recorded by the treatment combination, $M_2F_1B_1$ and it was on par with $M_1F_1B_1$. At 9 MAP the values ranged from 9.74 kg ha^{-1} to 147.83 kg ha^{-1}. $M_1F_1B_1$ recorded the highest value (147.83 kg ha^{-1}) and it was superior to $M_1F_1B_1$, $M_2F_2B_1$ and $M_1F_2B_2$. At 11 MAP the highest yield was recorded by the treatment combination, $M_2F_1B_1$ (406.96 kg ha^{-1}) followed by $M_2F_1B_2$ (298.21 kg ha^{-1}) $M_2F_2B_1$ (273.65 kg ha^{-1}) and $M_1F_1B_1$ (240.22 kg ha^{-1}). $M_0F_0B_0$ recorded the lowest values at all stages of harvests. Total fresh spike yield varied from 19.22 kg ha^{-1} to 627.17 kg ha^{-1}. The highest yield was recorded by the combination $M_2F_1B_1$ (627.17 kg ha^{-1}) which was found significantly superior to other treatments and it was followed by $M_1F_1B_1$, $M_2F_2B_1$ and $M_2F_1B_2$ with mean values of 477.01 kg ha^{-1}, 466.25 kg ha^{-1} and 453.18 kg ha^{-1} which were on par. As in the case of earlier harvests, $M_0F_0B_0$ showed the lowest yield (Plates 7, 8, 9 and 10).

At 7 MAP, the maximum dry spike yield was recorded by $M_2F_1B_1$ and was on par with $M_1F_1B_1$ (59.01 kg ha^{-1} and 55.96 kg ha^{-1} respectively). After nine months of planting the highest dry spike yield was recorded by $M_1F_1B_1$ (83.01 kg ha^{-1}) which was superior to $M_2F_1B_1$, $M_1F_2B_1$ and $M_3F_1B_1$. At 11 MAP, the highest yield was recorded by $M_2F_1B_1$ (239.33 kg ha^{-1}) and it was followed by $M_2F_1B_2$ (177.18 kg ha^{-1}), $M_2F_2B_1$ (159.39 kg ha^{-1}) and $M_1F_1B_1$ (141.12 kg ha^{-1}). Similar to individual harvests, $M_2F_1B_4$ recorded the highest total dry spike yield

Plate 7. Spike production in long pepper as influenced by organic manures, inorganic fertilizers and bio inoculants ($M_2F_1B_1$)

Plate 8. Management of long pepper garden-IPNS involving $M_2F_1B_1$

Plate 9.Management of long pepper garden - IPNS involving

$M_1\ F_1\ B_1$

Plate 10. Management of long pepper garden
-control (M0F0B0)

(371.04 kg ha^{-1}) which was followed by $M_1F_1B_1$ (280.09 kg ha^{-1}), $M_2F_2B_1$(267.42 kg ha^{-1}) and $M_2F_1B_2$ (266.93 kg ha^{-1}) which were on par. Similar to fresh spike yield, the treatment combination $M_0F_0B_0$ recorded the lowest yield at all harvests (Table 21).

4.2.9 Alkaloid content

Data regarding the alkaloid content in spikes are presented in Tables 20 and 21.

There was not much variation in alkaloid content due to the effect of organic manures, inorganic fertilizers and bio inoculants. Among the organic manures, FYM recorded the maximum alkaloid content (5.78 %) followed by vermicompost (5.75 %). When compared to control, the increase in alkaloid content recorded by FYM and vermicompost were 6.40 and 5.90 per cent respectively. Alkaloid content was found to be maximum in F_1 followed by F_0. The highest alkaloid content was observed when B_1 was inoculated *ie.*, 0.53 per cent increase over control.

The alkaloid content ranged from 5.08 to 6.13 per cent due to the interaction effect of organic manures, inorganic fertilizers and bio inoculants. The maximum alkaloid content was recorded by $M_1F_0B_1$ (6.13 %) followed by $M_2F_0B_2$ (6.08 %), $M_2F_1B_1$ (6.03 %) and $M_3F_1B_2$ (6.02 %). The alkaloid content of spikes collected from natural habitat was found to be 5.63 per cent.

4.2.10 Soil nutrient status

4.2.10.1 Available soil nitrogen

The data pertaining to available soil nitrogen after the experiment are furnished in Table 22.

Among the organic manures, neemcake application recorded the maximum available soil nitrogen (165.27 kg ha^{-1}) followed by coir pith compost (153.28 kg ha^{-1}). Inorganic fertilizer treatment, F_1 recorded the least amount of soil nitrogen (126.95 kg ha^{-1}) and significantly different from F_0 and F_2. The bio inoculant treatment with no inoculation recorded

Table 22. Available soil nutrient status (kg ha^{-1}) as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatments	N, kg ha^{-1}	P_2O_5, kg ha^{-1}	K_2O, kg ha^{-1}
Organic manures			
M_1	133.72	71.21	155.87
M_2	150.66	89.31	179.44
M_3	153.28	68.78	219.10
M_4	165.27	62.34	213.57
M_0	72.40	37.77	154.45
SE	0.738	2.004	2.117
CD	2.408	6.534	6.904
Inorganic fertilizers			
F_0	144.37	75.32	197.44
F_1	126.95	56.76	173.44
F_2	133.87	65.57	182.58
SE	0.281	2.048	0.816
CD	1.105	8.039	3.205
Bio inoculants			
B_1	110.91	67.67	164.41
B_2	131.67	56.34	181.05
B_0	162.62	73.43	208.00
SE	0.452	1.220	0.974
CD	1.278	3.451	2.754

Table 23. Available soil nutrient status (kg ha^{-1}) as influenced by the interaction effect of organic manures, inorganic fertilizers and bioinoculants

Treatments	N. kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}
$M_1F_0B_1$	121.29	100.00	140.98
$M_1F_0B_2$	152.58	58.00	158.35
$M_1F_0B_0$	166.44	64.79	226.17
$M_1F_1B_1$	100.68	60.37	112.85
$M_1F_1B_2$	138.32	43.66	134.83
$M_1F_1B_0$	154.30	88.37	196.03
$M_1F_2B_1$	118.24	83.52	120.83
$M_1F_2B_2$	140.63	59.89	150.29
$M_1F_2B_0$	111.02	82.26	162.57
$M_2F_0B_1$	124.51	104.48	167.13
$M_2F_0B_2$	142.42	91.06	199.11
$M_2F_0B_0$	215.40	89.64	226.86
$M_2F_1B_1$	121.79	78.92	135.05
$M_2F_1B_2$	136.31	46.11	161.69
$M_2F_1B_0$	176.89	85.43	191.39
$M_2F_2B_1$	121.96	120.69	128.29
$M_2F_2B_2$	137.74	102.51	189.71
$M_2F_2B_0$	178.98	85.02	216.13
$M_3F_0B_1$	144.29	72.06	215.66
$M_3F_0B_2$	152.07	55.13	231.06
$M_3F_0B_0$	199.71	86.93	249.77
$M_3F_1B_1$	125.72	57.20	194.16
$M_3F_1B_2$	142.94	47.06	189.84
$M_3F_1B_0$	167.29	67.89	212.73
$M_3F_2B_1$	129.35	65.24	215.07
$M_3F_2B_2$	149.88	71.38	226.88
$M_3F_2B_0$	168.32	95.13	236.77
$M_4F_0B_1$	149.92	91.93	207.67
$M_4F_0B_2$	163.69	85.71	221.58
$M_4F_0B_0$	221.85	95.78	241.82
$M_4F_1B_1$	126.89	48.58	190.85
$M_4F_1B_2$	153.32	50.76	199.65
$M_4F_1B_0$	167.06	64.33	221.74
$M_4F_2B_1$	144.45	37.25	193.66
$M_4F_2B_2$	169.34	32.78	215.04
$M_4F_2B_0$	190.93	53.95	230.10
$M_0F_0B_1$	54.86	36.56	148.33
$M_0F_0B_2$	73.99	36.70	153.01
$M_0F_0B_0$	82.66	60.10	174.13
$M_0F_1B_1$	40.13	32.61	154.21
$M_0F_1B_2$	57.99	35.83	144.24
$M_0F_1B_0$	94.67	44.28	162.76
$M_0F_2B_1$	39.55	28.67	141.45
$M_0F_2B_2$	63.96	27.63	140.92
$M_0F_2B_0$	143.85	37.56	171.06
SE	1.750	4.726	2.176
CD	4.951	13.367	6.154

the maximum available soil nitrogen. B_1 recorded the lowest amount of soil nitrogen.

Due to the interaction effect of organic manures, inorganic fertilizers and bio inoculants, the quantity of available soil nitrogen ranged from 39.55 to 221.85 kg ha^{-1}. The maximum quantity was recorded by $M_4F_0B_0$ and significantly different from others, followed by $M_2F_0B_0$ (215.40 kg ha^{-1}). The available soil nitrogen was the lowest in $M_0F_2B_1$ (39.55 kg ha^{-1}) and was on par with $M_0F_1B_1$ (40.13 kg ha^{-1}) (Table 23).

4.2.10.2 Available soil phosphorus

The data pertaining to available soil phosphorus are given in Table 22.

Among the organic manures the maximum soil phosphorus was recorded by vermicompost (89.31 kg ha^{-1}) followed by FYM (71.21 kg ha^{-1}) and among the inorganic fertilizers the maximum quantity of available soil phosphorus was recorded by the control (75.32 kg ha^{-1}). Among the bio inoculants the least quantity of available phosphorus was recorded by the bio inoculant combination of FP +AM and the maximum content by the control treatment.

The maximum available soil phosphorus (120.69 kg ha^{-1}) was recorded by $M_2F_2B_1$ and the least amount of soil phosphorus was recorded by $M_0F_2B_2$ (27.63 kg ha^{-1}) indicating the influence of organic manure on the available soil phosphorus (Table 23).

4.2.10.3 Available soil potassium

Data relating to available potassium in soil are presented in Table 22.

Among the organic manures, coirpith compost recorded the maximum available potassium in soil (219.10 kg ha^{-1}) followed by neemcake (213.57 kg ha^{-1}). Among the inorganic fertilizes, F_1 recorded the lowest quantity of potassium in soil. The bio inoculant treatment with no inoculation recorded the highest quantity and the B_1 recorded the least quantity of available potassium in soil.

Due to the interaction effect of treatments the quantity of available soil potassium ranged from 112.85 kg ha^{-1} ($M_1F_1B_1$) to 249.77 kg ha^{-1} ($M_3F_0B_0$) (Table 23).

4.2.11 Microbial colonisation

Colonisation of Azospirillum, Fluorescent pseudomonads and per cent infection and spore load of AMF were analysed and presented in Tables 24 and 25.

4.2.11.1 Azospirillum

The data on Azopirilum colonisation observed at 9 MAP are furnished in Table 24.

Among the organic manures, FYM and vermicompost recorded significantly higher values when compared to other sources. It was observed that coirpith compost and neemcake did not favour the multiplication of Azospirillum. Not only the source, but the quantity of nutrients also tend to influence Azospirillum colonisation. Application of the highest dose of NPK *ie.*, 60:60:120 kg ha^{-1} yr^{-1} recorded maximum colonisation and it was 47.10 per cent higher when compared to control. Artificial application of bio inoculants were found to influence colonisation and B_1 recorded the highest value (2.60 x 10^5 cfu g^{-1}) and it was 98.40 per cent higher over no inoculation.

Data on interaction effects of organic manures inorganic fertilizers and bio inoculants on the colonisation of Azospirillum are given in Table 25. The highest level of colonisation was recorded by $M_1F_2B_1$ (7.00 x 10^5 cfu g^{-1}) and it was significantly superior to all other treatment combinations. It was followed by $M_2F_2B_1$ (4.00 x 10^5 cfu g^{-1}) and $M_2F_1B_1$ (4.00 x 10^5 cfu g^{-1}) revealing the increased colonisation of Azospirillum at higher levels of inorganic fertilizers. The increase in colonisation in $M_1F_2B_1$ was 319.20 per cent over control ($M_0F_0B_0$).

Table 24. Rhizosphere, microflora as influenced by organic manures, inorganic fertilizers and bio inoculants

Treatment	AZ, 10^5 cfu g^{-1}	FP, 10^5 cfu g^{-1}	AMF	
			Per cent infection, %	Spore load, g^{-1} soil
Organic manures				
M_1	2.04	3.78	65.00	108.85
M_2	2.04	2.56	63.53	85.55
M_3	1.30	2.93	49.00	91.65
M_4	1.81	3.00	45.17	81.65
M_0	1.44	3.19	43.92	66.10
SE	0.109	0.278	*	*
CD	0.354	0.907	*	*
Inorganic fertilizers				
F_0	1.42	3.78	49.68	98.30
F_1	1.67	2.60	62.63	90.00
F_2	2.09	2.89	47.65	77.65
SE	0.122	0.099	*	*
CD	0.480	0.390	*	*
Bio inoculants				
B_1	2.60	5.38	54.34	97.35
B_2	1.27	2.69	67.58	107.65
B_0	1.31	1.20	32.71	61.00
SE	0.111	0.191	*	*
CD	0.314	0.539	*	*

* Data not analysed

4.2.11.2 Fluorescent pseudomonads

The mean values of colonisation of fluorescent pseudomonads recorded at 9 MAP is given in Table 24.

The significant effect of organic manures on the colonisation of fluorescent pseudomonads was evident and the maximum number was recorded by FYM (3.78×10^5 cfu g^{-1}) which was on par with neemcake (3.00×10^5 cfu g^{-1}) and control (3.19×10^5 cfu g^{-1}). Vermicompost and coirpith compost recorded lower values indicating that compost was not a favourable medium for the growth of fluorescent pseudomonads. Cultivation of long pepper without the addition of inorganic fertilizers was found favourable for enhancing colonisation and the improvement was 30.70 per cent over F_2. Among the bio inoculants B_1, *ie.*, combined application of AZ + FP + AM recorded maximum colonisation and it was 348.00 per cent higher compared to B_0. Colonisation in B_2 was only 124.00 per cent higher compared to control.

Data on colonisation of fluorescent pseudomonads due to the interaction of organic manures, inorganic fertilizers and bio inoculants are presented in Table 25. The highest colony count was obtained in $M_1F_1B_1$ (8.67×10^5 cfu g^{-1}) which was on par with $M_1F_0B_1$ (7.33×10^5 cfu g^{-1}), $M_0F_0B_1$ (7.33×10^5 cfu g^{-1}) and $M_3F_0B_1$ (7.00×10^5 cfu g^{-1}) indicating the enhancement of colonisation in the absence of inorganic fertilizers.

4.2.11.3 AMF

The data relating to spore load and per cent infection of AMF as influenced by organic manures, inorganic fertilizers and bio inoculants are presented in Table 24.

Among the organic manures, FYM ranked first with respect to spore load (108.85) and per cent infection of AMF (65.00 %) There was 47.90 per cent increase in AMF per cent infection and 64.60 per cent increase in spore load compared to control. With respect to spore load, F_0 performed better compared to F_1 and F_2. But the per cent infection

Table 25. Rhizosphere microflora as influenced by the interaction effect of organic manures, inorganic fertilizers and bio inoculants

Treatments	AZ. 10^5 cfu g^{-1}	FP. 10^5 cfu g^{-1}	AMF	
			Per cent infection, %	Spore load, g^{-1} soil
$M_1F_0B_1$	2.33	7.33	76.40	125
$M_1F_0B_2$	1.00	3.67	97.23	120
$M_1F_0B_0$	1.33	1.33	25.00	75
$M_1F_1B_1$	2.00	8.67	86.28	145
$M_1F_1B_2$	1.33	2.33	83.00	140
$M_1F_1B_0$	1.00	1.33	42.00	95
$M_1F_2B_1$	7.00	6.33	68.60	105
$M_1F_2B_2$	1.33	1.67	87.00	125
$M_1F_2B_0$	1.00	1.33	20.62	50
$M_2F_0B_1$	2.00	5.00	52.06	110
$M_2F_0B_2$	1.33	1.33	76.00	155
$M_2F_0B_0$	1.33	1.33	29.00	70
$M_2F_1B_1$	4.00	4.67	90.82	85
$M_2F_1B_2$	1.33	1.33	83.71	130
$M_2F_1B_0$	1.33	1.00	60.00	50
$M_2F_2B_1$	4.00	5.33	73.00	95
$M_2F_2B_2$	1.33	2.00	64.62	90
$M_2F_2B_0$	1.67	1.00	42.74	70
$M_3F_0B_1$	1.33	7.00	33.00	110
$M_3F_0B_2$	1.00	5.33	85.87	140
$M_3F_0B_0$	1.33	1.33	26.00	85
$M_3F_1B_1$	1.33	3.33	48.20	95
$M_3F_1B_2$	1.00	1.66	84.61	95
$M_3F_1B_0$	1.33	1.33	31.00	65
$M_3F_2B_1$	2.00	3.67	38.27	75
$M_3F_2B_2$	1.00	1.67	53.40	90
$M_3F_2B_0$	1.33	1.00	41.23	55
$M_4F_0B_1$	1.67	4.33	23.00	105
$M_4F_0B_2$	1.33	4.33	63.00	120
$M_4F_0B_0$	1.00	1.00	35.72	60
$M_4F_1B_1$	2.33	2.67	53.30	85
$M_4F_1B_2$	1.67	2.33	80.00	90
$M_4F_1B_0$	1.00	1.00	36.62	45
$M_4F_2B_1$	1.67	7.00	20.31	100
$M_4F_2B_2$	1.67	3.33	62.00	75
$M_4F_2B_0$	2.00	1.00	32.70	55
$M_0F_0B_1$	1.67	7.33	33.00	70
$M_0F_0B_2$	1.00	4.67	63.51	90
$M_0F_0B_0$	1.67	1.33	26.60	40
$M_0F_1B_1$	2.67	3.67	73.41	95
$M_0F_1B_2$	1.67	2.33	66.22	85
$M_0F_1B_0$	1.00	1.33	21.00	50
$M_0F_2B_1$	1.00	4.33	46.60	60
$M_0F_2B_2$	1.00	2.33	43.00	70
$M_0F_2B_0$	1.33	1.33	22.00	35
SE	0.430	0.738	*	*
CD	1.217	2.087	*	*

* data not analysed

increased with application of 30:30:60 kg NPK $ha^{-1}yr^{-1}$ (62.63 %). Among the bio inoculants B_2 scored the highest spore load and per cent infection (107.65 and 67.58 per cent respectively) followed by B_1.

Organic manures X inorganic fertilizers X bio inoculants interaction showed a wide variation with respect to spore load and per cent infection. Per cent infection ranged form 20.31 per cent ($M_4F_2B_1$) to 97.23 per cent ($M_1F_0B_2$). $M_1F_0B_2$ was followed by $M_2F_1B_1$ (90.82 %) and $M_1F_1B_1$ (86.28 %) $M_1F_0B_2$ recorded 267.00 per cent increase in infection per cent over control ($M_0F_0B_0$). With regard to spore load of AMF the maximum was noticed in $M_2F_0B_2$ (155) followed by $M_1F_1B_1$ (145), $M_1F_1B_2$ (140) and $M_3F_0B_2$ (140) indicating that spore production of AMF was enhanced by lower levels of inorganic fertilizers (Table 25).

Discussion

5. DISCUSSION

The results of the two experiments presented in the previous chapter are discussed in the following paragraphs.

5.1 POT CULTURE

Nursery management for quality planting material production in long pepper.

5.1.1 Bio inoculants

Production of quality planting material is of prime importance in commercial mediculture. Long pepper is a long duration crop which gives economic yield for more than five years and hence appropriate techniques are to be adopted for the production of quality saplings. The effect of bio inoculants and the composition of rooting media on biometric characters, dry matter production, root characters and microbial colonisation were studied in detail.

In general, dual inoculation of FP+AM and combined inoculation of AZ+FP+AM resulted in maximum vine weight, leaf number, leaf area, vine weight and dry matter production (Table 5 and Fig. 4). The effect of single inoculation was not significant in the case of AZ and FP in influencing biometric characters and dry matter production. Root parameters *viz*., root number, root spread, and root weight were also favourably influenced by dual inoculation of FP+AM and combined inoculation of AZ+FP+AM (Table 5). Single inoculation of AZ and FP had no significant effect on root production.

AM association resulting in growth promotion in black pepper was reported by Bopaiah and Khader (1989). Sivaprasad *et al*. (2003) reported increased plant height due to the application of fluorescent pseudomonads .It is also reported that *Glomus monosporum* was the most promising arbuscular mycorrhizal fungus in promoting establishment and growth of

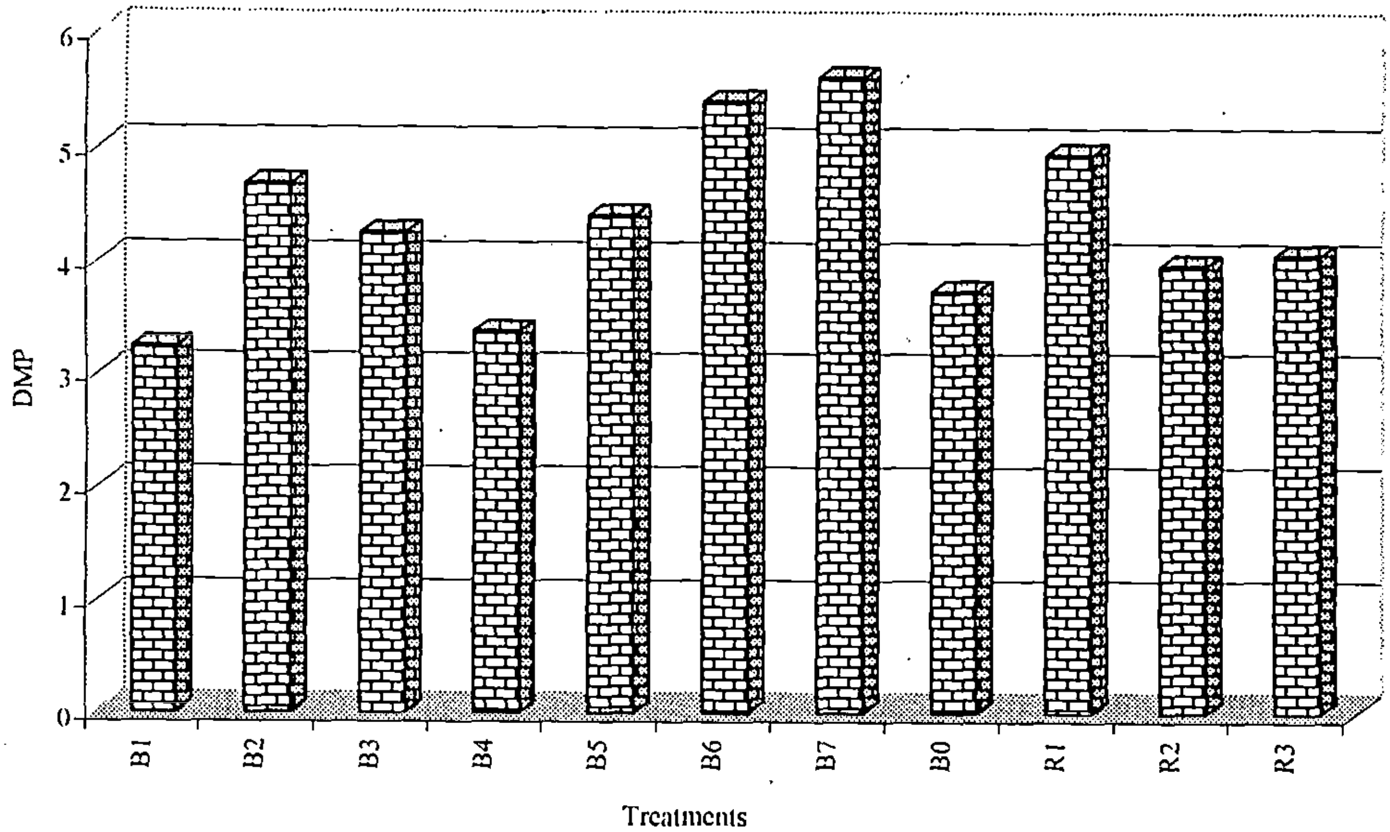


Fig. 4. Drymatter production as influenced by bioinoculants and rooting media, g plant^{-1}

black pepper under green house conditions (Sivaprasad, 1995). The positive influence of AMF association on plant growth was due to increased partitioning of phosphorus between root and shoot system which would result in better utilization of photosynthates by aerial parts (Smith, 1980). The enhancement of plant growth by fluorescent pseudomonads has been attributed to the yellow green fluorescent siderophores produced (Kloepper *et al.*, 1980). They are known to produce several growth hormones like auxins and cytokinins which leads to certain morphological changes in plant like increased leaf expansion and shoot growth.

It is reported higher root production in Azospirillum inoculated black pepper cuttings. The improvement in root development consequent to Azospirillum inoculation might be due to the production of significant quantities of plant growth hormones such as gibberellins, cytokinins and auxins like IAA (Tien *et al.*, 1979). The root length increased especially in the root elongation zone. Enhanced rooting in black pepper by AMF was reported by Sarma *et al.* (1996). The positive influence of AMF was due to increased surface area of roots. The beneficial effects of Plant Growth Promoting Rhizobacteria (PGPR) particularly, fluorescent pseudomonads in promoting root development was due to the secretion of growth hormones like gibberllic acid substances *ie.*, A_9 like substances(Katzenelson and Cole, 1965; Suslow, 1982; Lifshetz *et al.*, 1987; Schippers *et al.*, 1987 and Weller, 1988). This might have resulted in increased root growth especially the root length (Sivaprasad *et al.*, 2003).

The positive influence of bioinoculants in promoting biomass production has been reported by several workers. The increased biomass production and growth has been attributed to fluorescent siderophores and production of phytohormones like auxins and gibberellins (Lopper and Schroth, 1986). Karthikeyan *et al.* (1995) also reported enhanced dry matter production by combined inoculation due to synergistic action of the above bio inoculants. The shoot growth was enhanced by the fluorescent pseudomonads (Garcia *et al.*, 2001).

The activity of bio inoculants depends upon several factors *viz.*, population, fertility status etc. Rhizosphere microflora *viz.*, Azospirillum, Fluorescent pseudomonads and AMF were enumerated and it is observed that inoculation of AMF either with fluorescent pseudomonads or with Azospirilum + Fluorescent pseudomonads recorded maximum infection per cent of AMF. However single inoculation of fluorescent pseudomonads was beneficial for enhancing its colonisation followed by dual inoculation with AMF and combined inoculation with AMF and Azospirilum (Table 5).

5.1.2 Composition of rooting media

Different sources of organic manures had no significant effect on many of the growth characters except vine weight (Table 5). An increase in vine weight was observed when FYM or vermicompost was included in the rooting media as a source of organic manure. With respect to dry matter production of saplings, the effect of FYM was more pronounced (Table 5) when compared to other sources of organic manures. Similar to growth characters, composition of rooting media had no significant effect on root weight, root colonisation of Azospirilum and fluorescent pseudomonads (Table 5). Per cent infection of AMF was also not influenced by the composition of rooting media (Table 5).

5.1.3 Integration of bio inoculants and rooting media

In general, integration of FYM or vermicompost with AZ+FP+AM or FP+AM was favourable for promoting most of the growth characters, dry matter production and colonisation of microflora (Table 6).

The effect of poultry manure was not at all satisfactory in the nursery. The inoculated and uninoculated long pepper cuttings failed to strike roots and sprout when that were planted in the rooting media containing poultry manure (Tables 5 and 6). The phytotoxic effect of poultry manure is relatively uncommon. However it is reported that excess application resulted in crop growth problems due to the rapid release of soluble salts, ammoniacal nitrogen and alkaline nature of the poultry waste. Weil *et al.*, (1979) reported reduced germination, emergence and seedling growth of corn due to combination of high soluble salts and ammoniacal nitrogen and nitrate nitrogen. Shortall and Liebhardt (1975) revealed significant reduction in corn yield due to high soil salinity level.

Based on the analysis of the above discussed parameters, it is concluded that combined inoculation of AZ+FP+AM and dual inoculation of FP+AM were beneficial compared to other bio inoculant treatments (Fig 16). Hence the following treatments were selected for further study.

1. AZ+FP+AM
2. FP+AM

5.2 FIELD EXPERIMENT

Nutritional management for long pepper under partial shade.

5.2.1 Growth Characters

Vegetative characters *viz.*, vine length and leaf number were favourably influenced by the application of FYM and vermicompost. Application of NPK @ 30:30:60 kg ha^{-1} yr^{-1} followed by 60:60:120 kg $ha^{-1}yr^{-1}$ registered higher values of vine length. Similarly dual inoculation with FP+ AM was beneficial to the crop in terms of vine length. The positive advantage of AM association was maximum when inorganic fertilizers were applied at low level especially nitrogen and phosphorus. Barea (1992) also reported that increased level of soluble phosphorus in soil was a determinant of mycorrhizal development in the root system. All the organic manures with B_2 inoculation without inorganic fertilizers produced comparatively longer vines. In case of leaf number, all the combinations in which FYM was integrated showed higher leaf number. At any level of inorganic fertilizers, B_2 produced higher leaf number. The treatment combination *viz.*, FYM + NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ and dual inoculation of FP+AM resulted in maximum leaf number. In integrated nutrient management system, the growth characters were not at all affected when NPK application was reduced to 30:30:60 kg ha^{-1} yr^{-1} compared to 60:60:120 kg $ha^{-1}yr^{-1}$ (Table

17). The increase in growth might be due to the presence of readily available nutrients and other growth promoting substances like enzymes, vitamins etc. present in FYM and vermicompost (KAU, 2002). The lower levels of inorganic fertilizer favoured the vine length. There are reports stating the adverse effect of higher levels of nitrogen on the growth and vine health (Balasubramanyan *et al*., 1992).

5.2.2 Physiological parameters

LAI and NAR were maximum when dual inoculation of FP+AM was integrated with FYM and NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ (Table 17 and Fig. 5). However there was improvement in RGR when NPK dose was increased to 60:60:120 kg ha^{-1} yr^{-1}. Lowering the dose of NPK to 30:30:60 kg $ha^{-1}yr^{-1}$ and combining it with vermicompost and dual inoculation with FP+AM enhanced CGR (Table 17).

5.2.3 Root Development

Most of the root characters were significantly influenced by treatment effects . Incorporation of FYM or vermicompost, application of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ and combined inoculation of AZ+FP+AM were found favourable for enhancing the root parameters (Table 17). Skipping of inorganic fertilizers did not result substantial variation in any of the root parameters when FYM was integrated with combined application of AZ+FP+AM, which indicates that combined inoculation of bio inoculants without the addition of inorganic fertilizers in soil well supplied with well rotten FYM was promoting root development (Fig. 6).

5.2.4 Dry matter Production and Nutrient Uptake

Maximum total dry matter production was recorded by the treatment combinations, $M_2F_2B_2$, $M_1F_2B_2$ and $M_1F_1B_2$ respectively after 7, 9 and 11 months of planting (Table 18).

The fluctuation in total DMP is highly influenced by the nutrient uptake. At 7 MAP vermicompost enhanced the uptake of nitrogen,

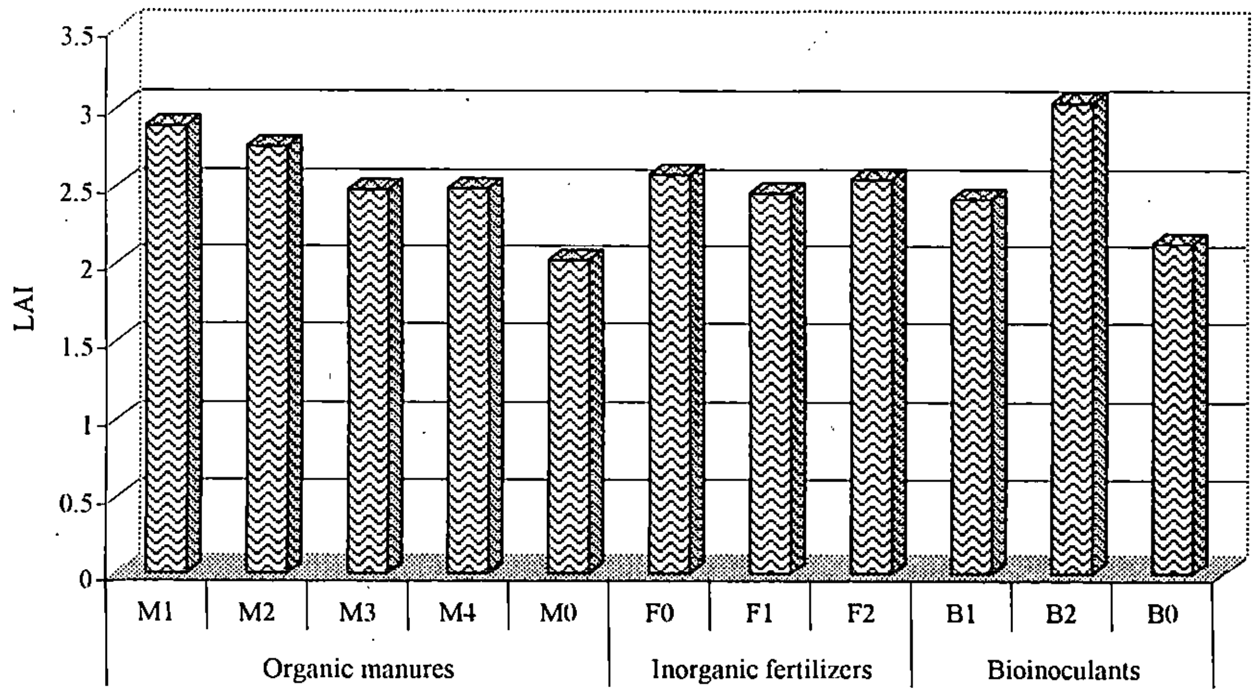


Fig. 5. LAI as influenced by organic manures, inorganic fertilizers and bioinoculants

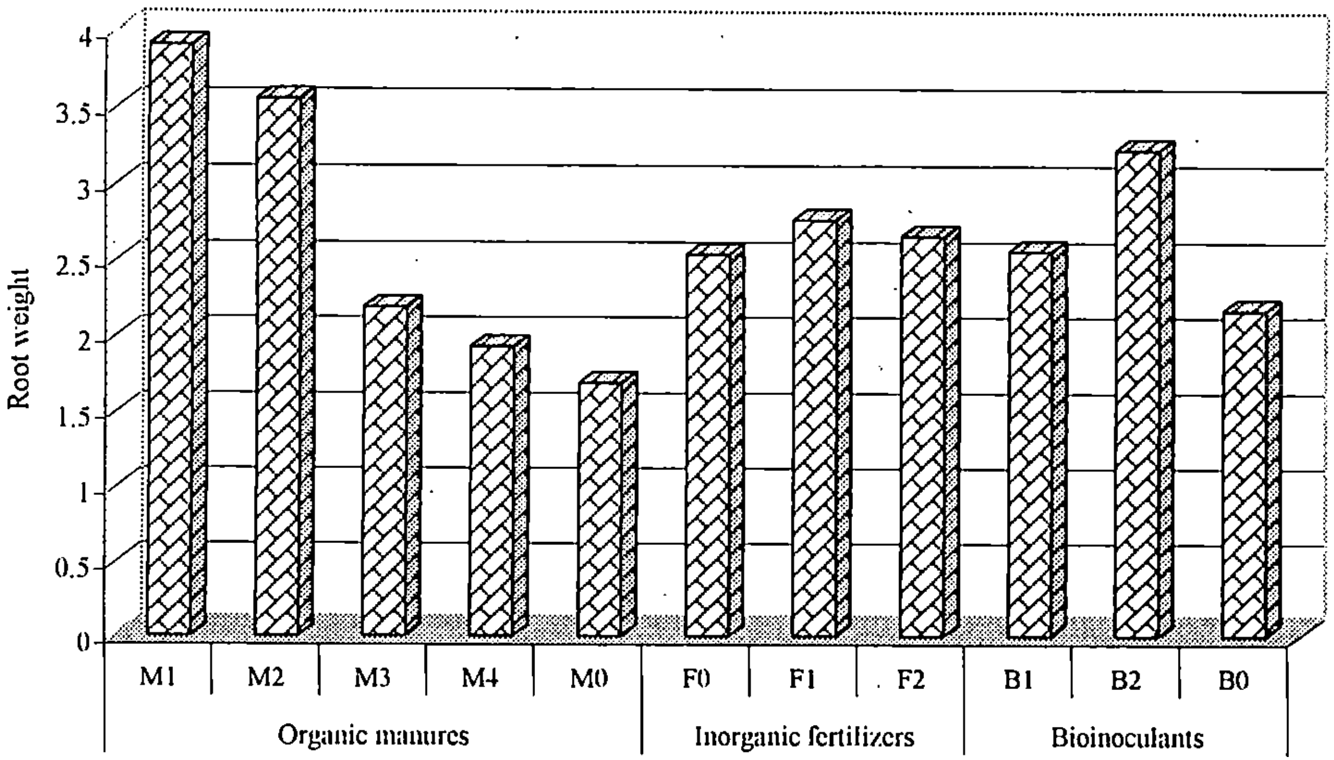


Fig. 6. Root weight as influenced by organic manures, inorganic fertilizers and bioinoculants, g

phosphorous and potassium. At 9 and 11 MAP, FYM and vermicompost were on par with respect to N and K uptake but vermicompost was significantly superior in the case of phosphorus uptake at all stages. The application of organic manures at higher doses improved the uptake of nitrogen. Earth worms are well known for stimulation of the P uptake by the redistribution of organic matter and increased enzymatic activation of phosphatases. This increased P availability in soil leading to higher P uptake. When organic sources of nitrogen was applied in higher proportion, it would have improved phosphorus availability in soil. The upake of all nutrients were significantly enhanced by 30:30:60 kg ha^{-1} yr^{-1}. FP+AM combination enhanced the uptake of nitrogen and potassium at all stages. In case of P uptake, B_1 performed well at 7 MAP. Thereafter B_2 (FP+AM) enhanced the P uptake considerably (Fig. 7).

Sivaprasad (1995) reported improved growth of mycorrhizae inoculated black pepper cuttings through elevated uptake of phosphorus. He also emphasised that the symbiotic association of AMF with plant root remarkably increased the nutrient uptake by increasing the surface area of absorption and mobilizing sparingly available nutrient sources by secretion of ectoenzymes (Baylis, 1959). The arbuscules helps in the transfer of nutrients from the fungus to the root system as phospholipids. Mycorrhizal association enhanced the accumulation of plant nutrient mainly through greater soil exploration by mycorrhizal hyphae (Abbot and Robson, 1984).

5.2.5 Yield attributes, yield and quality

The spike number per plant is an important yield attribute governing the final yield. FYM and vermicompost were on par in spike production at 7MAP. Thereafter FYM was found to be superior when the crop was not given any organic manures. Long pepper requires heavy manuring for its growth and production. The slow growth of plants in control plots resulted in subsequent delay in bearing. In case of inorganic fertilizers higher levels

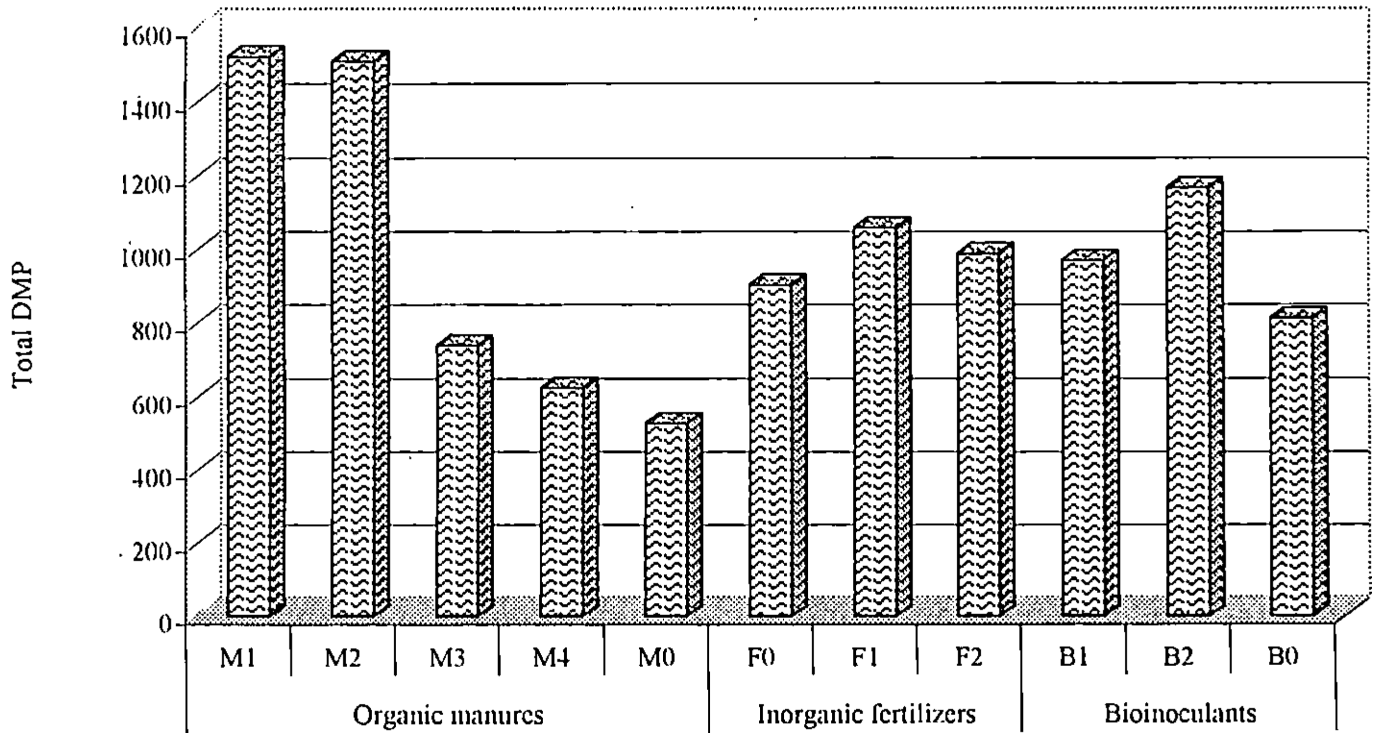


Fig. 7. Total DMP as influenced by organic manures, inorganic fertilizers and bioinoculants, kg ha^{-1}

of NPK produced higher number of spikes and there was no significant difference compared to the moderate dose. During all stages the combination AZ+FP+AM recorded the maximum spike production (Fig. 8).

In case of both fresh and dry spike yield, FYM and vermicompost were on par at 7 and 9 MAP. At 11 MAP, vermicompost was found to yield better. Long pepper responded well to the addition of organic manures. Addition of 30:30:60 kg NPK $ha^{-1}yr^{-1}$ and combined inoculation of AZ+FP+AM increased both fresh and dry spike yield. The combination of $M_2F_1B_1$ *ie.*, vermicompost, 30:30:60 kg NPK ha^{-1} yr^{-1} and AZ+FP+AM recorded the maximum yield at 7 and 11 MAP (Fig. 9, 10, 11 and 17).

A similar trend was observed in subsequent harvests with respect to total fresh and dry spike yield (Fig. 18).

The quality of dry spikes was analysed for total alkaloid content. The composite sample of each treatment was analysed (pooled analysis). There was not much variation in alkaloid content among the treatments. FYM (5.78 %), F_1 (5.64 %) and B_1 (5.64 %) recorded maximum values. Samples collected from the natural habitats, recoded a lower value (5.63 %). The alkaloid content ranged from 5.03 to 6.13 per cent due to the interaction among organic manures, inorganic fertilizers and bio inoculants. The maximum alkaloid content was observed when FYM was integrated with combined inoculation of AZ+FP+AM without the addition of inorganic fertilizers.

5.2.6 Available soil nutrients

The lowest values of available soil N and K were recorded by FYM, 30:30:60 kg NPK $ha^{-1}yr^{-1}$ and the bio inoculant combination of AZ+FP+AM. The reduction in treated plots might be due to the increased absorption of soil nutrients by AZ+FP+AM. The plants inoculated with AMF and Azospirillum fixed more nitrogen. In addition to P solubilisation, these microorganisms could mineralize organic P into a soluble form. These reactions have taken place in the rhizosphere and

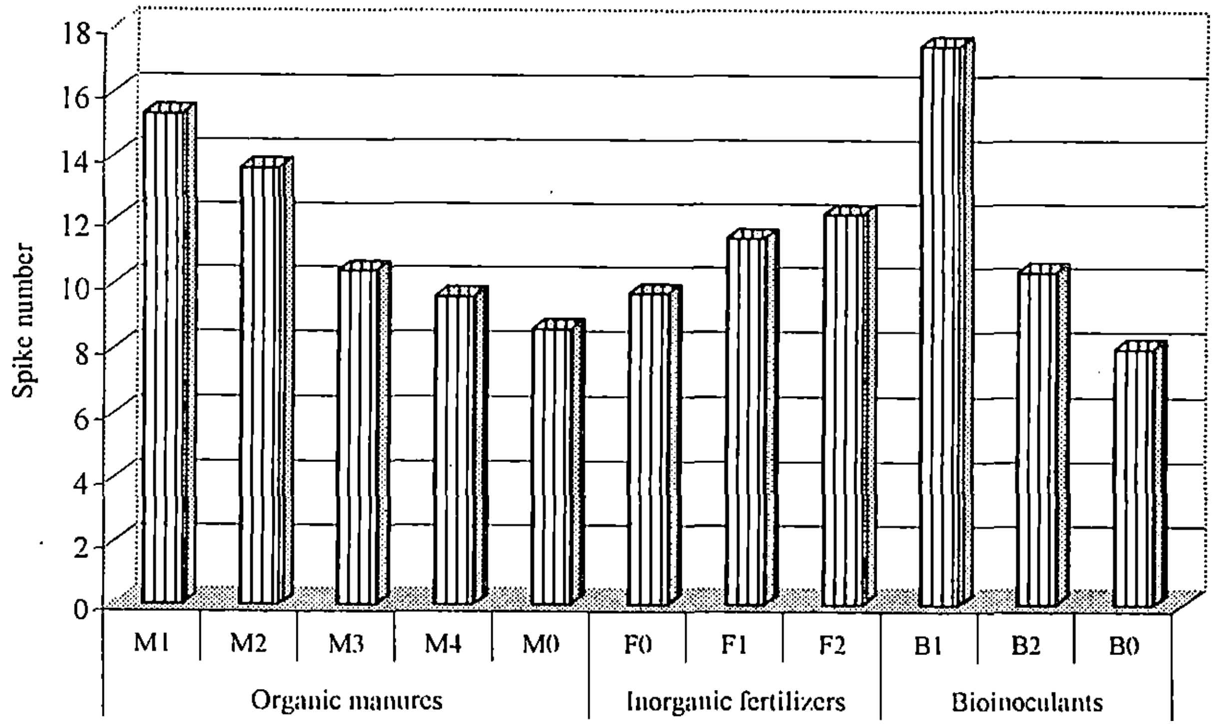


Fig. 8. Spike Number as influenced by organic manures, inorganic fertilizers and bioinoculants

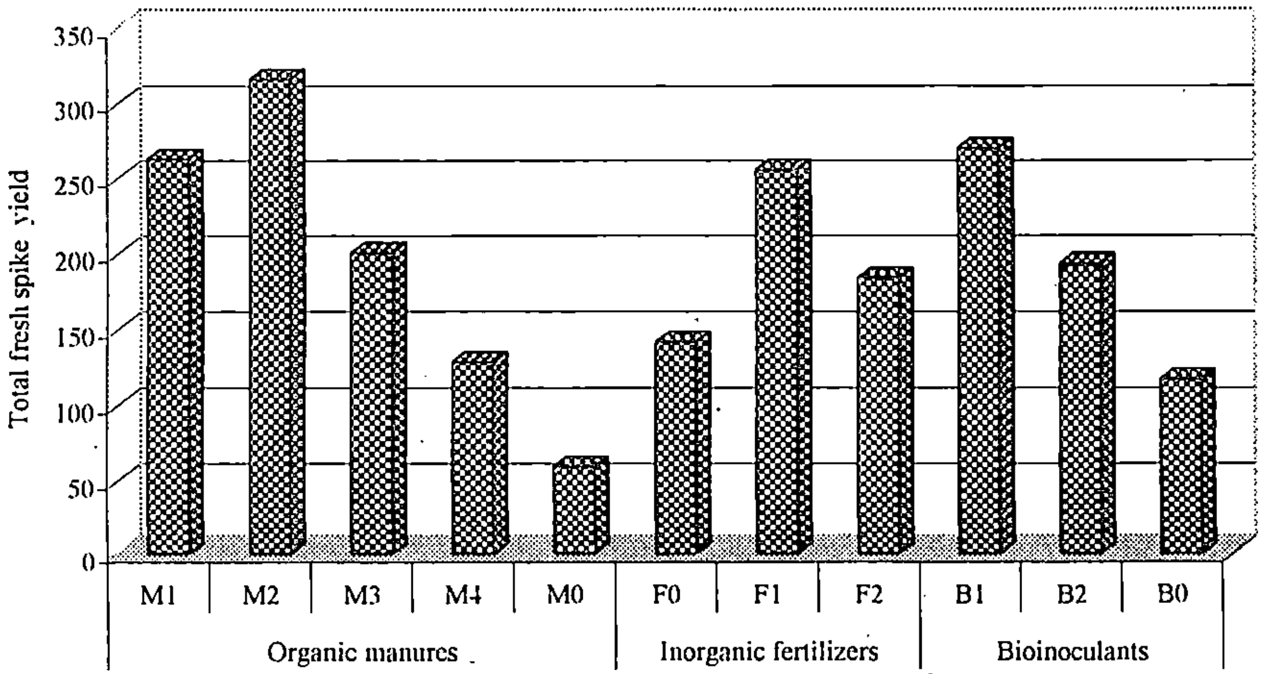


Fig. 9. Total fresh spike yield as influenced by organic manures, inorganic fertilizers and bioinoculants, kg ha^{-1}

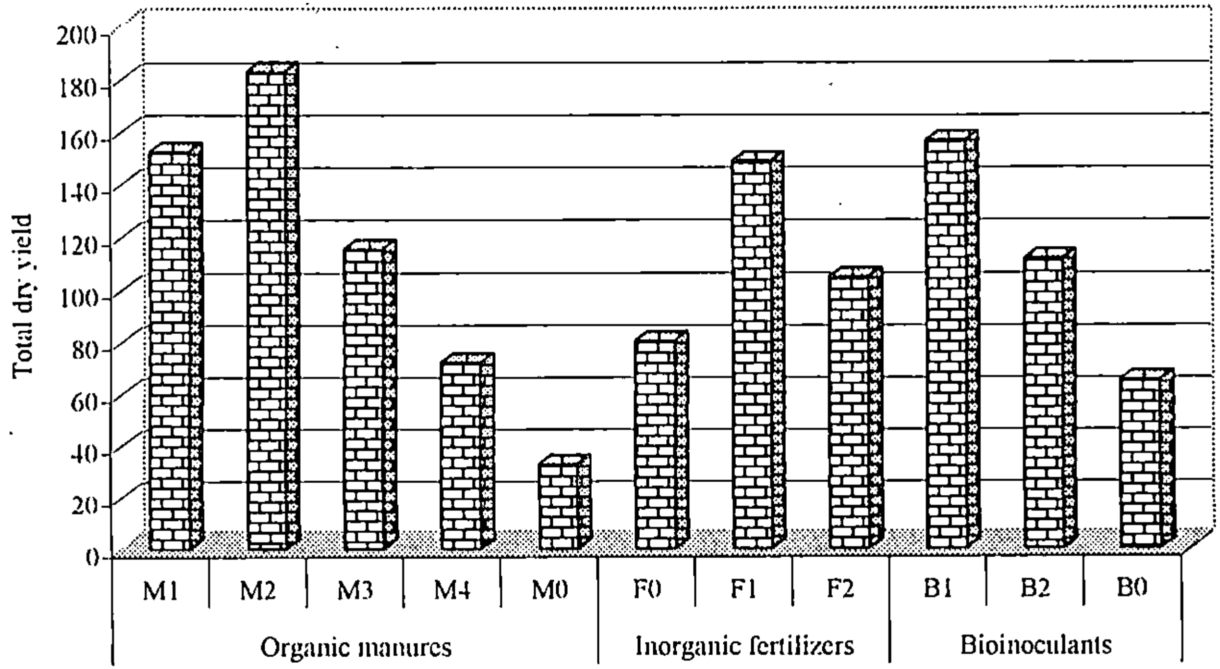


Fig. 10. Total dry spike yield as influenced by organic manures, inorganic fertilizers and bioinoculants, kg ha^{-1}

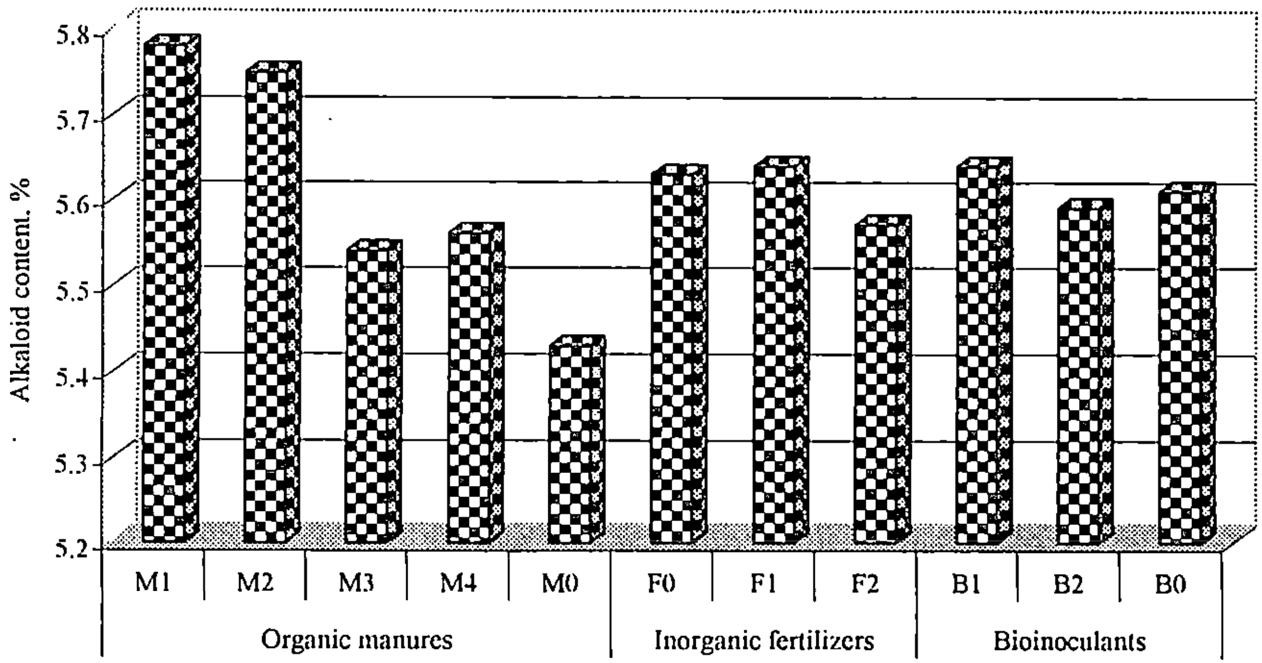


Fig.11. Alkaloid content as influenced by organic manures, inorganic fertilizers and bioinoculants, %

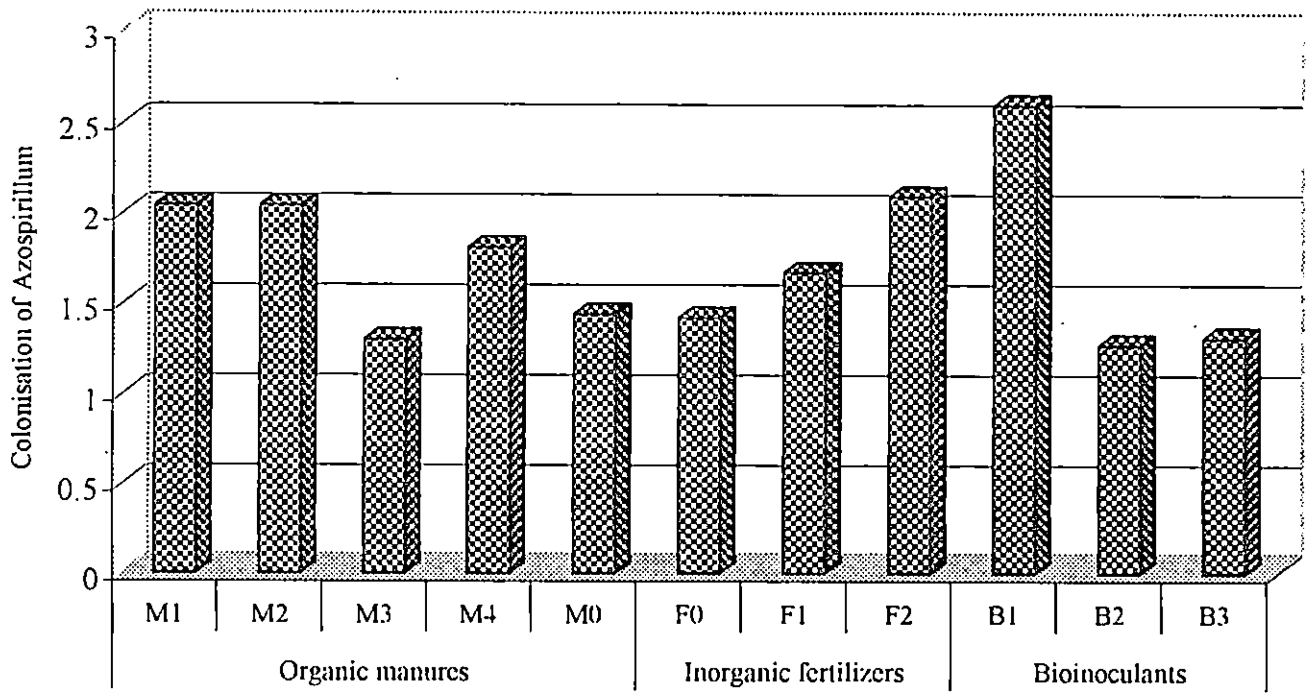


Fig. 12. Colonisation of Azospirillum as influenced by organic manures, inorganic fertilizers and bioinoculants, 105 cfu/ml

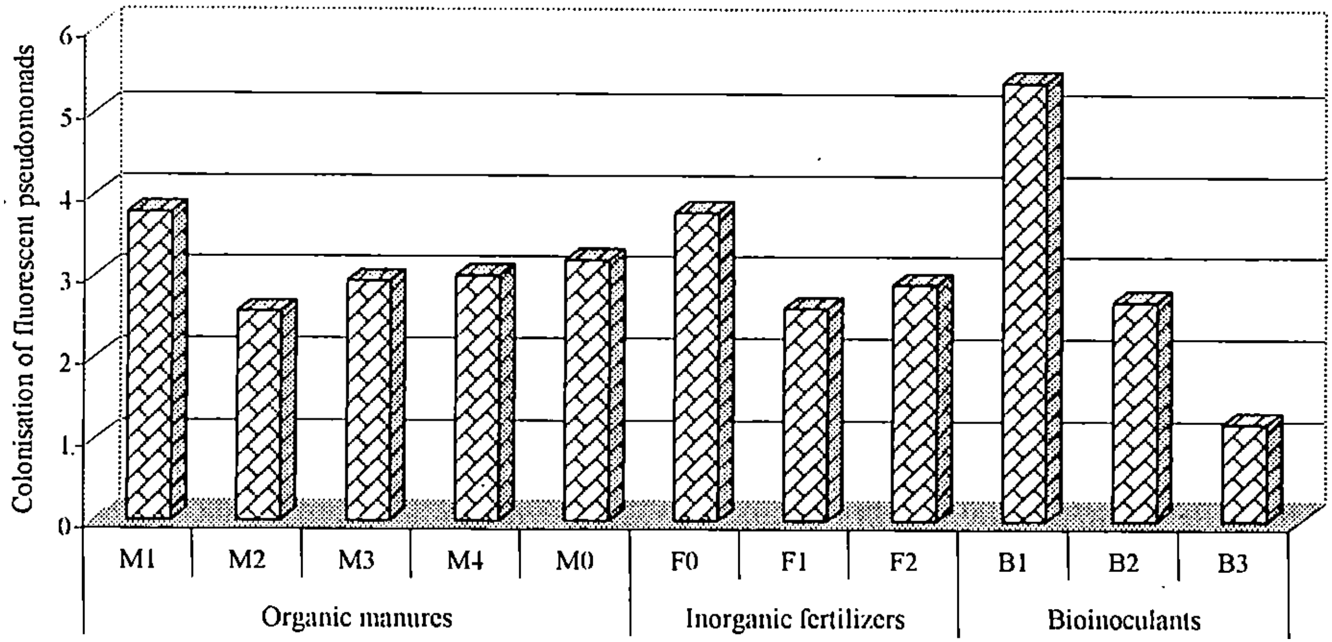


Fig. 13. Colonisation of fluorescent pseudomonads as influenced by organic manures, inorganic fertilizers and bioinoculant, 10^5 cfu g^{-1}

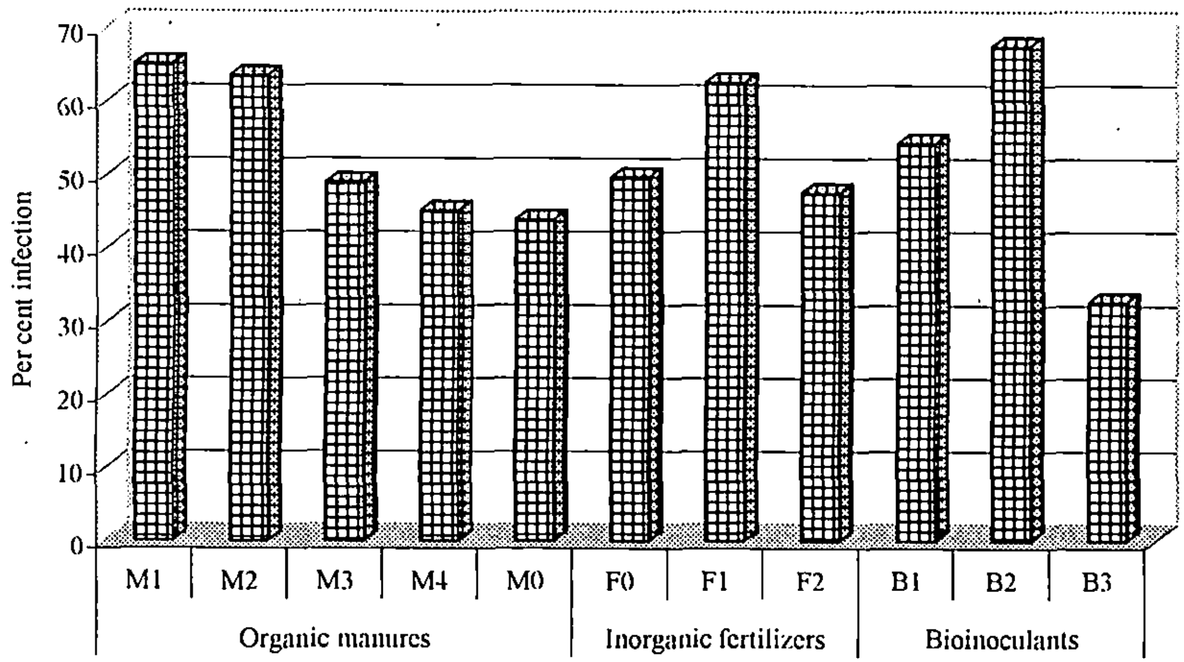


Fig. 14. Per cent infection of AMF as influenced by organic manures, inorganic fertilizers and bioinoculants, %

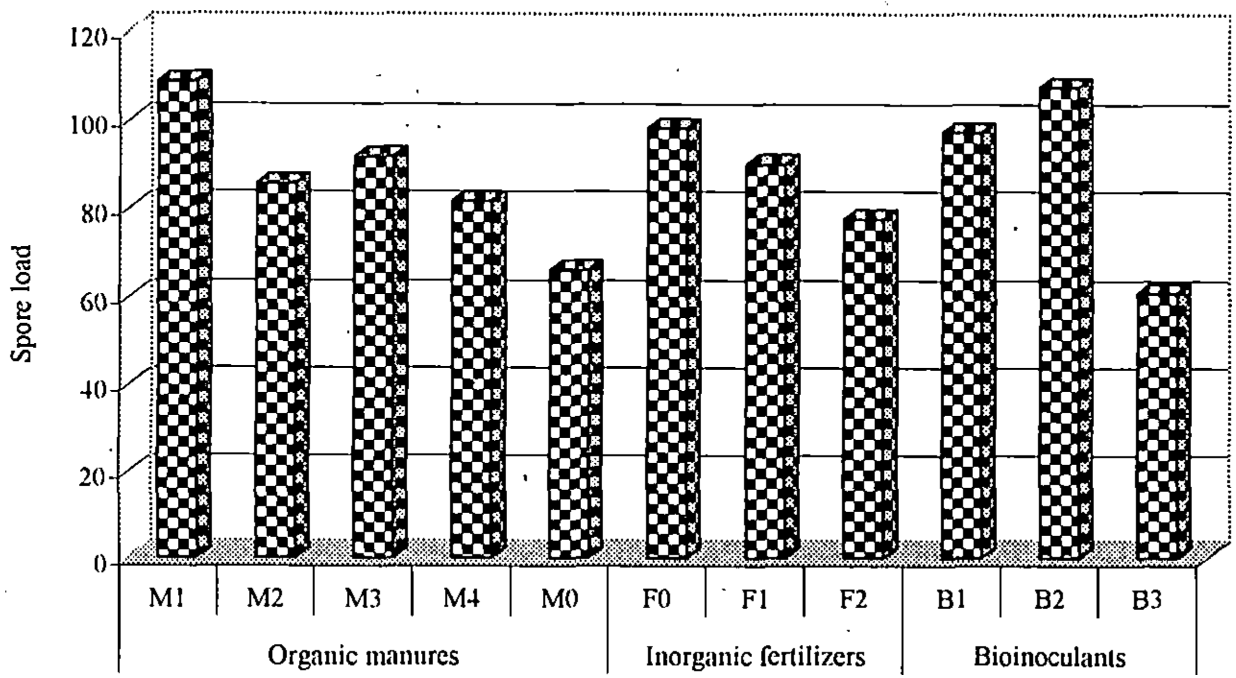


Fig. 15. Spore load of AMF as influenced by organic manures, inorganic fertilizers and bioinoculants

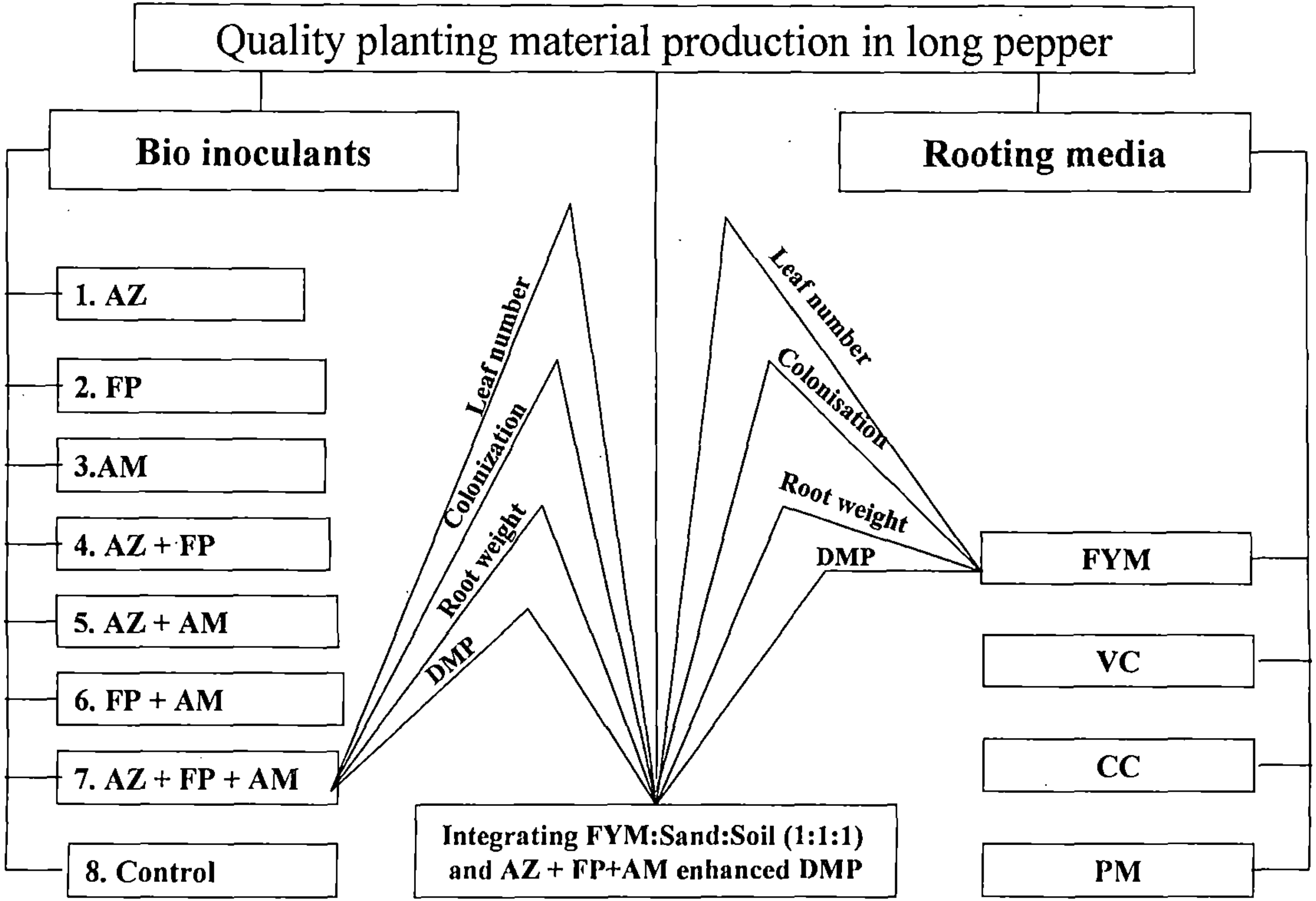
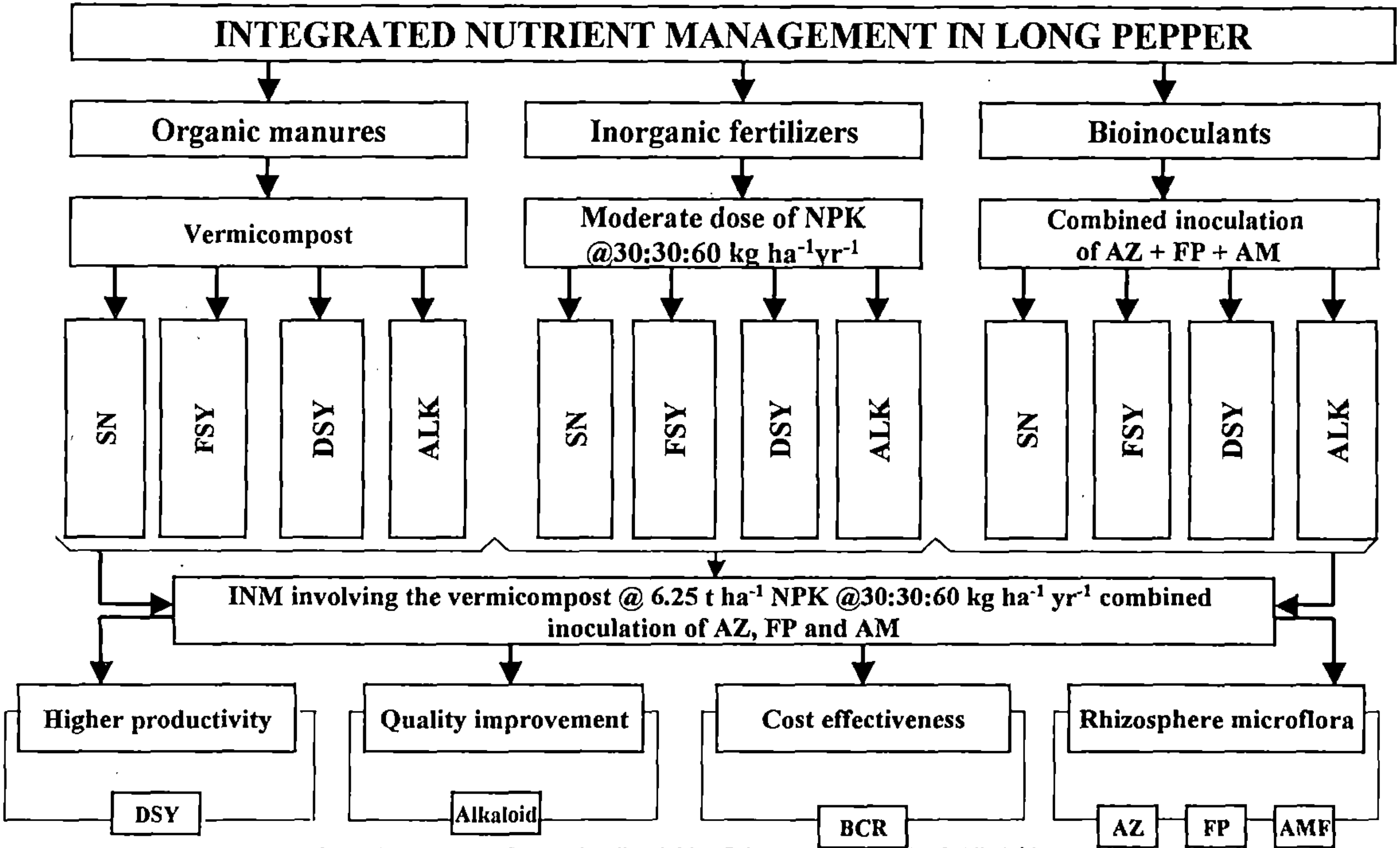


Fig.16. Sustainability pathway to nursery management in long pepper



SN-Spike number, FSY-Fresh spike yield, DSY-Dry spike yield ALK-Alkaloid, BCR-Benefit cost ratio AZ-Azospirillum FP-Fluorescent pseudomonads, AM-AMF

Fig. 17. Sustainability pathway to soil fertility management in long pepper

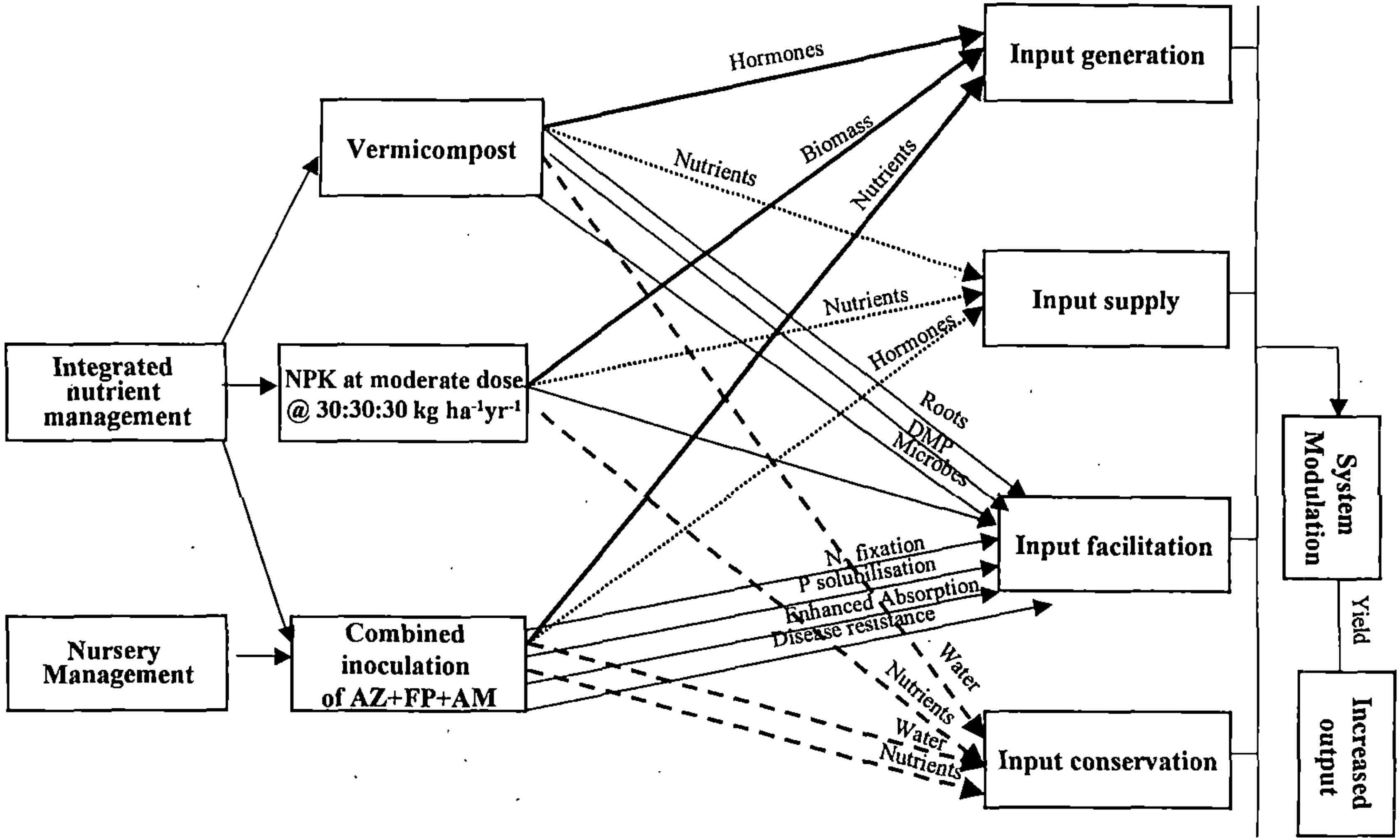


Fig. 18. Sustainability pathway to soil fertility management in commercial mediculture (long pepper)

because the microorganisms rendered more P into solutions than that is required for their own growth and metabolism was available in the soil.

5.2.7 Rhizosphere microflora

FYM followed by neemcake enhanced colonisation of fluorescent pseudomonads. Cultivation of long pepper without the addition of inorganic fertilizers was found favourable in enhancing the colonisation. Combined inoculation of AZ+FP+AM increased FP colonisation. The highest colony count was recorded by $M_1F_2B_1$. The treatment combination, $M_1F_2B_1$ was found superior with respect to colonisation of Azospirillum. Per cent infection and spore load of AMF were highest in the treatment combination $M_2F_0B_2$ (Fig. 12, 13, 14 and 15).

Summary

6. SUMMARY

Two experiments were conducted under the research project "Rhizosphere modulation for higher productivity of long pepper (*Piper longum* Linn.)" at the College of Agriculture, Vellayani, during 2002-2003 with the objective of developing an integrated nutrient management strategy for cultivation of long pepper under partial shade.

Pot culture

Nursery management for quality planting material production in long pepper.

The experiment, laid out in CRD consisted combination of eight levels of bio inoculants *viz.*, Azospirillum (AZ), Fluorescent pseudomonads (FP), AMF(AM), Azospirillum+Fluorescent pseudomonads (AZ+FP), Azospirillum + AMF (AZ+AM), Fluorescent pseudomonads+AMF (FP+AM), Azospirillum + Fluorescent pseudomonads + AMF (AZ+FP+AM) and no bioinoculants (B0) and four composition of rooting media *viz.*, FYM : Sand : Soil (1:1:1), Vermicompost : Sand : Soil (1:1:1), Coirpith compost :Sand: Soil (1:1:1) and Poultry manure: Sand : Soil (1:1:1).

Dual inoculation of FP and AM resulted in maximum vine length. Dual inoculation of FP and AM followed by combined inoculation of AZ+FP+AM gave maximum leaf number. The effect of dual inoculation of FP and AM was remarkable in increasing the leaf area. Integrated use of FY+FP+AM resulted in higher leaf area.

Combined inoculation of AZ+FP+AM increased vine weight. Similarly improvement in vine weight was obtained when FY or VC were included in the rooting media. Integrated application of FY and FP+AM recorded the maximum vine weight.

Dry matter production was maximum when combined inoculation of FP + AM or AZ + FP + AM was practiced. Application of FY also increased dry matter accumulation. Integrated nutrient management involving the application of FY + FP + AM and VC + AZ + FP + AM showed maximum dry matter production.

Maximum root number, root length, root spread, root weight were recorded by AZ + FP + AM, AM, AZ + FP + AM and FP + AM respectively. Inclusion of VC and FY in the rooting media enhanced root length and root spread respectively. Composition of rooting media had no significant effect on root number and root weight. However, the treatment combination of VC + AZ + FP + AM recorded maximum root length.

Dual inoculation of AZ + AM enhanced the Azospirillum colonisation. Integration of dual inoculation with vermicompost resulted in maximum colonisation of Azospirillum.

Single inoculation of FP recorded the highest colonisation. Dual inoculation of FP with AM and combined inoculation of FP with AM and AZ also recorded higher values. However, when AZ was inoculated in the treatment combination, there was considerable reduction in FP colonisation. When FP was applied along with VC there was tremendous increase in FP colonisation.

Inoculation of AM either with FP or with AZ+FP recorded maximum infection per cent of AMF. When the above treatment combinations were integrated with FY or VC, there was considerable improvement in infection per cent of AMF.

Field Experiment

Nutritional management for long pepper under partial shade.

Field experiment consisting of five sources of organic manures *viz.*, FYM, vermicompost, coirpith compost and neemcake, three levels of inorganic fertilizers *viz.*, 0:0:0, 30:30:60, 60:60:120 kg $ha^{-1}yr^{-1}$, and three levels of bio inoculants *viz.*, AZ + FP + AM, FP + AM, and no bio inoculants was conducted to evolve an efficient integrated nutrient management strategy for intercropped long pepper in coconut garden.

FY followed by VC recorded maximum vine length. Application of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ upto 8^{th} month and thereafter 60:60:120 kg $ha^{-1}yr^{-1}$ showed higher values. FP+ AM favoured the vine length throughout the period of study.

Application of FY and VC and inoculation with FP+AM enhanced leaf number. Treatment combinations, $M_1F_1B_2$, $M_1F_2B_2$ followed by $M2F_0B_2$ recorded higher leaf number.

Root length, root number, root spread and root weight increased with the application of organic manures *viz.*, FYM and VC. Application of the moderate dose of NPK *ie.*, 30:30:60 kg $ha^{-1}yr^{-1}$was beneficial in enhancing root number, root length and root weight. Combined inoculation of AZ+FP+AM showed higher values of root number, spread and length. However, root weight was maximum when dual inoculation of FP+AM was done.

The superior performance of the treatment combinations was evident in physiological characters, $M_2F_1B_1$, $M_1F_1B_1$ and $M_1F_0B_2$ recorded significantly higher LAI. NAR was found to be superior in the treatment combination $M_1F_1B_2$ followed by $M_2F_0B_2$ and $M_2F_2B_2$. The RGR recorded the highest value in the treatment combination, $M_2F_2B_2$. $M_2F_1B_2$ recorded the highest CGR at 11 MAP.

Maximum Total DMP was recorded by the treatment combinations $M_2F_1B_2$, $M_1F_2B_2$ and $M_1F_1B_2$ respectively after 7, 9 and 11 months of planting.

In general, FY and VC application, moderate dose of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ and B_1 enhanced the spike number. $M_2F_1B_1$ during first harvest and $M_1F_0B_1$ in the subsequent harvests recorded higher spike number.

Source of organic manures significantly influenced the spike yield and the application of VC followed by FY resulted in higher total fresh and dry spike yield. Moderate dose of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ was found sufficient in maximising total spike production both fresh and dry .

With respect to bio inoculants, B_1 followed by B_2 recorded the highest yield. Integrated nutrient management involving the application of VC, NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$ and combined inoculation of bio inoculants, *viz*, AZ+ FP+AM recorded maximum fresh dry and total spike production at all harvests.

FY followed by VC, moderate dose of NPK @ 30:30:60 kg $ha^{-1}yr^{-1}$and combined application of AZ+FP+AM recorded the maximum alkaloid content. Incorporation of FYM without the addition of inorganic fertilizers but integrating with combined inoculation of AZ+FP+AM recorded maximum alkaloid content.

FYM followed by neemcake enhanced the colonisation of FP. Without the addition of inorganic fertilizers was found in enhancing colonisation. Combined application of AZ+FP+AM increased FP colonisation. The highest colony count was recorded by $M_1F_1B_1$

The treatment combination, $M_1F_2B_1$ was found superior with respect to colonisation of Azospirillum.

Per cent infection and spore load of AMF were highest in the treatment combination, $M_1F_0B_2$.

Integrated use of vermicompost FYM, application of the moderate dose of NPK @30:30:60 kg $ha^{-1}yr^{-1}$ and combined inoculation of FP+AM recorded maximum nitrogen and potassium uptake.

After seven months of planting phosphorus uptake was maximum in the treatment combination $M_1F_1B_2$. However, $M_1F_1B_1$ showed maximum uptake subsequently.

The treatment combination, $M_4F_0B_1$ recorded the maximum available soil nitrogen. Maximum available phosphorus was recorded by the treatment combination $M_2F_2B_1$. Available potassium in the soil was maximum when coirpith compost was used as the source of organic manure without any inorganic fertilizers and bio inoculants ($M_3F_0B_0$).

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* Originals not seen

RHIZOSPHERE MODULATION FOR HIGHER PRODUCTIVITY IN LONG PEPPER (*Piper longum* Linn.)

BIJILY KRISHNAN

Abstract of the
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Department of Agronomy
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM 695 522

ABSTRACT

Increasing demand of plant based raw materials to user industries has emphasised the need to promote commercial cultivation of medicinal species. Integration of mediculture with agriculture offers tremendous possibilities for improving crop productivity and profitability besides generation of employment. Development of a sustainability pathway to soil fertility management is a necessity for popularization of intercropping of long pepper in coconut gardens.

Two experiments under the project, "Rhizosphere modulation for higher productivity in long pepper (*Piper longum* Linn.)" were carried out at the College of Agriculture, Vellayani during 2002-03 to standardise nursery management practices for quality planting material production and to manage the rhizosphere for maximising the yield of spikes and biochemical constituents in long pepper under partial shade.

The pot culture experiment consisted of combinations of eight levels of bio inoculants, *viz.*, Azospirillum (AZ), Fluorescent pseudomonads (FP), AMF (AM), Azospirillum + Fluorescent pseudomonads (AZ + FP), Azospirillum + AMF (AZ + AM), Fluorescent pseudomonads + AMF (FP + AM), Azospirillum + Fluorescent psuedomonads + AMF (AZ + FP + AM) and no bio inoculants (B0) and four composition of rooting media *viz.*, FYM: Sand : Soil(1:1:1), Vermicompost : Sand: Soil (1:1:1), Coir pith compost: Sand: Soil (1:1:1), and Poultry manure : Sand : Soil (1:1:1).

Dual inoculation of FP+AM followed by combined inoculation of AZ+FP+AM gave maximum leaf number. Integrated application of FY+FP+AM and VC+AZ+FP+AM recorded maximum dry matter production. Maximum root number, root length, root spread and root weight were recorded by AZ+FP+AM, AM, AZ+FP+AM and FP+AM respectively. Inclusion of VC and FYM in the rooting media, enhanced root length and root spread respectively.

Integration of dual inoculation with vermicompost resulted in maximum colonisation of Azospirillum. Single inoculation of FP recorded higher colonisation. Dual inoculation of FP with AM and combined inoculation of FP with AMF and AZ also recorded higher value. The treatment combinations, FY/VC+FP+AM and FY/VC+AZ+FP+AM recorded maximum AMF inoculation

In the field experiment, the response of long pepper to five sources of organic manures *viz*, FYM, vermicompost, coir pith compost, neemcake, and no organic manure, three levels of inorganic fertilizers *viz.*, 0:0:0, 30:30:60, 60:60:120 kg NPK $ha^{-1}yr^{-1}$and three levels of bio inoculants *viz.*, AZ+FP+AM, FP+AM, and no bio inoculant were studied.

Application of FYM/VC, moderate dose of NPK (@30:30:60 kg $ha^{-1}yr^{-1}$) and combined inoculation of AZ+FP+AM were beneficial for the development of an efficient root system. In general, FY/VC, application of moderate dose of NPK and B_1 enhanced spike number. Source of organic manure significantly influenced spike yield and application of VC followed by FYM resulted in higher total fresh and dry spike yield. Moderate dose of NPK, was found sufficient in maximising the total spike production. With respect to bio inoculants, B_1 followed by B_2 recorded higher yield. Incorporation of FYM without the addition of inorganic fertilizers but integrating with combined inoculation of AZ+FP+AM recorded the maximum alkaliod content.

It is concluded that integrated nutrient management system involving incorporation of vermicompost @6.25 t $ha^{-1}yr^{-1}$, addition of NPK @30:30:60 kg $ha^{-1}yr^{-1}$and combined application of bio inoculants *viz*, Azospirillum, Fluorescent pseudomonads and AMF was found favourable for enhancing both total fresh and dry spike yield and total alkaloid production in long pepper under partial shade.

Appendix

APPENDIX

Weather parameters during the experimental period
(June 2002-May 2003)

Period	Maximum Temperature, ^0C	Minimum Temperature, ^0C	Rainfall, mm	Evaporation, mm	Relative Humidity, %
June	30.5	24.1	161.1	3.6	82.3
July	30.4	28.9	33.2	3.9	82.3
August	29.9	23.4	101.4	3.7	81.7
September	31.2	23.3	32.4	4.7	75.5
October	30.1	23.3	416.5	2.7	86.3
November	30.2	23.4	95.5	2.1	85.5
December	30.9	21.5	3.2	2.8	72.8
January	31.5	21.4	1.6	3.6	75.3
February	31.7	22.8	68.3	3.8	77.8
March	32.5	23.5	69.0	4.2	76.9
April	32.8	24.7	80.2	4.0	78.4
May	31.5	23.0	3.5	3.5	76.8