# STANDARDISATION OF ORGANIC MANURES AND EFFECT OF MICROBIAL INOCULANTS ON GROWTH, YIELD AND QUALITY OF KASTHURI TURMERIC (*Curcuma aromatica* Salisb.)

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**Thesis submitted in partial fulfillment of the requirement**
**for the degree of**

## DOCTOR OF PHILOSOPHY IN HORTICULTURE

**Faculty of Agriculture**
**Kerala Agricultural University, Thrissur**

**2009**

**DEPARTMENT OF PLANTATION CROPS AND SPICES**
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# DECLARATION

I hereby declare that this thesis entitled “Standardisation of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)” is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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# CERTIFICATE

Certfified that this thesis entitled "**Standardisation of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)**" is a record of research work done independently by Smt. **J.D. NIRMALATHA (2005-22-101)** 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.

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*DEDICATED TO MY*
*HUSBAND AND DAUGHTER*

# ACKNOWLEDGEMENT

*I would like to express my deep sense of gratitude and indebtedness to :*

*Dr. G.R. Sulekha, Professor, Department of Plantation Crops and Spices and Chairman of the Advisory Committee for her affectionate guidance, valuable suggestions, constructive criticisms, constant untiring devotion, much beyond her formal obligation throughout the study which enabled me to complete this work.*

*Dr. B.K. Jayachandran, Professor and Head, Department of Plantation Crops and Spices as a member of the Advisory Committee for his constructive criticism, valuable suggestions and help rendered during the endeavour and constant encouragement throughout the course of investigation.*

*Dr. B.R. Reghunath, Professor, Department of Plantation Crops and Spices as a member of the Advisory Committee for his valuable suggestions and critical scrutiny of the manuscript and whole hearted help rendered during the endeavour.*

*Dr. K.K. Sulochana, Professor, Department of Plant Pathology as a member of the Advisory Committee for her expert guidance, constructive suggestions, whole hearted interest and critical supervision throughout the conduct of the work and preparation of the thesis amidst her hectic schedule.*

*Dr. K. Ushakumari, Professor, Department of Soil Science and Agricultural chemistry for her affectionate guidance, valuable advice, timely suggestions, keen interest and constructive criticism throughout my Ph.D. programme.*

*Dr. P.C. Jessykutty, Associate Professor, Department of Plantation Crops and Spices for her valuable suggestions and help rendered.*

*Dr. D.S. Radha Devi, Professor and Head Department of Plant Breeding for her whole hearted help rendered during the anatomical studies.*

*Dr. Vijayaraghavakumar, Professor and Head, Department of Agricultural Statistics, Dr. K. Vasanthakumar, Professor and Head, Department of Processing technology and Dr.Roy Stephen, Associate Professor and Head, Department of Plant Physiology for their timely help and suggestions during the course of my research work.*

*Mr. C.E. Ajith Kumar, Junior Programmer, Department of Agricultural Statistics for the analysis of data and its proper interpretation.*

*M/s. Athira Computers, Kesavadasapuram, Thiruvananthapuram for the prompt computerized type setting and preparation of thesis.*

*Miss. Sajana, J.N. and Mr. Unni, B. of the Department of Plantation Crops and Spices for their help at various stages of study, their love and encouragement which made this task an easy one.*

*My friends Reshmi. C.R., Reshmi, J. Sajitha, J.P., Beena, Gowri Priya and Anis for their moral support and encouragement in completion of the work.*

*My aunt Mrs. Thilaka Jayachandra, and my in laws for their help, understanding and support during the study.*

*My husband and daughter Miss. Nivethitha, R.N. who sacrificed a much for making this endeavour a success.*

*Kerala Agricultural University for the award of Senior Research Fellowship.*

*Above all I bow my head before God Almighty who gave me courage and strength to pursue this endeavour to completion.*

***J. D. Nirmalatha***

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# LIST OF ABBREVIATIONS

% - Per cent
@ - At the rate of
AGR - Absolute growth rate
AOAC - Association of Official Agricultural Chemists
B:C ratio - Benefit - Cost ratio
CD - Critical Difference
CGR - Crop growth rate
cm - Centimetre
cm$^2$ - Square Centimetre
CO$_2$ - Carbon dioxide
cv. - Cultivar
DAI - Days after incubation
DAP - Days after planting
day$^{-1}$ - Per day
DMP - Dry matter production
et al. - And others
Fig - Figure
FYM - Farm Yard Manure
g - Gram
ha$^{-1}$ - Per hectare
kg ha$^{-1}$ - Kilogram per hectare
kg - Kilogram
LAI - Leaf area index
m - metre
m$^2$ - Square metre
MAP - Months after planting
mg - milligram
NAR - Net assimilation rate
nm - Nanometer
NS - Non significant
NVEE - Non-volatile ether extract
$^{o}$C - Degree Celsius
RBD - Randomized Block Design
RGR - Relative crop growth
Rs. - Rupees
s - Second
SE - Standard error
Spp. - Species
t - Tonnes
v/w - Volume by weight
var. - Variety
*viz.* - Namely
µm - Micrometre

# INTRODUCTION

# 1. INTRODUCTION

Kasthuri turmeric (*Curcuma aromatica* Salisb.) belonging to the family Zingiberaceae is a medicinal and aromatic plant with multiple uses. Several commercially produced cosmetics and ayurvedic preparations contain kasthuri turmeric. Skin care is the major domain of application of this aromatic plant. Rhizome of *Curcuma aromatica* are also used in medicines as a stomachic, carminative and emmenogogue, for skin diseases and recently as a health food in Japan (Kojima et al., 1998).

Eventhough kasthuri turmeric has got wide range of application, it is getting slowly depleted from cultivation due to various reasons. The ignorance about the true identity of the crop is the major reason for the decline in cultivation of this crop. This also makes it easy for vendors to sell any turmeric in the disguise of kasthuri turmeric. Easily available *Curcuma zedoaria* (Manjakoova (Mal.)) is the common *Curcuma* spp. sold at an exorbitant price as kasthuri turmeric by many vendors (Sasikumar, 2000).

Detailed study conducted in the Department of Plantation crops and spices helped to identify true kasthuri turmeric accessions through morphological, physiological, anatomical, biochemical and RAPD techniques (Manual Alex, 2005).

The true kasthuri turmeric is characterized by oblong rhizomes that have a pale yellow or creamy colour, a camphoraceous aroma with an essential oil content ranging from 5.0 -7.0 per cent and curcumin content of 0.05 to 0.10 per cent. The plants are moderately tall with a light green colour and characterized by the presence of hairs on lower side of the leaf.

The mid-rib of the leaf is green (Plate 1) whereas it is purple in the case of *C. zedoaria* (Plate 2). The plants of *C. zedoaria* are tall when compared to *C. aromatica*. The rhizomes of *C. zedoaria* are light orange yellow in colour with a curcumin content of about 1.5 per cent and an essential oil content of only 1.5 to 2.0 per cent *Curcuma zedoaria* is grown in many parts of the country unlike *Curcuma aromatica*.

At present there is no package of practices recommendations for true kasthuri turmeric. Hence it is necessary to standardize agrotechniques for the cultivation of true kasthuri turmeric, which may finally lead to export of quality kasthuri turmeric.

The indiscriminate use of chemicals and tendency of farmers to abandon the use of FYM, green leaves, compost or incorporate crop residue in the soil led to soil degradation. A global loss of productive crop land due to soil degradation is estimated to be 60 to 70 lakh ha. each year (Misra et al., 1999). Thus proper soil management without impairing soil health is a pre-requisite for achieving higher productivity from agricultural land. Enhancing and sustaining the productivity of the soil resource is a major challenge before the resource managers as most of our important production system are showing signs of fatigue in high productivity areas due to deterioration of soil fertility, wide spread nutrient deficiencies, and inadequate and imbalanced supply of plant nutrients. In view of the above soil degradation as well as the hazardous polluting effects of pesticides and fertilizers on environment, there is a growing awareness in the farming community about the alternate agricultural system.

Considering the world demand for organic food, the improvement of soil health and productivity and the availability of local resources, the organic farming practice can be encouraged. Demand is increasing by 30 per cent per year but supply only by 10 per cent. Our farmers can take

Plate 1. *Curcuma aromatica*

Plate 2. *Curcuma zedoaria*

advantage of this opportunity presently available in the international market by offering organically produced spice, aromatic and medicinal products.

The concept of organic farming is based on a holistic approach where nature is perceived to be more than just an individual element. In this farming system there is a dynamic interaction between soil, humus, plant, animal eco-system and environment. Hence organic farming differs from industrial agriculture as in the latter, biological system are replaced by technical production system with liberal use of chemicals (Palaniappan and Annadurai, 1999).

The use of organic sources as nutrients are known from the beginning of agriculture (Gowda and Babu, 1999). India has a potential of manurial resources like FYM, green manures, compost, crop residues etc. The on-farm re-cycling of organic wastes and the application of bulky organic manures such as FYM and compost are adopted to sustain good soil health. Apart from these manures, other organic sources like vermicompost, neem cake, coirpith compost and bioinoculants and biofertilizers are also used.

Guidelines for organic spice and aromatic plants production were approved by the National Standards Committee constituted by IFOAM members during 1998 (Spices Board, 1998a). Quality requirement for export to different countries have been formulated (Spices Board, 1998b). Research Programmes on organic farming have commenced since the concept of sustainable farming has caught on in India (Anon, 2000).

Considering the importance of organic agriculture in the present context, the investigation was undertaken with the following objectives.

1. To standardize an optimum dose of organic manures for growing kasthuri turmeric (*Curcuma aromatica* Salisb.).

2. To assess the relative efficiencies of different organic sources in the release of nutrients to the soil, through incubation studies.
3. To assess the effect of organic manures and microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.).
4. To assess the effect of organic manures in the physical and chemical properties of the soil.
5. To evaluate the effect of microbial inoculants in the biological properties of the soil.
6. To study the residual effect of organic manures on succeeding vegetable crop (*Amaranthus* sp.).
7. To work out the economics of cultivation using different organic manures.

# REVIEW OF LITERATURE

## 2. REVIEW OF LITERATURE

Kasthuri turmeric (*Curcuma aromatica* Salisb.) is a medicinal and aromatic plant with multiple uses. Several commercially produced cosmetics and ayurvedic preparations contain kasthuri turmeric. Rhizome of *Curcuma aromatica* is also used in medicines as stomachic, carminative and emmenogogue for skin diseases and recently as nutraceutical in Japan (Kojima et al., 1998).

Awareness on health and environmental issues is spreading fast globally in recent years. Considering the world demand for organic food, the improvement of soil health and productivity and availability of local resources the organic farming practices can be encouraged. The on farm recycling of organic wastes and the application of organic manures such as of FYM and compost are adopted to sustain soil health. Apart from these manures other organic sources like neemcake and biofertilizers are also used. The biological alternatives to fertilizers are receiving greater attention in the crop production scenario due to increase in prices, concerns on environmental and health effects of chemical fertilizers. The popular bioinoculants are Arbuscular Mycorrhizal Fungi (AMF), *Pseudomonas fluorescens*, *Trichoderma* sp., *Azospirillum* sp. etc. Biofertilizers save N/P requirement upto 50 per cent in most crops and also increase the yield (Kanauja and Naraynan, 2003).

Though there are reports about organic farming practices in spices like ginger and turmeric, medicinal and aromatic crops, so far no work has been standardized for organic practice in true kasthuri turmeric (*Curcuma aromatica* Salisb.). Hence literature of different organic manures, microbial inoculants and their integrated effect on growth, yield, and quality of ginger, turmeric and *Curcuma zedoaria* (Manjakuva) known as duplicate kasthuri turmeric are specifically reviewed in this chapter. Where ever information is lacking pertinent literature on other crops have been included.

## 2.1. ORGANIC MANURES

### 2.1.1. Farmyard manure

This is the traditional organic manure and is most readily available to farmers, since produced locally. On an average well rotten FYM contains 0.5 per cent nitrogen, 0.2 per cent phosphorus and 0.5 per cent potassium (Gaur et al., 1971). FYM serves as a good source of almost all plant nutrients. It improves soil physical characteristics like infiltration rate, total porosity and hydraulic conductivity of red soil with hardpan. It also improves the water holding capacity of soil. The manure provides nutrients enhanced aeration and microbial activities.

### 2.1.2. Vermicompost

Vermicompost is an important organic manure. This is produced by decomposition of biowaste by earthworm activity and contains higher amount of nutrients, hormones and enzymes and hence possess stimulatory effect on plant growth. Application of vermicompost could substitute 25 to 50 per cent recommended dose of fertilizers in Sorghum (Sarad et al., 1996). Vermicompost is a potential source of readily available plant nutrients, growth enhancing substances and a number of beneficial micro organisms like nitrogen fixing, phosphorus solubilising and cellulose decomposing organisms. Vermicompost can substitute or complement chemical fertilizers. It contains various amino acids and minerals which humidified the organic matter and surrounding soil and act as a biofertilizer for plants (Shanbhag, 1999).

### 2.1.3. Coirpith compost

Coirpith which is abundantly available in Kerala as a by-product from coir industries, is found to be a good source of organic manure after narrowing down its C : N ratio with *Pleurotus sajor caju*. Nagarajan et al. (1985) observed that coir pith is having about 5.33 per cent of maximum water holding capacity. Coir pith is rich in potash and would be available for plants over years (Singh, 2001).

### 2.1.4. Neem cake

Neemcake is rich in plant nutrients, alkaloids like nimbin and nimbidin and certain sulphur compounds inhibit nitrification process (Reddy and Prasad, 1975 and Rajkumar and Sekhon, 1981). As a result it acts like a slow releasing nitrogen fertilizer by inhibiting nitrification process. Neemcake increases the agronomic use efficiency and nutrient use efficiency and insect repellent action (Nihad, 2005). It is also rich in nutrients, supress nematode population and increase insect repellent action. It is a rich source of N, P, K, Ca, Mg which favours growth of plant (Som et al., 1992).

## 2.2. EXPERIMENT I

Laboratory incubation studies of organic manures

According to Sheeba (2004), incubation study of organic manures revealed that available N, P and K in soil increased upto 45 days. High availability for available N, P and K was for treatment with enriched vermicompost. In the case of organic carbon, due to application of vermicompost, organic carbon content of soil suddenly increased and then showed a declining tendency. Enriched vermicompost showed highest values of organic carbon. Research on ecofriendly production of slicing cucumber (*Cucumis sativus*) through organic sources was done by Asha Raj (2006). From her study of nutrient release pattern, it is observed that poultry manure mineralized rapidly releasing almost all its nutrients within a period of 30 to 60 days whereas FYM and Neem cake released nutrients slowly over a period of 75 to 120 days. Enriched vermicompost and enriched coirpith compost released nutrients gradually over a period of 60 to 75 days.

The nutrient release pattern of different organic manures was studied by various workers. Rubins and Bear (1942) have indicated the relationship between C/N ratio and N immobilization in soil. They have shown that when plant materials with a wide C/N ratio are added to soil, the quantity of N immobilized in microbial cells may increase to levels that may seriously deplete the soil of the mineral N for plant growth. Allison and Klein (1945) have reported that immobilization of nitrogen proceed very rapidly during the first seven days, then at a constantly decreasing rate. According to Rao and Mikkleson (1976) materials with a wide C : N ratio cause immobilization of nitrogen initially resulting in the beneficial effect to be noticed later. Alexander (1977) has proposed that the organic carbon to organic phosphorus ratio of the soil and the added substance may be used to predict net immobilization and mineralization of P in the soil. If these ratios are 300:1 or more, then immobilization occurs. The critical level of P in organic material to serve as a balance between immobilization and mineralization is calculated to be about 0.2 per cent. Parr and Papendick (1978) have suggested that the nitrogen immobilization potential and maximum decomposition rate of a substrate may be characterized by the C:N ratio of the organic material added to soil.

Shivananda (1986) carried out a laboratory study to find out the rate of N mineralization in soils amended with castor cake, FYM, maize straw and paddy straw. Among these, castor cake was mineralized rapidly and it released high amounts of $NH_4$-N and $NO_3$-N. An increase in available N content of soil up to 20 days after FYM application and a decrease there after was noticed in a long-term field experiment with wheat (Gupta et al., 1988).

The results of the study carried out at Central Research Institute for Dry land Agriculture, Hyderabad during 1994 to evaluate the releasing pattern and availability of P from different soil types of Ranga Reddy district of AP shows that increasing levels of FYM and applied P increased the available P in all types of soils. Increased availability of nitrogen in earth worm casts compared to the non-ingested soil has been reported by Tiwari et al. (1989). Haimi and Huhta (1990) reported that earthworm increase either directly or indirectly the proportion of mineral N available for plants at any given time, although N was clearly immobilized in the initial stage.

Higher concentrations of available P in earth worm cast compared with the surrounding soil or litter has been observed by Sharpley and Syers (1987). Mackey et al. (1983) found that incorporation of earth worm to soil incubated with phosphate rock resulted in a 32 per cent increase in Bray-extractable soil phosphorus after 70 days.

Debnath and Hajra (1972) observed from their incubation studies that available $K_2O$ content increased up to 16th day, a decrease on 30th day followed by an increase and then stabilized when FYM and daincha were added. Basker et al. (1994) inferred from the incubation experiment that the exchangeable K content increased significantly due to earthworm activity. The higher concentration of exchangeable K of the soil with worms compared with that of the soil without worms at the same moisture level confirm the positive role of earthworms in influencing this fraction of K.

Increased concentration of available and exchangeable K content in worm casts compared to surrounding soil was reported by Tiwari et al. (1989). He stated that compared to non-ingested soil, different forms of K increased in value in earth worm casts. Selective feeding of earth worms on organically rich substance which breakdown during passage through the gut, biological grinding, together with enzymatic influence on finer soil materials were likely to be responsible in increasing the different forms of K.

In an incubation study Hulagur (1996) reported that the amount of mineralized nitrogen from neem cake increased up to seven days after incubation. Recovery of mineral N from neem cake diminished at 14th day of incubation and thereafter there was gradual increase.

Bijulal (1997) observed from an incubation study that available N content increased up to 90 days of incubation and declined there after. The release of available P increased steadily upto 120 days of incubation. In contrast to other nutrients, available K reached its peak within shorter span of 60 days, which decreased thereafter. In all the cases application of enriched vermicompost (enriched with rock phosphate) recorded higher nutrient contents as compared to FYM and ordinary compost. In an incubation study conducted with FYM, poultry manure and vermicompost, Nair et al. (2003) reported that there was a progressive increase in the availability of N and $P_2O_5$ till the 90th day for all the three manures. In the case of available $K_2O$ for all the three organic manures there was a progressive increase upto the 60th day and there after decreased. Among the three organic manures, poultry manure showed higher availability of the three nutrients. Sheeba (2004), inferred from an incubation experiment that available N, $P_2O_5$ and $K_2O$ content of the soil increased upto 45 days of incubation, then the availability slowly declined. She also reported that the available nutrient contents were higher for vermicompost enriched with neem cake and bone meal as compared to that of ordinary vermicompost and farm yard manure.

## 2.3. EXPERIMENT II

Effect of organic manures on growth, yield, and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)

### 2.3.1. Effect of organic manures on growth characters

#### ***2.3.1.1. Effect of Farmyard manure***

In turmeric, application of FYM showed its superiorty in growth characters during initial stages and during the later stage coir compost was found superior (Subbaroa and Ravishankar, 2001). Application of FYM in turmeric showed its superiority in growth characters during initial stage of growth while during the later stages of growth coirpith compost was superior (Rakhee, 2002). Shah et al. (2000) observed increased growth characters like number of branches per plant, plant height, etc when FYM was applied @ 10 t $ha^{-1}$ + NPK 60 : 40 : 30 kg $ha^{-1}$ over control in *Plumbago zeylanica*. According to Vidyadharan (2000) when highest level of FYM applied (20 t $ha^{-1}$) in arrowroot resulted in increased plant height number of leaves per plant, sucker number per hill and dry matter production. In Ginger FYM recorded maximum plant height at all growth stages (Sreekala, 2004).

### *2.3.1.2. Effect of Vericompost*

The effect of vermicompost was studied in turmeric by Vadiraj et al. (1996). He found that when varieties like Armour and Suroma when treated with vermicompost showed 30 per cent increase in plant height and 70 per cent increase in leaf area over control. Similarly plant height, number of leaves, number of branches, stem girth, leaf stem ratio in Amaranthus was increased by vermicompost application. In turmeric according to Rakhee (2002) morphological parameters like tiller number and rhizome thickness was on par with FYM, but root length was on par with vermicompost. Arunkumar (2000) found that highest level of vermicompost applied maintained their superiority in case of plant height, number of leaves and number of branches in amaranthus at all stages. According to Sailaja Kumari and Ushakumari (2001) better growth of cowpea plants were recorded when vermicompost and FYM was applied.

### *2.3.1.3. Effect of coirpith compost*

An increase in plant height was observed in rice fields by application of coirpith compost (Thilagavathi and Mathan, 1995). Suharban et al. (1997) in a pot culture experiment with bhindi reported that plant height was significantly influenced by coirpith compost treatment. According to Rakhee (2002) in turmeric maximum plant height, number of tillers and number of leaves was obtained during 6 MAP and 8 MAP. The maximum rhizome spread was recorded by coirpith at 8 MAP. Similarly root spread and root weight was influenced by coirpith and gave the maximum value at 8 MAP.

#### *2.3.1.4. Effect of Neem cake*

When neem cake was applied as organic manure in amaranthus, an increase in number of leaves were recorded (Arunkumar, 2000) Sharu (2000) reported that growth characters like plant height, number of branches obtained by neem cake application was found to be on par with POP (20 t FYM + 70 : 40 : 25 kg NPK ha$^{-1}$) in chilli. Santhosh Kumar (2004) observed that neem cake was found to be effective in improving the biometric characters in *Plumbago rosea*.

### 2.3.2. Effect of organic manures on yield and yield components

#### *2.3.2.1. Effect of Farmyard manure*

Application of FYM alone resulted in higher yield in turmeric (Balashanmugham et al., 1989) and also in arrowroot (Vidhyadharan, 2000). Rakhee (2002) reported that FYM application increased rhizome yield (29.22 t ha$^{-1}$), top yield 13.52 g plant$^{-1}$, and dry turmeric (55.09 g plant$^{-1}$). Application of FYM alone resulted in higher yield in yam (Mohankumar and Nair, 1979). Sharma et al. (1988) revealed that FYM was more effective in increasing tuber yield in potato than green manuring with daincha. The results of long term fertilizer experiment conducted at Tamil Nadu Agricultural University, Coimbatore in a mixed red and medium black soil for a period of sixteen years revealed significant differences in the yield of finger millet maize and cowpea due to FYM application (Muthuswamy et al., 1990). According to Bai and Augustin (1998) in

Kacholam application of FYM increased yield of rhizomes by 2.03 times as compared to that of absolute control. According to Joseph (1998) weight and number of fruits per plant in snake gourd were highest in FYM treated plants. A study on the effect of organics and inorganics in betel vine (Arulmozhiyan et al., 2002) revealed highest yield attribute by the application of FYM @ 200 kg ha$^{-1}$. In ginger application of FYM alone resulted in higher yield (Sreekala, 2004).

### *2.3.2.2. Effect of vermicompost*

Vadiraj et al. (1996) reported increased yield in turmeric plants treated with vermicompost alone or in combination with inorganic fertilizers. Dry turmeric weight was maximum during four MAP. When vermicompost was applied in turmeric the rhizome yield 25.58 t ha$^{-1}$ and top yield 17.17g plant$^{-1}$ was obtained (Rakhee 2002). Among organic manures tested by Maheswarappa et al. (1997) in arrowroot intercropped in coconut garden vermicompost recorded highest rhizome yield compared to composted coirpith. Niranjana (1998) reported that vermicompost application gave higher biomass yield till 45 DAT in Amaranthus. Arunkumar (2000) reported higher yield and quality of amaranthus than POP recommendation in vermicompost treated plots. In an organic study conducted by Ankarao and Haripriya (2003) in chillie, among the various organic manures incorporation of vermicompost (5 t ha$^{-1}$) was considered as the best in improving the yield.

### *2.3.2.3. Effect of coirpith compost*

Coirpith compost application has increased the yield in turmeric (Selvakumar et al., 1991). Rakhee (2002) reported that coirpith compost as a source of organic manure had positive influence on rhizome yield which was on par with FYM. The rhizome yield was 34.32 t ha$^{-1}$, dry rhizome yield during 8 MAP was 59.35 g plant$^{-1}$ and top yield recorded when FYM applied, was 14.32 g plant$^{-1}$. Usefulness of coirpith in increasing the yield of many crops like ground nut, sorghum, pearl millet to the extent of 10-30 per cent over control has been reported by Savithri and Khan, (1994). Lourdiraj et al. (1996) reported an increased yield in ground nut when coirpith compost was applied. Yield of sesamum could be increased by 63 per cent with application of coirpith compost over farmer's practice (Venkatakrishnan and Ravichandran, 1996). In mulberry plants coirpith compost application increased the growth and yield of leaves (Prince et al ., 2000).

#### *2.3.2.4. Effect of Neem cake*

In turmeric when neem cake was applied @ 2 t ha$^{-1}$ a high yield of 4884 kg ha$^{-1}$ was obtained (Sadanandan and Hamza, 1998). In a study conducted by Rakhee (2002) in neem cake, when neem cake was applied the rhizome yield was 21.32 t ha$^{-1}$, top yield 21.32 g plant$^{-1}$ and dry rhizome yield was 46.30 g plant$^{-1}$. In ginger when neem cake was applied @ 1 t ha$^{-1}$ before planting gave maximum yield (KAU, 1990). According to Sadanandan and Hamza (1998) application of organic cakes increased the yield in ginger. An experiment was conducted in Kerala Agricultural University, Thrisuur, in banana crop, to study the best source of organic manure. The result revealed that neem cake containing 5.2 per cent N (950 g plant$^{-1}$) was the best source in increasing yield (KAU, 1993).

### 2.3.3. Effect of organic manures on physiological characters

#### *2.3.3.1. Effect of FYM*

According to Rakhee (2002), highest DMP was obtained when FYM was applied in turmeric during 2 MAP and 4 MAP. At 60-120 DAP maximum CGR was produced by vermicompost and was on par with FYM. At 120-180 DAP FYM produced maximum CGR and was on par with coirpith compost RGR was maximum when FYM was applied after 180 DAP. Leaf area index was maximum when FYM was applied during initial stages. Root shoot ratio was maximum when FYM was applied in turmeric during the initial stages.

Similarly in turmeric highest leaf area, Leaf area index, Crop growth rate, total dry matter production, and harvest index was obtained when FYM was applied along with biofertilizers (Velmurugan et al., 2006). According to Sreekala (2004), in ginger physiological parameters like DMP, CGR, LAI and HI were higher in plots treated with FYM + AMF and FYM + NC + AMF + *Trichoderma*. In *Plumbago rosea* highest DMP and harvest. Index was obtained in the treatment containing FYM + NC along with microbial inoculants. Highest NAR was observed by plants supplied with FYM + vermicompost and microbial inoculants (Nihad 2005). In mint when FYM was applied alone (12.5 t $ha^{-1}$) the leaf area obtained was 12.90 $cm^2$ (Arumugham Shakila and Prabhu 2007).

### *2.3.3.2. Effect of vermicompost*

According to Vadiraj et al. (1996) the effect of vermicompost in turmeric was highly influenced in increasing the physiological parameters. It was found that, 70 per cent increase in leaf area when vermicompost was applied. In turmeric NAR, CGR and RGR was the highest for vermicompost treated plots from 120-180 DAP (Rakhee 2002). An experiment on *Alpinia galanga* as the intercrop in coconut revealed increase in dry matter accumulation in rhizome at harvest due to FYM and vermicompost application (Maheswarappa et al., 2000). The integrated nutrient management studies in chilli revealed that RGR, CGR and NAR were the highest in vermicompost applied plants (Sharu 2000). An experiment was conducted in cauliflower to show the better response to the application of organic manures. It was found that leaf area, leaf area index, dry matter production were highest with combined application of vermicompost along with panchakavya (Velmurughan et al., 2006). According to Babu Ratan et al. (2005), when vermicompost was applied to banana, leaf area was found to be influenced. In amaranthus an experiment was conducted on organic manures. It was found that leaf width, leaf length and dry matter production was highest in vermicompost treated plots (vermicompost 5 t ha$^{-1}$) (Rajendran et al., 2006). Physiological characters like leaf area and dry matter production in mint resulted in highest value with the treatment vermicompost @ 2.5 t ha$^{-1}$ plus humic acid 0.2 per cent along with panchagavya (Arumugam Shakila and Prabu, 2007).

#### *2.3.3.3. Effect of coirpith compost*

An increased plant height and dry matter production has been reported in rice following the application of partially decomposed coirpith in rice field with sandy clay loam soil (Thilagavathi and Mathan, 1995). According to the research findings of Rakhee (2002) coirpith compost application in turmeric highly influenced the physiological parameters like DMP, CGR, LAI, LAD, root : shoot ratio during the later stages of crop growth (after 180 DAP).

#### *2.3.3.4. Effect of neem cake*

In chilli DMP and LAI obtained by application of neem cake were found on par with POP (20 t FYM + 75 : 40 : 25 kg NPK ha$^{-1}$) as observed by Sharu (2000). Influence of different organic manures and their combinations were studied on growth and leaf nutrient status of banana by Babu Rotan et al., 2006. He reported that application of neemcake and poultry manure registered highest leaf area plant$^{-1}$. Effect of organic manures on growth and yield was studied on organic manures in Ashwagandha. It was found that ashwagandha showed better response in physiological aspects when neem cake was applied. (Padmanabhan and Chezhiyan, 2006).

### 2.3.4. Effect of organic manures on biochemical characters

Consumer satisfaction is directly related to product quality. Manojkumar and Sivaraman, (2002) defines the term quality as the degree of excellence of a product or its suitability for a particular use. The quality of produce encompasses sensory properties (appearance, texture, taste and aroma) nutritive values, chemical constituents, mechanical properties and functional properties. With the global food including increasingly turning towards oils, and oleoresins the scope of India to earn enormous foreign exchange of organic spices through aggressive marketing of these value added spices is indeed bright.

#### *2.3.4.1. Effect of FYM*

According to Vidyadharan (2000), highest protein content in arrow root was recorded at highest level of FYM. Sreekala (2004) studied the effect of organic manures and bio inoculants in ginger. She reported the FYM application recorded crude fibre content 5.76 per cent, starch content 42.38 per cent and NVEE 5.4 per cent. In *Plumbago rosea* root plumbagin content was found highest in FYM treatment (Nihad 2005). In sweet basil FYM applied @ 10 t ha$^{-1}$ gave maximum oil yield (Sangeetha and Jayakumar 2006).

#### *2.3.4.2. Effect of vermicompost*

Various organic manures have positive influence on the biochemical / quality aspects like curcumin content, volatile oil, NVEE, crude fibre content, starch, total carbohydrates, protein and chlorophyll content when vermicompost was applied. Tomati et al. (1990) observed that incorporation of vermicompost increased protein synthesis by 24 per cent and 32 per cent in lettuce and radish, thus improving the quality of these crops. Starch content of sweet potato tuber was maximum when nitrogen was supplied as vermicompost (Suresh Kumar, 1996). Protein content of cowpea grains were more in vermicompost treated plot compared to FYM application (Sailaja Kumari and Ushakumari, 2001). Rakhee (2002) reported that when vermicompost was applied to turmeric the volatile oil content was 4.30 per cent and curcumin content was 4.87 per cent Biochemical aspects on guava was studied by Athani et al. (2006). He confirmed that TSS (11.51$^{o}$B), ascorbic acid (214.53 mg100 $g^{-1}$), reducing sugar (5.25 %) and total sugars (9.00 %) were recorded in vermicompost + recommended dose of fertilizer. In a study conducted on the effect of bio fertilizers and organic manures on cabbage. (Taiyab Ali Saifee et al., 2006) found that vermicompost + biofertilizer increased total chlorophyll content (0.49 mg 100 $g^{-1}$).

### *2.3.4.3. Effect of coirpith compost*

In arrow root, Maheswarappa et al. (1997) found that application of coirpith compost produced lower values of chlorophyll content, starch and crude protein compared to application of FYM and vermicompost. In yams tuber quality in terms of starch and crude protein were markedly improved by coirpith compost application (Suja, 2001). Rakhee (2002) reported that maximum volatile oil (5.10 %) and curcumin content was obtained when coirpith compost was applied in turmeric. In green chillies coir pith compost 5 t $ha^{-1}$ + biofertilizers gave better performance in improving the crude protein, ascorbic acid (Subbiah and Hemalatha 2006).

### *2.3.4.4. Effect of neem cake*

In ginger, application of neem cake @ 2.5 t $ha^{-1}$ enhanced oil content and increased oleoresin content (Sadanandan and Hamza, 1998). Sreekala reported that neem cake application in ginger recorded volatile oil content of 4.13 per cent and curcumin content (5.77 %), starch content (42.43 %) NVEE (5.2 %). Neem cake application in turmeric was found superior with regard to curcumin recovery (Sadanandan and Hamza 2006). Sharu (2000) reported that mean weight of fruit and keeping quality were maximum when nutrients were supplied to chilli through neem cake alone.

### 2.3.5. Effect of organic manures on soil physical properties

#### *2.3.5.1. Effect of FYM*

Increase in soil moisture retention due to addition of FYM was observed by Salter and Williams (1963). Havangi and Mann (1970) reported that a continuous application of FYM decreased the bulk density of soil. Maheswarappa (1999) studied the influence of planting material, plant population and organic manures on yield of East Indian galangal as well as the change in soil physico chemical and biological properties. The bulk density of soil decreased from 1.38 gcc$^{-1}$ in FYM @ 32 t ha$^{-1}$ from the initial value of 1.55 g cc$^{-1}$. According to Singh et al. (2000) application of FYM significantly brought down the bulk density of both surface and subsurface soils in comparison with the control.

#### *2.3.5.2. Effect of vermicompost*

Kala and Krishnamoorthy (1981) described the role of earthworms in the degradation of organic wastes and in improving the physico-chemical properties of soil. Vermicompost enhances the soil structure improves the water holding capacity and porosity and facilitates the root penetration and growth (Lee, 1985). Maheswarappa et al. (1999) studied the effect of organic manures on soil physical properties and reported that vermicompost application decreased the bulk density of the soil to a greater extent.

#### *2.3.5.3. Effect of coir pith compost*

According to Rakhee (2002) coirpith compost had no significant influence on the physical properties of soil. In ginger an organic study was conducted by Sreekala (2004). She reported that coirpith compost application increased the water holding capacity of soil and decreased the bulk density.

### *2.3.5.4. Effect of neem cake*

When neem cake was applied in rice fallow rotation for ten years improved the water retention characteristics of an alluvial sandy loam soil (Biswass et al., 1969). Sadanandan and Hamza (1998) reported improved physical condition of the soil as a result of organic cake application in ginger.

## 2.3.6. Effect of organic manures on soil chemical properties

Effect of organic manures on soil dynamics Srivastava (1985) observed that the application of organic manures resulted in increased organic content, total N and available P and K status of soil. Kabeerathumma et al. (1990) in a long term manurial experiment, after thirteen years of continuous cropping observed increased nutrient status in organic treated plots compared to inorganic treatment and use of organic matter enhances the soil productivity (Sangeetha, 2004).

### *2.3.6.1. Effect of FYM on available N,P,K, organic carbon and soil pH*

Increased availability of potassium due to the combined application of FYM with 100 per cent recommended quantity of NPK in the long term fertilizer was reported by Aravind (1987). Higher efficiency of FYM in producing higher yield and improving chemical properties of soil compared to oil cakes and urea. This was reported by Gomes et al. (1993). A study was carried out at Central Research Institute for Dryland Agriculture, Hyderabad during 1994 to evaluate the releasing pattern and availability of P from different types of soil. The study revealed that increasing levels of

FYM and applied P increased the available P in all types of soil. Hedge et al. (1998) reported that nutrients P & K and organic carbon doubled when FYM or vermicompost was applied. The soil pH changed to neutrality. However there was negligible difference between vermicompost and FYM with respect to nutrients and organic carbon. According to Maheswarappa et al. (1998) an increase in the organic carbon and pH was recorded in FYM. Available phosphorus content in post harvest soil was maximum in Rock Phosphate + FYM treatment, pH, organic carbon and EC were on par due to Rock Phosphate and SSP application (Venkatesh et al., 2003).

### *2.3.6.2. Effect of vermicompost on available N, P, K, organic carbon and soil pH*

Organic manures greatly influence the nutrient status of the soil namely available N, P, K, organic carbon, EC and soil pH. Vermicompost is rich in microbial load, organic matter, available N, P & K [Gaur (1982), Brady (1994)]. Scheu (1987) found large amounts of mineralized N in the presence of large earthworm biomass. Several workers like (Tomati et al., 1988, Romero and Chamooro, 1993, Parkin and Berry, 1994, and Rao et al., 1996) reported that there is increased availability of N in earthworm casts compared to non ingested soil. Reddy and Mahesh (1995) reported an increased availability of N and K in soil by the application of vermicompost compared to FYM. Increased concentration of available and exchangeable K content in vermcasts were reported by Lal and Vleeschawar (1982) and Tiwar et al. (1989). According to Maheswarappa et al. (1998) organic carbon content was the highest in vermicompost treated plot compared to other treatment. A perceptible increase in pH was also recorded. Rakhee (2002) reported that among chemical properties of soil organic manures had not influenced soil pH and organic carbon content. But in case of available N glyricidia leaves recorded maximum value and was on par with vermicompost. In case of soil K same result was obtained. For available P though glyricidia gave maximum results FYM, vermicompost gave comparable results in turmeric field.

### *2.3.6.3. Effect of coirpith compost, available $K_2O$, organic carbon and soil pH*

According to Nagarajan et al. (1985) coirpith is having about 5.33 per cent of maximum water holding capacity. As coir pith is found to contain appreciable amount of K, studies revealed that 50 per cent of K fertilizer could be saved by its application to irrigated maize and finger millet in Tamil Nadu (Savithri et al., 1993). Coir pith is rich in potash and would be available for plants over the years (Singh 2001). According to Rakhee (2002) NPK status of the soil was influenced by organic manures. In case of soil N vermicompost recorded maximum value. Coir pith compost gave comparable results in case of soil pH.

### *2.3.6.4. Effect of neemcake on available N, P, K, organic carbon and soil pH*

Neem cake contain the alkaloids nimbin, nimbidin which inhibit the nitrification process (Saharwat and Pamer 1975). Neem cake when applied to ginger it increased the yield of ginger, organic carbon content and potash to the soil (Sadanandan Iyer 1986). Neem cake has the capacity of releasing nitrogen over a stipulated period of crop growth (Hulagur 1996). Neem cake @ 1 kg plant$^{-1}$ along with 600 : 300 : 600 g NPK plant$^{-1}$ could maintain available NPK status of the soil at the highest level (Borah et al., 2001) in crop growth and yield. When FYM alone was applied the yield of turmeric was found to increase (Balashanmugham et al., 1989).

### 2.3.7. Effect of organic manures on uptake of N, P and K

Suresh Lal and Mathur (1981) while studying on crop yield under varied conditions reported that continuous use of inorganic fertilizers alone has detrimental effect on crop production whereas their combination with FYM can regulate the nutrient uptake from the soil. Susan et al. (1998) reported that inclusion of FYM favour the uptake of N in cassava. In ginger, application of FYM 48 t $ha^{-1}$ + 25 percent N through *Azospirillum* recorded higher total uptake of N, P and K (KAU, 1999). Venkatesh et al. (2003) reported that in ginger mother rhizomes significantly increased N, P and K uptake by rhizomes due to application of P sources and FYM. Venkitaswamy (2003) reported that application of coirpith compost in coconut garden the uptake of N, P and K was high. According to Sheeba (2004), nitrogen uptake was found maximum in enriched vermicompost treatment which was on par with (FYM + full NPK) in Amaranthus. In *Plumbago rosea* the treatment FYM + Neem cake (50 % N of POP + microbial inoculants gave the highest N, P, K uptake (Nihad 2005). Venkitaswamy (2003) stated when coirpith compost was applied in coconut garden the uptake of N, P and K was high. According to Asha Raj (2006) in slicing cucumber for enriched coirpith compost N uptake was 32.41 kg $ha^{-1}$, P 22.14 kg $ha^{-1}$ and K 49.4 kg $ha^{-1}$.

In rice according to Kala et al. (1992) vermicompost treated plots recorded higher uptake of N and P. According to Anina (1995) application of vermicompost increased the uptake of nutrients by plants. Increased uptake of nutrients and higher yield in tomato (Pushpa, 1996) and also in chilli uptake of nutrients increased by vermicompost application (Rajalekshmi, 1996). Enriched vermicompost application resulted in higher nitrogen content in soil, this was reported by Asha Raj (2005). According to Rakhee (2002) in turmeric soil nitrogen content and potassium content was maximum value when glyricidia leaves were applied and was on par with vermicompost application. Sheeba (2004), reported that uptake of N, P, K was maximum in enriched vermicompost in Amaranthus crop. In rye grass, neemcake and Karanja cake improved the uptake of nitrogen especially of higher level of application (Hulagar, 1996). In *Plumbago rosea* the treatment, FYM + Neem cake + microbial incoculants resulted in higher uptake of N and P (Nihad, 2005). Sheeba (2004) reported that plant uptake of major nutrients was maximum for enriched vermicompost treatment, in Amaranthus.

### 2.3.8. Effect of organic manures on Nutrient Balance Sheet

Sreekala (2004) stated that the balance sheet for available nitrogen, phosphorus and potassium showed lower net loss in FYM + green leaves treatment. According to Asha Raj (2006) in slicing cucumber nutrient balance sheets indicated deficit balance of available N, P and K in soil. Combined application of enriched vermicompost, AMF and *Azospirillum* proved beneficial in lowering the net losses of N and K whereas net loss of P was lowest with neem cake as compared to all other treatments and POP recommendation.

### 2.3.9. Effect of organic manures on Incidence of pests and diseases

The constant use of chemical pesticides and fungicides may bring about many environmental and ecological problems. Kasthuri turmeric being an export oriented crop, the residual toxicity and connected problems are matters of major concern. The increasing awareness about environmental consequences of fungicide application and the growing interest for pesticide free agricultural produce promoted many to think of organic farming. Various amendments like coirpith compost, FYM, neem cake and vermicompost were found to suppress the various pests and diseases.

Mutitu et al. (1988) observed that the *Fusarium oxysporum* f sp. *Phaseoleos* bean can be reduced b y the application of FYM. Dayakar et al. (1995) reported that when FYM was applied along with 50:50 NP fertilizer, the population of pigeon pea pod borer was lower than under the use of straight inorganic fertilizer alone. The activity of *Apporrectodea trapeziodes* the largest earthworm can substantially decrease the symptoms caused by *Rhizoctonia* in wheat seedlings (Stephen et al., 1993). Dube et al. (1994) evaluated the control of fungal root disease of cereal crops using earthworms and biocontrol agents, and influence of earth worms on *Rhizobium* populations. Jiji (1997) reported that vermicompost produced with *Eudrillus euginiae* was significantly superior over control with respect to the count of fungi and bacteria.

Alam and Khan (1974) observed that neemcake, mahucake and mustard cake controlled phytonematodes in the field as effective as DD and nemagon. Rajani (1998) investigated the effectiveness of neem cake @ 200 g $m^{-2}$ for managing root-knot nematode in kacholam. In *Piper nigrum, Plumbago rosea* crop loss due to root-knot nematode was 20-26 percent, which can be effectively controlled by neem cake (Santhoshkumar, 2004). The experiment conducted at Kerala Agricultural University reported that the nematode population in soil and root mat was found to be minimum in neem cake treatment and maximum in treatment with nitrogen alone (KAU, 2001). A study on the integrated nutrition management of chilly by Sharu (2000) revealed lowest incidence of bacterial wilt when chemical fertilizers and neemcake were applied. Study on the effect of organic manures and *Azospirillum* on growth, yield and quality of ginger resulted minimum incidence of soft rot in plots treated with neem cake alone @ 3.8 t $ha^{-1}$ (KAU 1999). Arulmozhiyan et al. (2002) studied the effect of organic and inorganic in betel vine and recorded lowest disease incidence of *Phytophthora* foot rot in vines which received neem cake.

### 2.3.10. Effect of organic manures on economics of cultivation/ B:C ratio

Economic analysis of different treatments revealed that 80 kg N $ha^{-1}$ through neem coated urea yielded higher B:C ratio than 100 kg N $ha^{-1}$ through prilled urea (Porwal et al., 1993). By using vermicompost as organic manure in sweet potato it is possible to bring down the use of chemical fertilizer. Vermicompost with half or ¾ NPK produced highest yield (Sureshkumar, 1996). According to Niranjana (1998), B : C ratio and net returns were maximum for dual inoculation with 75 per cent POP and *Azospirillum* with 50 per cent POP in amaranthus. The results of three farming systems organic, integrated and conventional in Australia when compared in terms of economic results, fertilizer input, leaching and pest control have revealed that total returns on the organic farming were higher than from other systems due to high premium on standard product prices (Bhardwaj, 1999). Influence of different organic manures and *Azospirillum* on growth, yield and quality of ginger was studied (KAU, 1999). The benefit cost ratio (2.32 : 1) was obtained when FYM @ 48 t $ha^{-1}$ was applied. Raj (1999) found that in Okra, FYM + neemcake application recorded the maximum profit and highest B:C ratio. According to Arunkumar (2000) vermicompost application at highest dose (37.5 t $ha^{-1}$) gave the maximum B:C ratio in amaranthus compared to other treatments. Maximum yield and minimum returns per rupee investment was obtained from 600 g N, 300 g $P_2O_5$, 300 g $K_2O$ + 15 kg neemcake $plant^{-1}$ $year^{-1}$ in acid lime soil (Ingle et al., 2001). The effect of different organic manures on turmeric was studied by Rakhee (2002). The results revealed that B:C ratio was maximum when coirpith compost was used and it was on par with FYM, vermicompost and poultry manure treatment.

In *Plumbago rosea* the treatment supplied with FYM + NC (50% N of POP + microbial inoculants recorded the highest B:C ratio (2.73) which was significantly different from the rest of the treatments (Nihad, 2005). Asha Raj (2006) found that enriched vermicompost and microbial inoculants produced highest net return and B:C ratio in *Amaranthus*.

## 2.4. EXPERIMENT III

*Residual effect of different organic manures on succeeding vegetable crops (amaranthus)*

Organic manure and phosphatic fertilizers have carry over effect on succeeding crops. About less than 30 per cent of nitrogen and small fraction of phosphorus and potash in organic manure may become available to immediate crop and rest to subsequent crops (Gaur, 1982). In contrast to chemical fertilizers the availability of nutrients present in bulky organic manure such as FYM, Neem cake, coirpith compost and vermicompost is slow. In case of FYM only one half of the nitrogen one sixth of the phosphoric acid and a little more than on half of the potash alone are readily available to plants during first season of application. The rest of the plant nutrients become available to the subsequent crops. (Thompson, 1993).

According to Reddy and Prasad (1975) residual study was conducted with different organic manure in amaranthus. Among the various manures the highest yield (15.07 t ha$^{-1}$) was obtained from the plots treated with neem cake. Sharu (2000) observed high residual soil potassium in plots treated with higher level of neemcake. Singh et al. (2001) studied the response of brown sarson to residual effect of FYM and found that seed yield, 1000 grain weight increased as a result of residual effect of application of organic manure on proceeding rice. Thus nutrients released from organic manures may not have been fully utilized by rice crop in the first year and notably benefited to succeeding brown sarson crop. The residual effect of farmyard manure, fertilizer and biofertilizer on wheat during two season was studied by Patidar and Mali (2002). Application of 10 t ha$^{-1}$ FYM and 75 per cent or 100 per cent recommended dose of fertilizer (N and P) to sorghum during rainy season had significant residual effect on succeeding wheat crop and increased grain yield on wheat. However, the effect of bioinoculants was limited to the immediate crop only.

The influence of nitrogen level and residual effect of organic manures on growth, yield and essential oil in ratoon crop of Davana under two irrigation regimes was investigated (Chalapathi et al., 2003). The residual effect of farmyard manure resulted in higher fresh herbage yield of 12.21 t ha$^{-1}$ and it was at par with residual effect of vermicompost. Residual study was conducted by Asharaj (2006). The results revealed that the residual effect of various organic manure treated plots was substantially higher as compared to that of chemical fertilizer treated plots (POP recommendation).

The highest green yield of amaranthus 15.07 t $ha^{-1}$ was recorded in neem cake applied plots and was followed by Enriched vermicompost (14.30 t $ha^{-1}$). Soil physical properties were considerably improved in plots that had residual organic manures as compared to residual POP. Poultry manure and neem cake application along with microbial inoculation lowered bulk density and particle density and improved porosity and WHC of the soil. Soil pH and organic carbon content were highest for FYM and CEC was highest with enriched vermicompost application. Residual EVC accumulated highest N content in soil whereas P, K, S and Zn were highest with residual poultry manure. Various physico-chemical properties and soil fertility status were considerably improved by residual effect of microbial inoculation.

## 2.5. EXPERIMENT IV

### Effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)

The efficacy of microbial inoculants proved to be an effective alternative to obviate the deficiencies realized through the exclusive reliance on chemicals. Microbial biocontrol agents are harmless to human beings and animals, cheaper than pesticides, highly effective throughout the crop growth period with high rhizosphere competence, easy to deliver, improve plant growth, increase yield, bestowed with high cost benefit ratio, environmentally safe, performs in a sustainable way and contributes for sustainable crop production. There is no risk of the pathogen developing resistance and residues in food and ground water. They are compatible with biofertilizer.

The different bioinoculantus used in the study

1. *Azospirillum brasilense*
2. Arbuscular mycorrhizal fungi (AMF)
3. *Pseudomonas fluorescens*
4. *Trichoderma harzianum*

### 2.5.1. *Azospirillum*

This saves N/P requirement upto 50 per cent in most of the crops and also increases yield (Kanauja and Narayanan 2003). The influence of different organic manures and *Azospirillum* on growth, yield and quality was found good in most of the crops (KAU, 1999). Biofertilizers like *Azospirillum* and *Azotobacter* sp. increased nut germination, plant height, stem girth, number of leaves per seedlings, root parameters and total plant biomass in cashew (Ramesh et al., 1998).

### 2.5.2. Arbuscular Mycorrhizal fungi (AMF)

AMF perform many valuable functions from their host plants. It seeks out nutrients particularly P from far greater soil area than the plant can access by itself. It increased the surface area of root mass. It aids in penetration of small hyphae into sites too small for plant root to reach. It also increases the uptake of N, K, S, Cu and Zn. It aids in better survival during drought. It protects against heavy metals and increases the accumulation of hormones like GA and cytokinin in plants. As the fungus acts as an extension of the root it increases the overall absorption capacity of roots due to morphological and physiological changes in the plant. AMF helps in better development of P solubilizing bacteria in the myco-rhizosphere (Sivaprasad and Meena Kumari, 2005).

### 2.5.3. *Pseudomonas flourescens*

They are known as plant growth promoting rhizobacteria (PGPR). They are used as biological control agents for the suppression of soil-borne diseases by competing with pathogens for resources such as nutrients, producing antibiotics or activating host defence mechanisms. They often bring about the growth effects synergistically. In case of spices several *pseudomonas* isolates have been obtained from black pepper and ginger and screened for their ability to suppress pathogens and some were listed for their antagonistic activity on both oomycetes pathogen and nematodes. These isolates were found to enhance growth of host plants (Anandaraj and Sarma, 2003). *Pseudomonas* produces antimicrobial compounds like Bacteriocins, pyrrolnitrin, pyoluteorin etc.

### 2.5.4. *Trichoderma*

The mode of action of *Trichoderma viride* is competition, antibiosis hyperparasitism, hyphal coiling, hyphal penetration, production of lytic enzymes. Induced resistance, plant growth promotion etc. The competition for carbon and nitrogen by *T. harzianum* suppressed the infection of *Fusarium oxysporum* for sp. *melonis* (Sivan and Chat, 1989) on several crops through competition. Antibiotics like trichodermin, dermadin, trichoviridin, viridian etc are produced by *Trichoderma*. Mycoparasitism relies on the production of mycoparasite for the lysis of cell walls. *Trichoderma* induces plant growth like increased germination, early emergence, fresh and dry weight of roots, shoots, root length, yield and flowering.

### 2.5.5. Effect of microbial inoculants on growth characters

#### *2.5.5.1. Effect of Azospirillum*

Inoculation of *Azospirillum* in combination with N profoundly increased the growth, yield of turmeric (Mohan et al., 2004). The investigations on turmeric (*Curcuma longa* L.) were carried out to study the effect of different organic manures and biofertilizers. The results revealed that FYM + *Azospirillum* + *Phosphobacteria* + AMF recorded earlier sprouting, greater plant height, lengthier and wider leaves (Velmurugan et al., 2006 b). Varma (1995) recorded significantly higher production of new leaves, branches fresh and dry weight of shoot in bush pepper inoculated with *Azospirillum*. When *Azospirillum* sp. + *Bacillus megaterium* was applied in Black pepper increased the growth parameters (Kandianan et al., 2000). It also enhances seedling growth, root development and vigour in corn seedling (Fulchieri et al., 1993. In coffee *Azospirillum* + *Bacillus* sp.

*Gigaspora margarita* applied found that increase in stem girth, tap root length and total dry weight of roots (Swarupa and Reddy, 1996). The beneficial effect of *Azospirillum* and *Phosphobacteria* on growth of cardamom was indicated from the studies carried out at Indian cardamom Research Institute (Muthuramalingam et al., 2000). In ginger a field experiment was conducted, and the results revealed that highest plant height number of tillers and number of leaves per plant over the normal rate of NPK were observed when biofertilizers like *Azospirillum* and *Azotobacteria* were applied (Nath and Korla, 2000). Reddy et al. (2003) reported that when *Azospirillum brasilense* was applied to coconut seedlings number of roots, branching and dry weight of root were increased. Sivaprasad et al. (2003) reported that *Azospirillum* application enhances growth promotion in crops. Similarly in birds' eye chilli *Azospirillum* + AMF + *Phosphobacteria* application increased plant height (70.78 cm) and number of branches per plant (6.95) (Praneetha and Lakshmanan, 2006).

#### ***2.5.5.2. Effect of AMF***

Thomas and Ghai (1988) observed an increase in plant height, number of leaves and shoot dry weight of pepper, panniyur-1 on inoculation with AMF. Similar results were reported on inoculation with *Glomus fasciculatum* and *Glomus etunicatum* in pepper (Sivaprasad et al., 1992). Inoculation of AMF at the time of planting in the nursery or field is recommended for improving growth and tolerance of crop plants against root pathogen particularly black pepper, cardamom, ginger, turmeric, cowpea and transplanted vegetables (KAU 1996). According to Kandiannan et al. (2000) among the invidual inoculants maximum growth of pepper was seen in AMF. In dual combinations, *Phosphobacteria* + AMF was the most effective in increasing the growth characters of black pepper. The effect of various bio-fertilizers on establishment and growth of pepper cuttings was studied by Ashithraj (2001). According to him the vine length, number of leaves and dry weight were significantly higher in plants inoculated with selected species and strains of AMF and N fixing bacteria. According to Sivaprasad (1993) the AMF namely *Glomus multicaule* and *Glomus fasciculatum* significantly enhanced growth of ginger. In tissue culture plantlets, physiological and biochemical changes induced by AMF association render the plantlets more resistant to microbial infection and stress conditions. Thus the major defects of TC plantlets could be corrected with desirable traits of AMF association. This is evident from the significant increase in survival and establishment recorded with TC plantlets of Jack (31 to 87 per cent), (zero to 65 per cent) in banana and alocasia (Sivaprasad et al., 1998). Mycorrhizal inoculation was found beneficial in improving the plant growth compared to control (Sreeramulu and Bhagyaraj, 1999). According to Muthuramalingam et al. (2000) application of bioinoculants namely AMF, *Azospirillum* and *Phosphobacteria* improved growth and development of vanilla and minimized the use of inorganic fertilizers. According to Gupta et al., 2003 AMF inoculation in periwinkle enhanced the growth and number of branches.

### *2.5.5.3. Effect of Pseudomonas*

*Pseudomonas fluorescens* are a group of plant growth promoting rhizobacteria (PGPR) which are naturally occurring in the soil that aggressively colonize plant roots and benefit plants by providing growth promotion (Kloepper 1994). *P. fluorescens* promote plant growth by secreting hormonas like Gibberallic acid (Wellor, 1985). These organisms also provide protection against diseases by suppressing deleterious and pathogenic microorganisms (Baker and Schippers, 1987). Kumar and Dube (1992) proved the efficacy of seed bacterization, with fluorescent pseudomonad on germination and growth of chickpea and soybean and disease like chickpea wilt was suppressed. Seed bacterization with these organisms has emerged as a powerful technology to enhance growth and yield besides providing protection against diseases (Dube, 1995). Gupta et al. (1995) reported that inoculation of *P. fluorescens* increased seedling emergence rate, length of root and shoot in tomato plants. Izhar et al., (1999) observed that seed treatment with *P. fluorescence* enhanced the growth of cotton and reduced infection of *R. solani*. Meena and Bhardwaj (2003) conducted a study to determine the effect of *P. flourescences* in strawberries. The results revealed that shoot and root length, fresh root weight and fresh shoot weight and dry weight of strawberry were increased. In black pepper when *P. fluorescence* was applied the growth response was improved and it acted as a biocontrol agent in suppressing the foot rot disease incidence (Sivaprasad et al., 2003). Rini (2005) reported that combined application of *Trichoderma* and *Pseudomonas* offered 100 per cent protection against seedling blight and enhanced growth and yield of tomato and chilli plants. *Pseudomonas* and *Trichoderma* when applied alone enhanced shoot weight and improved root characters like root length, root weight etc., however combined application enhanced the vegetative growth of plants at 90 DAP. The application of *Pseudomonas* and *Trichoderma* in chilli and tomato suppressed the diseases caused by *Rhizoctonia solani* and *Fusarium oxysporum* in tomato and chilli and produced healthy plants.(Rini and Sulochana, 2007).

### *2.5.5.4. Effect of Trichoderma*

According to Joseph (1977), *T. viride* was the most effective isolate for suppression of rhizome rot, growth enhancement and yield in ginger. Baker et al. (1984) found *Trichoderma harzianum* can stimulate the growth of plants, including various floricultural and horticultural plants. According to Chang et al. (1986). Pepper seed germinated two days earlier in raw soil containing the fungus than untreated controls. Windham et al. (1988) reported that addition of *Trichoderma* sp. to autoclaved soil increased root and shoot dry weight of tomato and tobacco. Similar result was also obtained in marigold by the combination of AMF and *Trichoderma* (Calvet et al., 1993). Inbar et al. (1994) observed that *Trichoderma harzianum* treated seedlings were more developed and grew more vigorously and were more resistant to damping off caused by *Pythium* sp and *R. solani*. Increase in seedling and plant growth of chickpea due to soil application of *T. harzianum* prior to sowing was also reported by Sharma et al. (1999). Priyadarshini (2003) reported that *T. harzianum* was found successful in managing the disease and enhancing the growth of amaranthus. In the organic production of turmeric, application of biofertilizers like *Trichoderma viride* (7.5 kg ha$^{-1}$) and phosphobacteria (7.5 kg ha$^{-1}$) was recommended (Ravikumar 2002). Combined application of *Trichoderma* and *Pseudomonas* suppressed the seedling rot of chilli and enhanced its growth (Rini and Sulochana, 2006).

### 2.5.6. Effect of microbial inoculants on yield and yield components

#### ***2.5.6.1. Effect of Azospirillum***

According to Subramanian et al. (2003) the application of *Azospirillum* increased the yield of turmeric. Inoculation of *Azospirillum* in turmeric increased the yield over control. (Mohan et al., 2004). Okon and Labandera (1994) evaluated data accumulated world wide over the past 20 years on field inoculation with *Azospirillum* and concluded that these bacteria promote yield of agriculturally important crops grown in different soils. In ginger Azofert application enhanced the size and yield of rhizome (Nath and Korla, 2000). Easwaran et al. (2003) reported that combined application of *Azospirillum* + *Phosphobacteria* + AMF increased green leaf yield in Tea. In onion Kanauja and Narayanan, (2003) found that application of *Azospirillum* and *phosphobacteria* increased yield by 18.3 per cent as well as saved 25 per cent of inorganic fertilizer and thereby reduced the cost of cultivation of onion. Yield increase was obtained by application of *Azospirillum* in rice, vegetables and plantation crops. Sivaprasad et al., 2003. Bijily Krishnan and Anilkumar (2006) studied on the rhizosphere nodulation for higher productivity in long pepper. The study revealed that application of vermicompost 6.25 t ha$^{-1}$ year$^{-1}$ and combined inoculation of bionoculants *Azospirillum* + *phosphobacteria* + AMF enhanced the total fresh and dry spike yield. Hiwale (2006) reported *Azospirillum* application in pomegranate cv. Ganesh increased the number of fruits plant$^{-1}$. In bird's eye chilli impact of bioinoculants was studied by Praneetha and Lakshmanan (2006). The results revealed that combined application of *Azospirillum* + AMF + *Phosphobacteria* recorded highest yield. In tomato application of 75 per cent N as vermicompost with *Azospirillum* recorded 45 per cent higher yield of tomato (Kannan et al., 2006). In cabbage combined application of organic manure (vermicompost and bionoculants (*Azospirillum* + AMF + *Phosphobacteria)* recorded the maximum yield (Taiyab Ali Saifee et al., 2006).

#### ***2.5.6.2. Effect of AMF***

The yield of pepper mint was found to be significantly increased compared to control through inoculation of AMF (Khaliq et al., 2001). Research trial was conducted in integrated nutrient management on five year old vanilla during 2001-2002 consisting 25 g each of VAM, *Azospirillum, Phosphobacteria* and four levels of NPK namely 25, 50, 75 and 100 g vine$^{-1}$ year$^{-1}$. It was observed that bean weight was maximum in bioinoculants treated plots combined with 100 kg NPK vine$^{-1}$ year$^{-1}$ (Parthiban and Easwaran, 2003). Gupta et al. (2003) observed that root colonization of AMF (*Glomus* spp) have significantly increased the fresh biomass yield of periwinkle in comparison to non inoculated control plants. In the case of chilli plants inoculated with AMF more number of fruits were obtained as compared to uninoculated plants which received 75 kg phosphorus ha$^{-1}$ (Kanauja and Narayanan, 2003). In *Polyanthus tuberosa* application of AMF + *Azospirillum* + *Phosphobacteria* recorded the maximum number of flowers spike$^{-1}$, single flower weight, maximum yield ha$^{-1}$ plot$^{-1}$ (Praneetha et al., 2006). In cassava it was observed that the number of tubers plant$^{-1}$ was more in AMF application (Saraswathi and Shanmugham, 2006). In cabbage according to Taiyab Ali Saifee et al. (2006), vermicompost application along with AMF + *Azospirillum* and *Phosphobacteria* recorded maximum yield. According to Udayakumar et al. (2006) effect of bioinoculants was studied in banana. The results revealed that maximum yield was obtained in 50 g plant$^{-1}$ *Glomus* sp. + 50 per cent recommended dose of fertilizers.

### *2.5.6.3. Effect of Pseudomonas*

Seed or root inoculation with *Pseudomonas* are reported to improve yield of potato (Burr et al., 1978). According to Kundu and Gaur, (1980) *Pseudomonas striata* increased yield in cotton. Seed bacterization with *Pseudomonas* has emerged as a powerful technology to enhance plant growth and yield in crops (Dube, 1995). The fluorescent pseudomonads treated pepper plants imparted maximum shoot and root biomass (Diby et al., 2001). Nandakumar et al. (2001b) used one mixture of PGPR against sheath blight in rice which in addition to disease suppression, increased grain yield. Asghar et al. (2002) isolated rhizobacteria from the rhizosphere of different *Brassica* species. Based on his study *B. juncea* seeds were inoculated with different isolates of rhizobacteria. Results revealed that number of pods plant$^{-1}$, 1000-grain weight and grain yield was high in *Pseudomonas* treated plants comparing to control. The beneficial effect of combined inoculation of *Trichoderma* sp. and *Pseudomonas flourescens* increased the growth and yield of black pepper (Anandraj and Sarma, 2003). Meena and Marimuthu (2006) found that incorporating green manure, neem cake and *Pseudomonas fluorescens* application in tomato as seed treatment (10 g kg /seed)/soil application (2.5 kg / 50 kg FYM ha$^{-1}$) and seedling dip (0.2 %) was found to be effective in managing *Fusarium* wilt disease. The highest yield of 27.0 t/ha was recorded in the combination green manure + neem cake and *Pseudomonas fluorescence* application. It was found that use of plant growth regulator, ($GA_3$) and plant growth promoting Rhizobacteria (*Pseudomonas fluorescence*) in cauliflower increased yield (Mohana Sundaram and Dhandapani 2006). Root rot disease incidence was suppressed in chilli by dual application of *Pseudomonas* and *Trichoderma* (Rini and Sulochana, 2006). They also reported that combined application of *Pseudomonas* and *Trichoderma* reduced seedling blight, fruit rot in chilli (Rini and Sulochana, 2007).

### *2.5.6.4. Effect of Trichoderma*

Joseph (1977) recorded maximum rhizome yield in ginger plants inoculated with *Trichoderma viride* and AMF. The combined application of neemcake (150 kg $ha^{-1}$) along with seed treatment using *Trichoderma viride* recorded maximum yield in fenugreek (IISR, 1998). According to Anandaraj and Sarma (2003), application of *Pseudomonas flourescens* + *Trichoderma* sp. in black pepper increased yield and there was suppression of root rot. Treatment of sunflower seeds with *T. viride* at the rate of 4 g $kg^{-1}$ reduced the root rot incidence to 18.1 per cent as against 37.1 per cent in control. It increased the yield by 2 per cent. In sesamum also root rot incidence was reduced and an increase in yield of 677 kg $ha^{-1}$ as against 301 kg $ha^{-1}$ in control was obtained. Basal application of neem cake combined with seed treatment (10 g $kg^{-1}$) of *Trichoderma* and soil application (40th day after sowing) of *T. viride* reduced stem rot incidence (60.94 % and 73.90 %) and enhanced yield by 25.07 and 20.93 per cent respectively under field conditions to control soil – borne diseases (Sivaprasad and Meena Kumari, 2005). According to Udayakumar et al. (2005) when combination of bioinoculants like 50 per cent recommended dose of fertilizer + 50 g *Glomus fasciculalum* + 50 g *Trichoderma harzianum* + 50 g *Azospirillum* applied to banana maximum yield was obtained. According to Rini (2005) application of *Trichoderma* increased crop growth in tomato and chilli plants and reduced wilt incidence.

### 2.5.7. Effect of microbial inoculants on Physiological characters

#### ***2.5.7.1. Effect of Azospirillum***

In amaranthus the physiological parameters were influenced by dual application of *Azospirillum* and AMF (Niranjana 1998). According to Nihad (2005) organic manures along with bioinoculants like *Azospirillum* and AMF increased NAR, CGR, total dry matter content and LAI in *Plumbago rosea*. The effect of biofertilizers on physiological and biochemical parameters was studied in turmeric by Velmurugan et al. (2006c). The results revealed that highest leaf area, LAI, photosynthetic rate, specific leaf weight, CGR, total dry matter production and harvest index was higher in treatment which received the combined application of FYM + *Azospirillum* + AMF.

#### *2.5.7.2. Effect of AMF*

According to Sreekala (2004) application of AMF + *Trichoderma* + FYM produced highest leaf area, LAI, DMP, CGR and LAD. When AMF (*Glomus fasciculatum*) was applied to banana, leaf area was found to increase and early shooting stage was noticed (Udayakumar et al., 2006). In turmeric Velmurugan et al. (2006c) reported that combined application of microbial inoculants like *Azospirillum* + AMF + FYM recorded highest leaf area, LAI, CGR and DMP.

#### ***2.5.7.3. Effect of Pseudomonas***

*Pseudomonas syringe* interferes with leaf chloroplasts, mitochandria and enhances the photosynthesis process thereby activating the physiological process in sunflower (Robinson et al., 2004). Ponmurugan and Baby (2001) reported that physiological parameters like photosynthates rate, water use efficiency and stomatal conductance was highly influenced by *Pseuodomonas* application in cocoa.

### *2.5.7.4. Effect of Trichoderma*

In *Plumbago rosea* Nihad (2005) found that *Trichoderma* application enhanced physiological parameters like LAI, CGR, NAR. Sreekala (2004) reported that FYM + *Trichoderma* + AMF application increased CGR, NAR, RGR, LAD, LAI etc.

### 2.6.8. Effect of microbial inoculants on biochemical characters

### *2.5.8.1. Effect of Azospirillum*

Inoculation with *Azospirillum* increased capsicin and ascorbic acid contents in chilli (Balakrishnan, 1988). Amirithalingam (1988) recorded highest ascorbic acid and capsicin content in chilli, in, *Azospirillum* treatment. Chattoo et al. (1997) observed that in Knol Khol, *Azospirillum* increased yield and quality attributes over control. Niranjana (1998) observed least fibre content in treatment which received *Azospirillum* inoculants with 75 per cent of package of practices recommendations of Kerala Agricultural University in amaranthus. Combined inoculation of *Azotobacter* and *Azospirillum* in turmeric revealed that combined inoculation increased the curcumin and protein content compared to single inoculated and un inoculated treatments. The investigation suggested that dual inoculation of *Azotobacte*r and *Azopirillum* along with fertilizer nitrogen (30 kg $ha^{-1}$) for quality improvement in turmeric (Jena and Das, 1997). The influence of different organic manures and *Azospirillum* on growth yield and quality of ginger was reported from KAU (1999). The results revealed that 15 per cent increase in essential oil content was noticed where, 25 per cent N were substituted through *Azospirillum.* In a study conducted by Velmurugan et al. (2006d) in turmeric, application of FYM + *Azospirillum* + AMF increased biochemical characters like chlorophyll, soluble protein and total phenols. According to Kannan (2006) study was conducted on organic and bioinoculants application in tomato and the study revealed that application of organic manures + *Azospirillum* improved quality of tomato fruits. According to Mohan et al.

(2004) in turmeric, combined application of *Azospirillum* and *Azotobacter* increased curcumin and oleoresin content.

Azophos application along with 75 kg N ha$^{-1}$ + 37.5 kg P ha$^{-1}$ recorded the highest phyllanthin and hypophyllanthin content in keezhanelli. (Balakumbahan et al., 2006). Efficacy of integrated nutrient management on sweet flag (*Acorus calamus* L) was studied by Kalyana Sundaram et al. (2006). The results revealed that inoculation of *Azospirillum* at 2 kg ha$^{-1}$ along with 75 kg N ha$^{-1}$ + 50 kg P ha$^{-1}$ recorded the maximum oil content and alkaloid content in sweet flag. In tomato quality parameters like TSS (%), ascorbic acid was highly influenced by inorganic fertilizers + FYM and *Azospirillum* (Kushwash et al., 2006). Vermicompost along with application of *Azospirillum* + *Phosphobacteria* improved total chlorophyll content and ascorbic acid in cabbage (Taiyab Ali Saifee, 2006).

#### *2.5.8.2. Effect of AMF*

Green chillies having higher ascorbic acid were obtained when plants were inoculated with AMF (Bagyaraj and Sreeramula, 1982). The quality attributes of tomato namely vitamin C content and TSS significantly increased over control by AMF inoculation (Sundaram and Arangarasan, 1995). AMF inoculated aromatic crops like *Cymbopogon martini* var *motia* have more essential oil than in control plants (Ratti and Janardhan, 1996). In geranium the cumulative herbage yield (103.32 t ha$^{-1}$) and essential oil yield (172.36 kg ha$^{-1}$) were significantly higher under fertigation with 80 per cent NPK + *Azotobacter* + *Azospirillum* and AMF application. (Pasha et al., 2003). In *Phyllanthus amaras* AMF along with 75 kg N ha$^{-1}$ + 37.5 kg P ha$^{-1}$ increased Phyllanthin and hypophyllanthin content (Balakumbahan et al., 2006). In turmeric, investigations were carried out to study the effect of different organic manures and bioinoculants with reference to biochemical parameters. Combined application of bioinoculants like *Azospirillum* +

AMF + *Phosphobacteria* along with FYM recorded higher chlorophyll, soluble protein and total phenol content (Velmurugan et al., 2006d).

### *2.5.8.3. Effect of Pseudomonas*

Robinson et al., (2004) reported that application of *P. syringe* enhanced production of chlorophyll, ascorbic acid in sunflower. Combined application of *Pseudomonas* + *Azospirillum* + AMF along with NPK increased total alkaloid content in long pepper. (Bijily Krishnan and Anil Kumar, 2006). According to Ponmurugan and Baby (2008) when *Pseudomonas* was applied to cocoa plants increased the amino acid content, chlorophyll content and carotenoids. *Gomaz* et al. *(*2006) found that application of *Pseudomonas* in prickly pear increased oil yield and decreased peroxide value.

### *2.5.8.4. Effect of Trichoderma*

The total protein content produced by *Trichoderma* sp. was significantly higher compared to untreated chickpea plants. (Srivastava et al., 2002). Effect of organic manures and bioinoculants was studied by Sreekala (2004) in ginger. She reported that highest content of volatile oil and non volatile ether extract was obtained when *Trichoderma* was applied.

### 2.5.9. Effect of microbial inoculants on soil microbial load

*Pseudomonas* application in wheat increased grain yield. Applying the bacteria as a soil drench (2.5x $10^9$ cfu $g^{-1}$ of soil) was more effective than coating the bacteria on wheat seed (3.4 x $10^7$ cfu $g^{-1}$ of seed). The soil drenched plots recorded more microbial population. The study further confirmed that soil type can influence the population and the level of biocontrol activity (Huang and Wong 1998). In *Pisum sativum* *Pseudomonas* application reduced the pH. The decrease in pH increased the fungal and yeast colony. The population of introduced and total

*Pseudomonas* is increased (Naseby and Lynch, 2005). When *Trichoderma* was applied as soil amendment the cfu increased by 60 days in treated plots. Fungal population reached a maximum of 62 x $10^4$ cfu $g^{-1}$ of soil with in 45 days (Prasad et al., 2002). Chitin added to sand soil based cultivation substrates stimulated the root colonization, growth of extra radial mycelium and production of spores of AMF fungi was observed in host plants like *Plantago lanceolata, Allium ampelloprasum* and *Lactuca sativa*. Stimulation of AMF sporulation was observed when autoclaved mycelium of *Fusarium oxysporum* was used instead of chitin. Increased numbers of actinomycetes in the substrates as a result of chitin treatment were recorded (Milan Gryndler et al., 2003).

# MATERIALS AND METHODS

# 3. MATERIALS AND METHODS

Studies on "Standardization of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb) were carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2006-2007 and 2007 – 2008. The objective of the study was to standardize an optimum dose of organic manure and to evaluate the effect of microbial inoculants on growth, yield and quality of kasthuri turmeric of high cosmetic value.

The details of the materials used and methods adopted for the study are presented in this chapter.

## 3.1. LOCATION

The field experiments were conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The area is situated at 8° 30' North latitude and 76° 54' East longitude at an altitude of 29 m above MSL.

## 3.2. SOIL

The soil of the experimental site is red loam and belongs to Vellayani series which comes under the order oxisol.

## 3.3. SEASON

Two field experiments were conducted, one from June 2006 to February 2007 and the other from July 2007 to March 2008. The same plots were used for the second year study and the treatments were superimposed.

## 3.4. SEED MATERIAL AND VARIETY

The planting material used was kasthuri turmeric, IISR accession collected from healthy rhizome bits of disease free plants with at least one bud weighing 15-20 g.

The study was taken up as four experiments.

## 3.5. EXPERIMENT I

### Laboratory Incubation studies of the organic manures

The incubation study was conducted in laboratory conditions to assess the relative efficiencies of various organic sources *viz*., FYM (20.0 t $ha^{-1}$, 30.0 t $ha^{-1}$ and 40.0 t $ha^{-1}$), vermicompost (15.0 t $ha^{-1}$, 20.0 t $ha^{-1}$ and 25.0 t $ha^{-1}$), coirpith compost (20.5 t $ha^{-1}$, 30.0 t $ha^{-1}$ and 40.0 t $ha^{-1}$) and neemcake (3.0 t $ha^{-1}$, 4.5 t $ha^{-1}$ and 6.0 t $ha^{-1}$) with one absolute control (Plate 3) and to study the nutrient release pattern. Soil sample were incubated at 60 per cent moisture content for 60 days and periodic sampling was done at 15 days interval. Soil analysis at 15 days interval for two months was done to assess.

Design : RBD
Replication : 3

1. Organic carbon content (Walkey & Black method, 1947)
2. Available Nitrogen (Subbiah & Asija, 1956)
3. Available phosphorous (Jackson, 1973)
4. Available potassium (Jackson, 1973)

## 3.6. EXPERIMENT II

### Effect of organic manures on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)

Two field experiments were conducted, one during 2006-2007 and the other during 2007-2008 (Plate 4).

## LAY OUT OF EXPERIMENT - I (INCUBATION STUDY)

**1. FYM**

$F_1$ – 20.0 t $ha^{-1}$
$F_2$ – 30.0 t $ha^{-1}$
$F_3$ – 40.0 t $ha^{-1}$

**2. Vermicompost**

$V_1$ – 15.0 t $ha^{-1}$
$V_2$ – 20.0 t $ha^{-1}$
$V_3$ – 25.0 t $ha^{-1}$

**3. Coirpith compost**

$C_1$ – 20.0 t $ha^{-1}$
$C_2$ – 30.0 t $ha^{-1}$
$C_3$ – 40.0 t $ha^{-1}$

**4. Neemcake**

$N_1$ – 3.0 t $ha^{-1}$
$N_2$ – 4.5 t $ha^{-1}$
$N_3$ – 6.0 t $ha^{-1}$

**REPLICATION I**

| | | | | | | |
|---|---|---|---|---|---|---|
| $V_3$ | $N_1$ | $F_1$ | $N_3$ | Ctrl. | $V_1$ | $V_2$ |
| $C_2$ | $F_3$ | $N_2$ | $F_1$ | $F_2$ | $C_3$ | |

**REPLICATION II**

| | | | | | | |
|---|---|---|---|---|---|---|
| $F_1$ | $V_1$ | $N_3$ | Ctrl. | $C_1$ | $N_1$ | $V_3$ |
| $N_2$ | $C_3$ | $F_2$ | $C_2$ | $V_2$ | $F_3$ | |

**REPLICATION III**

| | | | | | | |
|---|---|---|---|---|---|---|
| $N_1$ | $V_1$ | $C_2$ | $F_2$ | $V_2$ | $N_3$ | $F_3$ |
| $C_3$ | Ctrl. | $C_1$ | $N_2$ | $V_3$ | $F_1$ | |

Plate 3. Laboratory incubation studies of organic manures

Plate 3. Laboratory incubation studies of organic manures

## LAY OUT OF EXPERIMENT - II (FIELD STUDY)

**1. FYM**

$F_1$ – 20.0 t $ha^{-1}$
$F_2$ – 30.0 t $ha^{-1}$
$F_3$ – 40.0 t $ha^{-1}$

**2. Vermicompost**

$V_1$ – 15.0 t $ha^{-1}$
$V_2$ – 20.0 t $ha^{-1}$
$V_3$ – 25.0 t $ha^{-1}$

**3. Coirpith compost**

$C_1$ – 20.0 t $ha^{-1}$
$C_2$ – 30.0 t $ha^{-1}$
$C_3$ – 40.0 t $ha^{-1}$

**4. Neemcake**

$N_1$ – 3.0 t $ha^{-1}$
$N_2$ – 4.5 t $ha^{-1}$
$N_3$ – 6.0 t $ha^{-1}$

**REPLICATION I**

| | | | | | | |
|---|---|---|---|---|---|---|
| $N_3$ | $C_2$ | $V_1$ | $F_3$ | $C_1$ | $C_3$ | Ctrl. |
| $V_2$ | $F_1$ | $N_1$ | $F_3$ | $V_2$ | $N_2$ | |

**REPLICATION II**

| | | | | | | |
|---|---|---|---|---|---|---|
| $C_1$ | $V_2$ | $N_2$ | $F_2$ | $V_1$ | $C_2$ | Ctrl. |
| $N_1$ | $V_3$ | $F_1$ | $N_3$ | $F_3$ | $C_3$ | |

**REPLICATION III**

| | | | | | | |
|---|---|---|---|---|---|---|
| $V_3$ | Ctrl. | $F_2$ | $N_3$ | $C_1$ | $F_3$ | $F_1$ |
| $C_2$ | $V_2$ | $V_1$ | $N_2$ | $N_1$ | $C_3$ | |

Plate 4. Field view of Experiment II

Design : RBD

Material : IISR accession of kasthuri turmeric (*Curcuma aromatica* Salisb.)

Replication : 3

Bed size : 1.2 x 3 m (2 beds consist of 1 plot)

No. of plots : 39

### 3.6.1. Treatments

A) Sources of organic manures (4)

1. FYM
2. Vermicompost
3. Coirpith compost
4. Neemcake

B) Levels of organic manures (3 levels)

1. FYM

$F_1$ – 20.0 t ha$^{-1}$
$F_2$ – 30.0 t ha$^{-1}$
$F_3$ – 40.0 t ha$^{-1}$

2. Vermicompost

$V_1$ – 15.0 t ha$^{-1}$
$V_2$ – 20.0 t ha$^{-1}$
$V_3$ – 25.0 t ha$^{-1}$

**3. Coirpith compost**

$C_1$ – 20.0 t ha$^{-1}$
$C_2$ – 30.0 t ha$^{-1}$
$C_3$ – 40.0 t ha$^{-1}$

4. Neemcake

$N_1$ – 3.0 t ha$^{-1}$
$N_2$ – 4.5 t ha$^{-1}$
$N_3$ – 6.0 t ha$^{-1}$

**5. Absolute control** - with no organic manures

### 3.6.2. Planting

Rhizome bits were planted at a depth of 5 cm with buds facing upwards at a spacing of 30 x 30 cm and covered with soil. Two g of *Trichoderma harzianum* per pit was applied before planting during second year as a prophylactic measure against rhizome rot.

### 3.6.3. After cultivation

Hand weeding was done as and when necessary. The crop was raised as rainfed but with need based life saving irrigations.

### 3.6.4. Plant protection

Pest and disease incidence were recorded periodically.

### 3.6.5. Observations

Two beds were maintained per treatment for taking observations. One bed was used for taking biometric observations and the other for destructive sampling. For taking biometric observations ten plants were selected at random from one bed. From the other bed, five plants were selected at random for destructive sampling. These observations were taken at two months interval starting from second to eighth month after planting.

#### *3.6.5.1. Growth characters*

##### 3.6.5.1.1. Plant height

The height of the plants was measured from the base of the main pseudostem to the tip of the top most leaf and was expressed in cm.

##### 3.6.5.1.2. Number of tillers

Number of tillers were determined by counting the number of aerial shoots arising around a single plant.

#### 3.6.5.1.3. Number of leaves

Number of leaves were determined by counting the number of leaves of all the tillers at bimonthly intervals from 2 MAP.

#### 3.6.5.1.4. Leaf area

The length and width of leaves were measured at bimonthly intervals from 2 MAP and the leaf area in $cm^2$ was calculated based on length and breadth method.

The following relationship was used for computing the leaf area (Randhawa et al., 1985).

$Y = 4.09 + 0.564$ (Length x Breadth)
Y = Leaf area
Length = Length of the leaf in cm
Breadth = Breadth of leaf in cm.

#### 3.6.5.1.5. Rhizome spread

The horizontal spread of rhizome was measured at bimonthly intervals from 2 MAP and expressed in cm.

#### 3.6.5.1.6. Rhizome thickness

Rhizome thickness was measured at bimonthly intervals from 2 MAP using micrometer and expressed in cm.

#### 3.6.5.1.7. Root length

The plants were uprooted from 2 MAP and maximum length of roots was measured and mean length expressed in cm.

#### 3.6.5.1.8. Root spread

Root spread was measured at bimonthly intervals from 2 MAP by spreading the root system on a marked paper and measuring the spread of the root system at its broadest part and expressed in cm.

3.6.5.1.9. Root weight

Roots separated from individual plants at bimonthly intervals from 2 MAP were taken and dried in hot air oven at 70-80°C and its weight was then taken and expressed in g plant$^{-1}$.

3.6.5.1.10. Number of fingers

The total number of fingers like primary, secondary and tertiary from the mother rhizome are counted.

### *3.6.5.2. Yield and yield components*

3.6.5.2.1. Rhizome yield - fresh

The fresh rhizome yield from each treatment was recorded by destructive sampling at bimonthly intervals till harvest and expressed in g plant$^{-1}$.

3.6.5.2.2. Rhizome yield - dry

The fresh rhizomes was washed, chopped and allowed to dry under sun for three days. It was then kept in hot air oven at 70-80°C till constant weight obtained and the dry rhizome yield was expressed in g plant$^{-1}$.

3.6.5.2.3. Top yield

The yield of above ground portion in individual treatment was recorded from four MAP to six MAP and expressed in g plant$^{-1}$ on dry weight basis.

3.6.5.2.4. Crop Duration

The number of days taken from planting to final harvest was recorded for each treatment.

### *3.6.5.3. Physiological characters*

#### 3.6.5.3.1. Dry matter production (DMP)

The leaves, petioles, pseudostem, rhizomes and roots of the uprooted plants were separated and dried to a constant weight at 70-80°C in a hot air oven. The sum of dry weights of component parts gave the total dry matter production of the plant and expressed as g plant$^{-1}$.

#### 3.6.5.3.2. Leaf area index (LAI)

Leaf area index was calculated at bimonthly intervals from two MAP. Ten sample plants were randomly selected for each treatment and number of leaves on each plant were counted. Maximum length and width of leaves from all the sample plants were recorded separately and leaf area was calculated based on length and breadth method.

$$\text{LAI} = \frac{\text{Sum of leaf area of N sample (cm}^2\text{)}}{\text{Area of land covered by N plants(cm}^2\text{)}}$$

#### 3.6.5.3.3. Crop Growth Rate

Crop growth rate (CGR) was calculated using the formula of Watson (1958) and expressed as g m$^{-2}$ day$^{-1}$

CGR = NAR x LAI
NAR = Net assimilation rate
LAI = Leaf Area Index.

#### 3.6.5.3.4. Relative Growth Rate (RGR)

Relative growth rate (RGR) was calculated as per the formula suggested by Blackman (1919) and expressed in g day$^{-1}$.

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{(t_2 - t_1)}$$

$W_1$ = Total dry weights of the plant at time $t_1$

$W_2$ = Total dry weights of the plant at time $t_2$

3.6.5.3.5. Net Assimilation Rate (NAR)

Net assimilation rate (NAR) was calculated as per the procedure given by Watson (1958) and as modified by Buttery (1970). The following formula was used to derive NAR and expressed in g $m^2$ $day^{-1}$.

$$\text{NAR} = \frac{W_2 - W_1}{(t_2 - t_1)\ (A_1 + A_2)/2}$$

where, $W_2$ – total dry weight of the plant in g at time $t_2$

$W_1$ – total dry weight of the plant in g at time $t_1$

$(t_2 - t_1)$ = time interval in days

$A_2$ = Leaf area ($cm^2$) at time $t_2$

$A_1$ = Leaf area ($cm^2$) at time $t_1$

3.6.5.3.6. Leaf Area Duration (LAD)

Leaf area duration (LAD) was calculated using the formula given by Power *et al.*, (1967).

$$\text{LAD} = \frac{L_1\ (L_1 + I) \text{ x } (t_2 - t_1)}{2}$$

where $L_1$ – LAI at first stage

$L_1 + I$ = LAI at second stage

$t_2 - t_1$ = Time interval between these stages

3.6.5.3.7. Rhizome: Shoot ratio

Rhizome and shoot dry weight of five observational plants were worked out and the mean expressed as the ratio between the average of rhizome weight and shoot weight.

3.6.5.3.8. Harvest Index (HI)

Harvest index was calculated at final harvest as the ratio of dry weight of rhizome to the dry weight of whole plant.

$$HI = \frac{Y\ econ}{Y\ biol}$$ where,

Y econ - total dry weight of rhizome
Y biol - total dry weight of plant

### *3.6.5.4. Anatomical characters*

3.6.5.4.1 Leaf cuticle thickness

Very thin free hand cross sections of three randomly selected leaves from each replication were taken and the cuticle thickness was observed using 40x objective and 10 x eyepiece and measured using micrometer and the values are expressed in micrometers.

3.6.5.4.2. Number of vascular bundles in rhizome and roots

Free hand thin cross sections of medium sized finger rhizomes and roots were taken and observed under 10 x objective and the number of vascular bundles were recorded.

3.6.5.4.3. Stomatal frequency

Stomatal frequency refers to the number of stomata per unit area of leaf. Stomatal frequency was recorded for both upper and lower surface of three randomly selected leaves from each replication. Leaf imprints were prepared for the purpose using adhesive, "Quick fix". It was uniformly applied on the surface of leaf and after five minutes the dried membrane was carefully peeled off and mounted on a microscopic slide with a drop of water. The stomata were observed and counted using 40 X objective and 10 X eyepiece. The field of the microscope was measured using a stage micrometer and the number of stomata per unit area was calculated (Taylor et al., 1997).

### *3.6.5.5. Biochemical characters*

Biochemical analysis was done at 4 MAP and 8 MAP.

#### 3.6.5.5.1. Rhizome

#### 3.6.5.5.1.1. Curcumin content

Curcumin content of rhizomes was estimated by the official analytical method suggested by Sadasivam and Manickam (1991).

$$\text{Percentage of curcumin} = \frac{0.0025 \times A_{425} \times \text{volume made up} \times \text{dilution factor} \times 100}{0.42 \times \text{weight of sample (g)} \times 1000}$$

since 0.42 absorbance at 425 nm = 0.0025 g curcumin.

#### 3.6.5.5.1.2. Volatile oil

Coarsely ground powder of dried rhizome was used for estimating volatile oil. The method adopted was hydro distillation using clevenger distillation apparatus for three hours. The oil content was expressed in percentage (V/W) on dry weight basis.

#### 3.6.5.5.1.3. Non volatile ether extract

Non volatile ether extract (NVEE) was estimated according to AOAC (1975) and expressed as percentage on dry weight basis.

3.6.5.5.1.4. Crude fibre

The fibre content of the rhizomes was estimated by acid and alkali digestion method (Sadasivam and Manickam, 1991).

3.6.5.5.1.5. Starch

Starch content in dried rhizomes was estimated by the method suggested by Sadasivam and Manikam (1991).

3.6.5.5.1.6. Total carbohydrate

Total carbohydrate was estimated by Anthrone method suggested by Sadasivam and Manikam (1991).

3.6.5.5.1.7. Protein

Protein content was found by estimating Nitrogen content and multiplying by 6.25.

3.6.5.5.2. Leaf

3.6.5.5.2.1. Chlorophyll content (chlorophyll a, chlorophyll b and total chlorophyll)

Photosynthetic pigments namely chlorophyll a, chlorophyll b and total chlorophyll were estimated by the following method described by Starnes and Hadley (1965).

### *3.6.5.6. Soil analysis*

Soil analysis was done initially, after the Experiment I & II and also after the residual study (Experiment III).

### 3.6.5.6.1. Soil physical properties

#### 3.6.5.6.1.1. Bulk density

Bulk density was determined by core method (Gupta and Dakshinamoorthy, 1980).

#### 3.6.5.6.1.2. Water holding capacity

This was determined by wet sieving method (Gupta and Dakshinamoorthy, 1980).

### 3.6.5.6.2. Soil Chemical properties

#### 3.6.5.6.2.1. pH

This was determined by pH meter with electrodes (Jackson, 1973).

#### 3.6.5.6.2.2. EC

Electrical conductivity was read in conductivity bridge.

#### 3.6.5.6.2.3. Organic carbon

Organic carbon was estimated by Walkley and Black's rapid titration method (Jackson, 1973).

#### 3.6.5.6.2.4. Available Nitrogen

Available Nitrogen in soil was determined by Alkaline permanganate method by titrimetric method (Subbiah and Asija,1956).

#### 3.6.5.6.2.5. Available phosphorus

This was determined by Bray No.1 Method using spectro photometer (Jackson 1973).

#### **3.6.5.6.2.6. Available potassium**

Available K was determined using Neutral normal ammonium acetate and available K was read in Flame photometer (Jackson,1973).

Soil analysis was done before and after the experiment.

### ***3.6.5.7. Plant analysis***

#### 3.6.5.7.1. Uptake of major nutrients (N, P, K)

Nitrogen was estimated by Microkjeldahl method (Jackson,1973). For the analysis of P and K, diacid extracts were prepared by digesting 1g of the sample in 15 ml of 2:1 concentrated nitric perchloric acid mixture. Aliquots of digests were taken for the analysis of total P and K. P was dertermined calorimetrically by Vanadomolybdo phosphoric yellow colour method (Jackson, 1973).The yellow colour was read in a spectro photometer (Spectronic 20) at a wavelength of 470 nm. K was estimated using flame photometer. The contents were calculated and expressed in percentage. The uptake of nitrogen, phosphorous and potassium contents by the plant was calculated by the nutrient contents of the plant with respective dry weight of the plant parts and expressed as kg ha$^{-1}$.

### ***3.6.5.8. Nutrient balance sheet***

Nutrient balance sheets were worked out for available N, $P_2O_5$ and $K_2O$ in each year as per the procedure outlined by Sadanandan and Mahapatra (1973). The following parameters were taken into account.

1. Initial status of nutrients in soil (Y) kg ha$^{-1}$
2. Total amount of nutrient added through manures (A) (kg ha$^{-1}$).
3. Amount of nutrient removed by the crop or uptake (B) (kg ha$^{-1}$)

4. Expected nutrient balance C = (Y +A) - (B) (kg ha$^{-1}$)
5. Actual nutrient balance or available nutrient status after the experiment (D) kg ha$^{-1}$
6. Net loss (-) or gain (+) = D - C (kg ha$^{-1}$).

#### *3.6.5.9. Incidence of pest and disease*

Incidence of pests and diseases were noted at regular intervals and timely control measures given.

#### *3.6.5.10. Economics of cultivation / B : C ratio*

The economics of cultivation was worked out after taking into account the cost of cultivation and prevailing market price of kasthuri turmeric. For calculating the cost, the different variable cost items like planting materials, manures, plant protection items, irrigation, labour charges etc. were considered at existing market rate during 2006-2007 and 2007-08.

The net income was calculated as follows :

Net returns (Rs ha$^{-1}$) = Gross income – cost of cultivation.

$$\text{Benefit cost ratio} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

### 3.7. EXPERIMENT III

### Residual effect of different organic manures on succeeding vegetable crop (*Amaranthus* sp.)

The residual effect of different treatments under Experiment I was studied using amaranthus crop. The total green yield of amaranthus were recorded from all treatment plots to study the residual effect.

The data recorded were subjected to analysis of variance technique as applied to RBD (Cochran and Cox, 1965) and the significance was tested by

F. test (Snedecor and Cochran, 1967). Separate analysis for each year and pooled analysis wherever applicable were carried out. Critical difference at one per cent was provided wherever the effects were found to be significant.

## 3.8. EXPERIMENT IV (pot culture study)

### 3.8.1. Effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)

Design: CRD
Material : IISR accession of kasthuri turmeric(*Curcuma aromatica* Salisb.)
Treatments: 16
Replication: 3
No. of pots: 104

#### *3.8.1.1. Treatments*

$T_1$ - *Azospirillum brasilense*
$T_2$ - Arbuscular Mycorrhizal Fungi (AMF) – *Glomus* sp.
$T_3$ - *Pseudomonas fluorescens*
$T_4$ - *Trichoderma harzianum*
$T_5$ - *Azospirillum* + AMF
$T_6$ - *Azospirillum* + *Pseudomonas*
$T_7$ - *Azospirillum* + *Trichoderma*
$T_8$ - AMF + *Pseudomonas*
$T_9$ - AMF + *Trichoderma*
$T_{10}$ - *Pseudomonas* + *Trichoderma*
$T_{11}$ - *Azospirillum* + AMF + *Pseudomonas*
$T_{12}$ - *Azospirillum* + AMF + *Trichoderma*
$T_{13}$ - AMF + *Pseudomonas* + *Trichoderma*
$T_{14}$ - *Pseudomonas* + *Azospirillum* + *Trichoderma*
$T_{15}$ - *Azospirillum* + AMF + *Trichoderma* + *Pseudomonas*
$T_{16}$ - Control
FYM was applied uniformly to all the treatments

# LAYOUT OF EXPERIMENT - IV (POT CULTURE STUDY)

$T_1$ - *Azospirillum brasilense*
$T_2$ - Arbuscular Mycorrhizal Fungi (AMF) – *Glomus* sp.
$T_3$ - *Pseudomonas fluorescens*
$T_4$ - *Trichoderma harzianum*
$T_5$ - *Azospirillum* + AMF
$T_6$ - *Azospirillum* + *Pseudomonas*
$T_7$ - *Azospirillum* + *Trichoderma*
$T_8$ - AMF + *Pseudomonas*
$T_9$ - AMF + *Trichoderma*
$T_{10}$ - *Pseudomonas*+ *Trichoderma*
$T_{11}$ - *Azospirillum* + AMF + *Pseudomonas*
$T_{12}$ - *Azospirillum* + AMF + *Trichoderma*
$T_{13}$ - AMF + *Pseudomonas*+ *Trichoderma*
$T_{14}$ - *Pseudomonas* + *Azospirillum* + *Trichoderma*
$T_{15}$ - *Azospirillum* + AMF + *Trichoderma* + *Pseudomonas*
$T_{16}$ - Control

**REPLICATION I**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $T_2$ | $T_9$ | $T_{12}$ | $T_{15}$ | $T_4$ | $T_7$ | $T_{10}$ | $T_{14}$ |
| $T_5$ | $T_1$ | $T_{11}$ | $T_8$ | $T_{13}$ | $T_3$ | $T_{16}$ | $T_6$ |

**REPLICATION II**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $T_3$ | $T_1$ | $T_{15}$ | $T_{12}$ | $T_9$ | $T_{16}$ | $T_5$ | $T_{14}$ |
| $T_{13}$ | $T_2$ | $T_6$ | $T_7$ | $T_4$ | $T_{10}$ | $T_8$ | $T_{11}$ |

**REPLICATION III**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $T_9$ | $T_{14}$ | $T_{16}$ | $T_1$ | $T_{12}$ | $T_6$ | $T_{13}$ | $T_2$ |
| $T_5$ | $T_{11}$ | $T_{15}$ | $T_4$ | $T_{10}$ | $T_8$ | $T_3$ | $T_7$ |

### *3.8.1.2. Observations*

Observations on morphological characters, yield components, physiological characters , anatomical characters and biochemical characters as in Experiment I was taken.

### *3.8.1.3. Soil biological properties before and after the experiment*

#### 3.8.1.3.1. AMF colonization percentage

AMF colonization percentage was recorded at 15 days interval starting from second month after inoculation for two months.

#### 3.8.1.3.2. Total microbial load

Total microbial load ie, fungal, bacterial and actinomycete load was calculated before and after the experiment. Number of colony forming units (cfu) of microbes were calculated using the formula

$$\text{cfu} = \frac{\text{Average number of colony developed x dilution factor}}{\text{Weight of soil taken}}$$

#### 3.8.1.3.2.1. Total bacterial load

The media used to find bacterial load is nutrient agar

Composition of Nutrient Agar

| | | |
|---|---|---|
| Peptone | - | 5 g |
| Beef extract | - | 3 g |
| Agar | - | 16 g |
| Distilled water | - | 1000 ml |
| pH | - | 7.0 |

### 3.8.1.3.2.2. Total fungal load

The media used was Rose Bengal Agar and the total fungal load was calculated.

Composition of Rose Bengal Agar

Glucose - 10 g
Peptone - 5 g
$K_2HPO_4$ - 1 g
$MgSO_4$ $7H_2O$ - 0.5g
Streptomycin - 30 mg
Agar - 15 g
Rose Bengal - 0.035 g
Distilled water - 1000 ml
pH - 7.0

### 3.8.1.3.2.3. Total actinomycetes load

Total actinomycetes load was calculated using Casein Agar media.

Composition of Casein Agar media.

Starch - 10.0 g
Casein (vitamin free) - 0.3 g
$KNO_3$ - 2.0 g
$Nacl_2$ - 2.0 g
$K_2HPO_4$ - 2.0 g
$MgSO_4$ $7H_2O$ - 0.05g
$CaCo_3$ - 0.02 g
$FeSO_4$ $7H_2O$ - 0.01 g
Agar - 15.0 g
Distilled water - 1000 ml
pH - 7.2

The experimental data were analysed statistically by applying the techniques of analysis of variance as applied to CRD as a pot culture experiment (Panse and Sukhatme, 1985). The CD at one per cent level of significance was provided wherever the effects were found to be significant.

# RESULTS

# 4. RESULTS

The study entitled, "Standardization of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2006-2007 and 2007-2008. The study was taken up as four experiments. The data collected were statistically analyzed and the results of four experimentation and laboratory estimation are presented in this chapter.

## 4.1. EXPERIMENT I

### Laboratory incubation studies of the organic manures

The incubation experiment was conducted to evaluate relative efficiency of different organic sources to release nutrients from soil and their influence on available Nitrogen, phosphorus, potassium and organic carbon. The soil mixed with different levels of organic manures were incubated for a period of sixty days at 60 per cent moisture level and were periodically analyzed and recorded at an interval of 15 days.

### 4.1.1. Available Nitrogen

Table 1 shows the data on available nitrogen content of incubated soil for different periods *viz.,* 0th, 15th, 30th, 45th and 60th day of incubation. Significant variations were observed during all the periods.

Table 1. Effect of organic manures on mineralisation pattern of available N (kg ha$^{-1}$)

| Treatment (t ha$^{-1}$) | 0th DAI | 15th DAI | 30th DAI | 45th DAI | 60th DAI |
|---|---|---|---|---|---|
| Soil alone | 180.60 | 185.20 | 198.20 | 200.10 | 173.25 |
| $F_1$-20.0 | 185.97 | 198.99 | 212.44 | 219.43 | 213.06 |
| $F_2$-30.0 | 198.70 | 201.15 | 215.44 | 220.60 | 225.95 |
| $F_3$-40.0 | 199.03 | 212.33 | 222.93 | 233.10 | 250.92 |
| $V_1$-15.0 | 190.40 | 199.31 | 211.37 | 215.95 | 219.85 |
| $V_2$-20.0 | 195.40 | 200.59 | 215.07 | 230.24 | 223.30 |
| $V_3$-25.0 | 215.31 | 225.11 | 256.62 | 269.39 | 272.40 |
| $C_1$-20.0 | 185.20 | 191.30 | 202.10 | 206.37 | 206.80 |
| $C_2$ -30.0 | 187.30 | 195.44 | 208.61 | 210.72 | 211.63 |
| $C_3$ -40.0 | 189.53 | 200.06 | 219.79 | 222.39 | 230.10 |
| $N_1$-3.00 | 197.04 | 210.20 | 218.15 | 226.54 | 232.25 |
| $N_2$-4.50 | 211.10 | 219.46 | 236.36 | 244.58 | 270.41 |
| $N_3$-6.00 | 220.05 | 240.54 | 260.43 | 269.33 | 289.58 |
| CD | 2.965 | 1.679 | 1.965 | 5.765 | 22.00 |
| SE | 3.13 | 1.005 | 1.375 | 11.84 | 172.49 |

CD Significant at 1% level

The treatment $N_3$ (6.0 t $ha^{-1}$ of neem cake) recorded the maximum available nitrogen content and was significantly superior to all other treatments throughout the incubation period. (Fig 1). During the 0th day of incubation $N_3$ recorded the highest value (220.05 kg $ha^{-1}$) and was significantly superior to all other treatments. This was followed by $V_3$ (215.31 t $ha^{-1}$) and $N_2$ (211.10 kg $ha^{-1}$). Treatment $F_3$ (199.03 kg ha-$^{1}$) was on par with $F_2$ (198.70 kg ha-$^{1}$). The control recorded lowest available nitrogen content (180.6 kg $ha^{-1}$). During the 15th day of incubation highest available nitrogen (240.54 kg $ha^{-1}$) was recorded in treatment $N_3$ and was significantly superior to all other treatments. This was followed by $V_3$ (225.11kg $ha^{-1}$) where $V_3$ was inferior to $N_3$ but superior to all other treatments. The control recorded the lowest available nitrogen (185.2 kg $ha^{-1}$).

During 30th day of incubation treatment $N_3$ recorded highest available nitrogen content (260.43 kg $ha^{-1}$). This was followed by treatments $V_3$, $N_2$ and $F_3$ the values recorded being 256.62, 236.36 and 222.93 kg $ha^{-1}$, respectively. The control recorded the lowest available nitrogen content of 198.20 kg $ha^{-1}$.

During 45th day of sampling $V_3$ treatment recorded the higher mean value for available nitrogen (269.39 kg $ha^{-1}$) and was on par with $N_3$ (269.33 kg $ha^{-1}$). This was followed by $N_2$ (244.58 kg $ha^{-1}$). The treatments $F_3$ and $V_2$ were on par recording available nitrogen of 233.10 and 230.24 kg $ha^{-1}$. $N_1$ and $C_3$ recorded the available nitrogen of 226.54, 222.39 kg $ha^{-1,}$ respectively. The control recorded lowest available nitrogen (200.10 kg $ha^{-1}$). At the last sampling (60th day) also $N_3$ recorded maximum available nitrogen (289.59 kg $ha^{-1}$) and was on par with $V_3$ (272.49 kg $ha^{-1}$) and $N_2$ (270.41 kg $ha^{-1}$). This was followed by $F_3$ (250.92 kg $ha^{-1}$) which was on par with $N_1$ and $C_{3.}$ The control recorded the lowest value (173.25 kg $ha^{-1}$).

### 4.1.2. Available phosphorus

Critical evaluation of data on available $P_2O_5$ content of soil shows significant variations among different treatments and available $P_2O_5$ content showed increasing trend throughout the growth period (Table 2). The treatment $V_3$ recorded the maximum $P_2O_5$ throughout incubation period (Fig 2.). At initial sampling $V_3$ recorded maximum available $P_2O_5$ content of 48.11kg $ha^{-1}$ and was superior to other treatments. Treatment $V_3$ was followed by $F_3$ recording available $P_2O_5$ (45.59 kg $ha^{-1}$) and $V_2$ recorded (43.4 kg $ha^{-1}$). The control recorded lowest available $P_2O_5$ (38.04 kg $ha^{-1}$). On 15th day of incubation $V_3$ recorded the highest mean value of 65.55 kg $ha^{-1}$ of $P_2O_5$. This was superior among all other treatments. This was succeeded by $N_3$ (61.38 kg $ha^{-1}$) which was on par with $C_3$ recording a value of 59.70 kg $ha^{-1}$. The control recorded the lowest available $P_2O_5$ content (42.27 kg $ha^{-1}$). During 30th day of sampling the maximum value was recorded by $V_3$ (81.97 kg $ha^{-1}$) which was on par with $F_3$ (76.33 kg $ha^{-1}$) and $N_3$ (72.68 kg $ha^{-1}$). The control recorded the lowest value (43.78 kg $ha^{-1}$).

On 45th day of sampling the treatment $V_3$ was on par with $N_3$ and recorded the $P_2O_5$ content of 113.68 kg $ha^{-1}$ and 106.86 kg $ha^{-1}$, respectively. Treatment $F_3$ recorded $P_2O_5$ content of 100.01 kg $ha^{-1}$. The control recorded the lowest value (40.34 kg $ha^{-1}$). At 60th day of sampling $V_3$ treatment recorded the highest $P_2O_5$ content and was superior compared to all other treatments recording a value of 124.10 kg $ha^{-1}$. This was followed by $F_3$ (119.97 kg $ha^{-1}$) and $N_3$ (116.98 kg $ha^{-1}$). The control recorded the lowest value (37.87 kg $ha^{-1}$).

### 4.1.3. Available potassium

There was significant variation between treatments with respect to $K_2O$ content (Table 3). The available soil K showed an increasing trend (Fig 3).

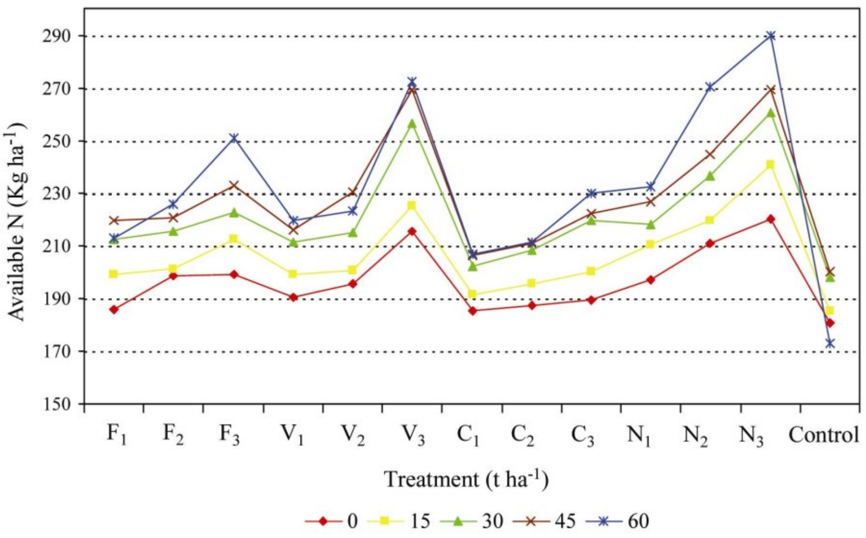


Fig. 1. Effect of organic manures on mineralization pattern of available N (Kg ha$^{-1}$)

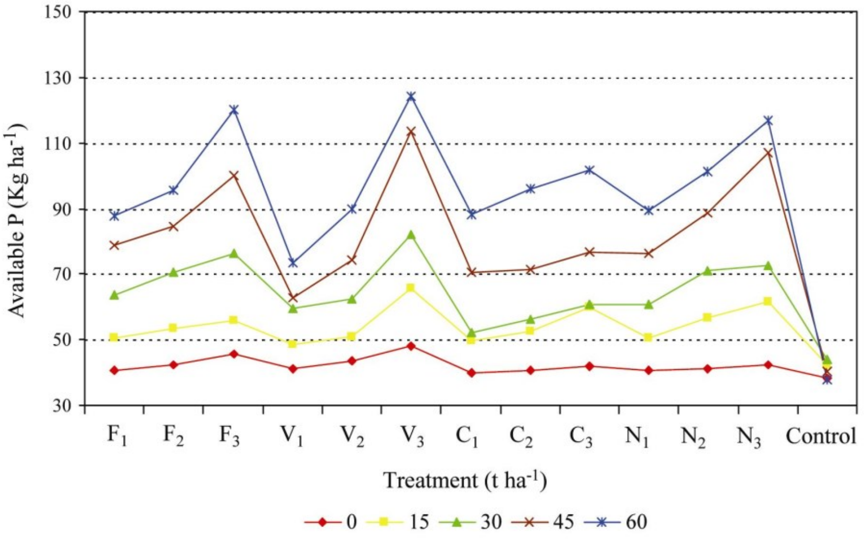


Fig. 2. Effect of organic manures on mineralization pattern of available $P_2O_5$ (kg ha$^{-1}$)

Table 2. Effect of organic manures on mineralisation pattern of available $P_2O_5$ (kg ha$^{-1}$ )

| Treatment | 0th DAI | 15th DAI | 30th DAI | 45th DAI | 60th DAI |
|---|---|---|---|---|---|
| Soil alone | 38.04 | 42.27 | 43.78 | 40.34 | 37.87 |
| $F_1$ -20.0 | 40.65 | 50.60 | 63.40 | 78.56 | 87.55 |
| $F_2$-30.0 | 42.33 | 53.50 | 70.44 | 84.42 | 95.55 |
| $F_3$-40.0 | 45.59 | 55.77 | 76.33 | 100.01 | 119.97 |
| $V_1$-15.0 | 41.08 | 48.62 | 59.33 | 62.58 | 73.50 |
| $V_2$-20.0 | 43.40 | 50.75 | 62.41 | 74.37 | 89.73 |
| $V_3$-25.0 | 48.11 | 65.55 | 81.97 | 113.68 | 124.10 |
| $C_1$-20.0 | 39.87 | 49.67 | 52.28 | 70.45 | 88.29 |
| $C_2$-30.0 | 40.59 | 52.60 | 56.36 | 71.34 | 95.82 |
| $C_3$-40.0 | 41.96 | 59.70 | 60.71 | 76.69 | 101.54 |
| $N_1$-3.00 | 40.81 | 50.54 | 60.60 | 76.09 | 89.31 |
| $N_2$-4.50 | 41.2 | 56.45 | 70.95 | 88.73 | 101.36 |
| $N_3$-6.00 | 42.20 | 61.38 | 72.68 | 106.86 | 116.98 |
| CD | 0.898 | 1.598 | 15.088 | 8.165 | 2.539 |
| SE | 0.287 | 0.550 | 5.189 | 2.808 | 0.873 |

CD Significant at 1% level

Table 3. Effect of organic manures on mineralisation pattern of available $K_2O$ (kg $ha^{-1}$)

| Treatment | $0^{th}$ DAI | $15^{th}$ DAI | $30^{th}$ DAI | $45^{th}$ DAI | $60^{th}$ DAI |
|---|---|---|---|---|---|
| Soil alone | 151.31 | 126.23 | 235.26 | 230.22 | 110.91 |
| $F_1$-20.0 | 169.45 | 218.18 | 280.35 | 231.9 | 261.77 |
| $F_2$-30.0 | 191.33 | 221.26 | 244.09 | 271.67 | 297.87 |
| $F_3$-40.0 | 211.37 | 221.91 | 253.39 | 278.30 | 305.92 |
| $V_1$-15.0 | 171.31 | 199.35 | 221.04 | 231.48 | 260.58 |
| $V_2$-20.0 | 200.14 | 210.54 | 233.88 | 252.08 | 282.63 |
| $V_3$-25.0 | 216.38 | 230.41 | 259.84 | 281.97 | 313.62 |
| $C_1$-20.0 | 185.63 | 200.84 | 256.07 | 250.61 | 280.90 |
| $C_2$ -30.0 | 188.41 | 210.96 | 258.84 | 260.70 | 291.31 |
| $C_3$-40.0 | 219.16 | 222.57 | 261.30 | 271.47 | 305.53 |
| $N_1$-3.00 | 178.63 | 200.56 | 211.613 | 240.78 | 281.03 |
| $N_2$-4.50 | 190.46 | 214.19 | 247.97 | 262.08 | 299.32 |
| $N_3$-6.00 | 206.31 | 224.20 | 256.70 | 278.04 | 310.10 |
| CD | 3.840 | 2.621 | 3.442 | 10.410 | 6.184 |
| SE | 1.275 | 0.901 | 1.184 | 3.579 | 2.127 |

CD Significant at 1% level

During initial sampling g $C_3$ (219.16 kg $ha^{-1}$) recorded highest $K_2O$ content. $C_3$ was on par with $V_3$ (216.38 kg $ha^{-1}$). At 15th day of sampling treatment $V_3$ recorded the highest $K_2O$ content (230.41 kg $ha^{-1}$) and was superior. Treatment $N_3$ (224.2 kg $ha^{-1}$) was on par with $C_3$ (222.57 kg $ha^{-1}$). The control recorded the lowest value of 126.23 kg $ha^{-1}$. At 30th day of sampling treatment $C_3$ recorded highest $K_2O$ content (261.30 kg $ha^{-1}$) which was on par with $V_3$ (259.84 kg $ha^{-1}$) and $C_2$ (258.84 kg $ha^{-1}$). The control recorded the lowest value (110.99 kg $ha^{-1}$). At 45th day of sampling treatment $V_3$ was on par with $N_3$ and $F_3$ recorded $K_2O$ content of 281.97, 278.04 and 278.30. kg $ha^{-1}$, respectively. At 45th day of sampling the control (soil alone) declined in $K_2O$ content. The control recorded lowest value (230.22 kg $ha^{-1}$). At 60th day of sampling $V_3$ treatment was on par with $N_3$ and recorded the highest $K_2O$ content of 313.62 and 310.10 kg $ha^{-1}$, respectively. This was succeeded by treatment $F_3$ (305.92 kg $ha^{-1}$) and $C_3$ (305.53 kg $ha^{-1}$) which were on par. The control recorded the lowest value (235.26 kg $ha^{-1}$).

### 4.1.4. Organic carbon

The organic carbon content was highly influenced by different organic manures (Table 4). The treatments showed significant variation with respect to organic carbon content (Fig 4). Organic carbon content of incubated soil increased up to 15th day of incubation and then showed a declining trend. As expected, control recorded lowest value. During initial sampling (0th day) treatment $V_3$ recorded the highest organic carbon content (0.85 %) and was superior to all other treatments. This was followed by $N_3$ (0.79 %). The treatment $F_3$ and $C_2$ recorded the same value (0.76%). The control recorded the lowest organic carbon content (0.52 %). At 15th day of sampling $V_3$ recorded highest organic carbon content (0.78 %). This was followed $F_3$, $V_2$ and $N_3$ the value obtained was 0.75, 0.70 and 0.68 percent respectively.

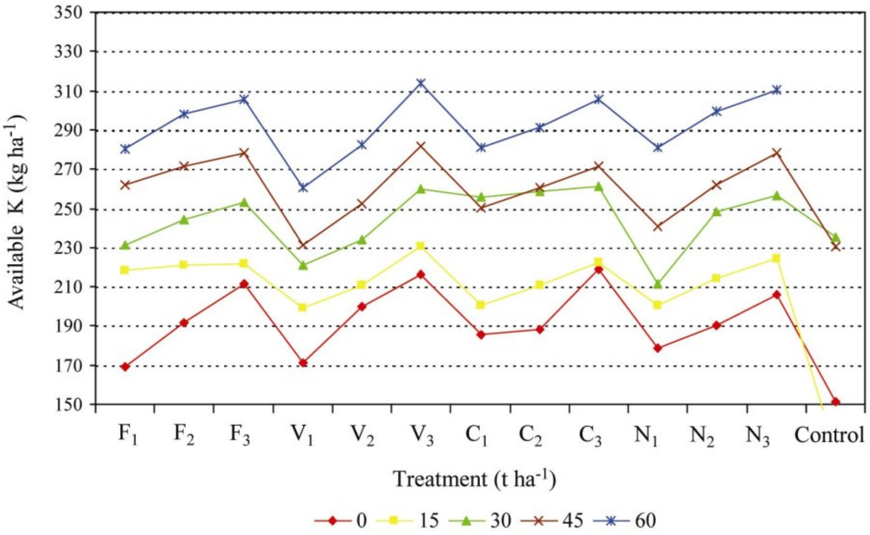


Fig. 3. Effect of organic manures on mineralization pattern of available $K_2O$ (kg ha$^{-1}$)

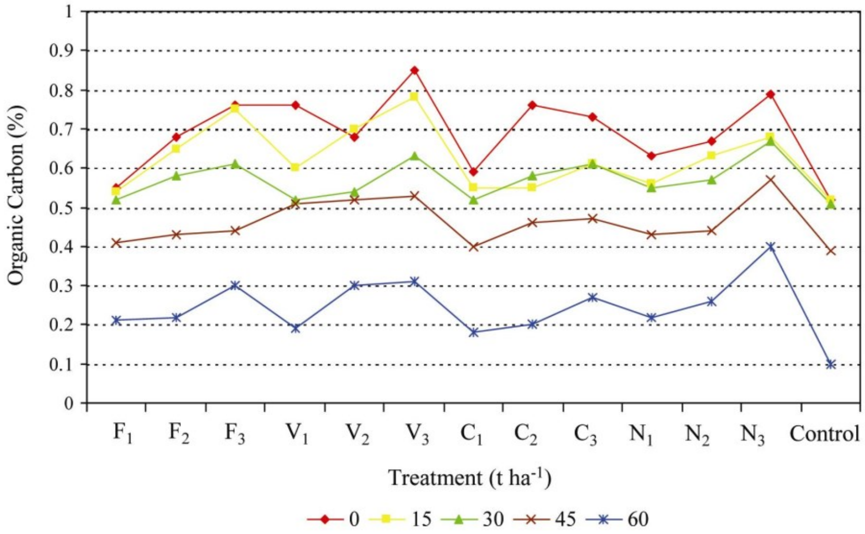


Fig. 4. Effect of organic manures on mineralization pattern of organic carbon (%)

Table 4. Effect of organic manures on mineralisation pattern of organic carbon (%)

| Treatment | 0th DAI | 15th DAI | 30th DAI | 45th DAI | 60th DAI |
|---|---|---|---|---|---|
| Soil alone | 0.52 | 0.52 | 0.51 | 0.39 | 0.10 |
| $F_1$-20.0 | 0.55 | 0.54 | 0.52 | 0.41 | 0.21 |
| $F_2$-30.0 | 0.68 | 0.65 | 0.58 | 0.43 | 0.22 |
| $F_3$-40.0 | 0.76 | 0.75 | 0.61 | 0.44 | 0.30 |
| $V_1$-5.0 | 0.76 | 0.60 | 0.52 | 0.51 | 0.19 |
| $V_2$-20.0 | 0.68 | 0.70 | 0.54 | 0.52 | 0.30 |
| $V_3$-25.0 | 0.85 | 0.78 | 0.63 | 0.53 | 0.31 |
| $C_1$-20.0 | 0.59 | 0.55 | 0.52 | 0.40 | 0.18 |
| $C_2$ -30.0 | 0.76 | 0.55 | 0.58 | 0.46 | 0.20 |
| $C_3$-40.0 | 0.73 | 0.61 | 0.61 | 0.47 | 0.27 |
| $N_1$-3.00 | 0.63 | 0.56 | 0.55 | 0.43 | 0.22 |
| $N_2$-4.50 | 0.67 | 0.63 | 0.57 | 0.44 | 0.26 |
| $N_3$-6.00 | 0.79 | 0.68 | 0.67 | 0.57 | 0.40 |
| CD | 0.019 | 0.018 | 0.060 | 0.021 | 0.028 |
| SE | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |

CD Significant at 1% level

The control recorded the lowest value (0.52 %). At 30th day of sampling $N_3$ recorded the highest organic carbon content (0.67 %) and was on par with $V_3$ (0.63 %). Treatment $C_3$ and $F_3$ recorded the same value (0.61 %). The control recorded least value (0.51 %). At 45th day of sampling also $N_3$ recorded the maximum organic carbon content (0.57 %) and was significantly superior. This was followed by $V_3$ and $V_2$. Treatments $N_2$ and $F_3$ recorded the same value (0.44 %). The control recorded least value (0.39 %). At 60th day of sampling $N_3$ (0.40 %) was significantly superior to other treatments. This was followed by $V_3$ (0.31 %). The control recorded the lowest value (0.10 %).

## 4.2. EXPERIMENT II

### Effect of organic manures on growth, yield and quality of Kasthuri turmeric (*Curcuma aromatica* Salisb.)

The experiment was conducted during two years and the results of two years study and pooled analysis wherever applicable are given below.

### 4.2.1. Growth characters

#### *4.2.1.1. Plant height*

The data presented in Table 5 shows the effect of four organic manures, viz., FYM, vermicompost, coirpith compost and neemcake each at three levels, on height of the plant at different growth stages of crop during 2006-07 and 2007-08, period. Significant differences in plant height were observed throughout the growth stages of the crop during first and second year of experimentation. During the growth of plant in the first year, at 60 DAP, the highest plant height was recorded by the plants given the treatment $V_3$ (Vermicompost 25.0 t $ha^{-1}$) which was on par with $N_3$ (Neemcake 6.0 t $ha^{-1}$) recording a value of 77.25 and 76.36 cm, respectively and they were significantly superior to all other treatments.

Table 5. Effect of organic manures on height of the plant (cm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year |
| $F_1$-20.0 | 54.38 | 62.60 | 69.12 | 73.25 | 112.92 | 127.54 | 115.26 | 132.93 |
| $F_2$-30.0 | 57.20 | 72.22 | 74.76 | 83.46 | 123.80 | 150.64 | 128.89 | 152.48 |
| $F_3$-40.0 | 69.81 | 78.49 | 91.02 | 97.52 | 132.42 | 162.75 | 134.61 | 174.62 |
| $V_1$-15.0 | 58.95 | 66.47 | 66.99 | 75.92 | 119.42 | 133.19 | 120.60 | 143.12 |
| $V_2$-20.0 | 60.56 | 75.91 | 77.25 | 88.74 | 131.68 | 157.65 | 130.72 | 160.33 |
| $V_3$-25.0 | 77.25 | 82.94 | 105.61 | 111.91 | 164.40 | 180.70 | 166.41 | 176.99 |
| $C_1$-20.0 | 52.09 | 60.08 | 68.40 | 69.94 | 105.60 | 119.12 | 103.97 | 131.90 |
| $C_2$-30.0 | 58.40 | 68.66 | 74.36 | 83.96 | 113.69 | 144.51 | 115.66 | 146.06 |
| $C_3$-40.0 | 67.54 | 76.31 | 78.08 | 91.27 | 123.34 | 158.88 | 124.01 | 170.47 |
| $N_1$-3.00 | 56.18 | 64.34 | 75.18 | 76.36 | 116.20 | 129.35 | 122.71 | 138.58 |
| $N_2$-4.50 | 61.26 | 73.64 | 84.99 | 86.46 | 126.48 | 153.61 | 132.07 | 156.24 |
| $N_3$-6.00 | 76.36 | 80.76 | 96.54 | 102.20 | 144.96 | 166.56 | 149.33 | 175.43 |
| Control | 45.17 | 58.33 | 60.50 | 64.53 | 91.50 | 113.22 | 91.57 | 127.62 |
| CD | 2.965 | 0.721 | 7.712 | 4.111 | 10.640 | 0.739 | 11.260 | 1.870 |
| SE | 1.016 | 0.250 | 2.640 | 1.410 | 3.210 | 0.180 | 3.900 | 0.640 |

CD Significant at 1 % level

But during second year, at 60 DAP, $V_3$ was found to be significantly superior to all other treatments and recorded a plant height of 82.94 cm which was succeeded by $N_3$ (80.76 cm). This was followed by $F_3$ - FYM (40.0 t $ha^{-1}$) which recorded plant height of 69.81 and 78.49 cm during first and second year, respectively. The control recorded the least plant height of 45.17 and 58.33 cm during first and second year of experiment, respectively. At 120 DAP, the same trend was followed in both years. $V_3$ was significantly superior and recorded values of 105.61 and 111.91 cm at first and second year, respectively (Plate 5). This was followed by $N_3$ during first and second year of experimentation with a plant height of 96.54 and 102.20 cm, respectively. Treatment $F_3$ succeeded $N_3$ in plant height during first year (91.02 cm) and second year (97.52 cm). The control plants recorded a plant height of 60.50 cm during first year and 64.53 cm during second year. On analyzing the data at 180 DAP, $V_3$ was found significantly superior to all other treatments and recorded a height of 164.40 cm, during first year and 180.70 cm during second year. This was followed by $N_3$ with plant height of 144.96 cm for the first crop and 166.56 cm for second crop. The control plots recorded the least plant heights of 91.50 and 113.22 cm during first and second year of experiment, respectively. At the final stage (240 DAP) the plant height reached to the maximum. $V_3$ was significantly superior and produced tallest plants during first and second year of experimentation, (166.41 and 186.99 cm, respectively). This was followed by $F_3$ (134.61 cm) in the first year which was on par with $N_2$ and $V_2$ recording a plant height of, 132.07 and 130.72 cm, respectively. But during second year, at final harvest stage, treatment $V_3$, was significantly superior and the plant height was 166.41 cm during first year and 186.99 cm during second year. This was succeeded by $N_3$ (149.33 and 175.33cm during first and second year, respectively). The growth was arrested in the control plants with the minimum plant height of 91.57 and 127.62 cm during first and second year, respectively.

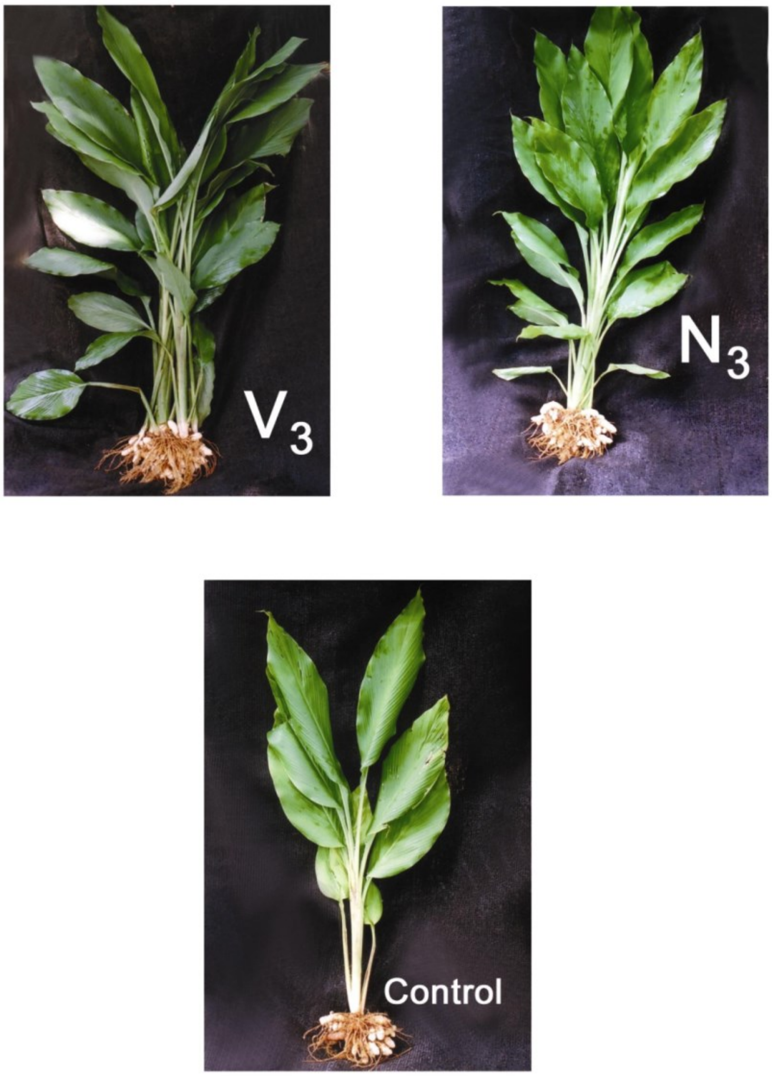


Plate 5. Effect of organic manures on plant growth in *Curcuma aromatica* Salisb. at 120 DAP

### 4.2.1.2. Number of tillers

The effect of various organic manures on number of tillers at different growth stages during the two years of experimentation is presented in Table 6. Application of various organic manures significantly influenced the number of tillers at 60,120, 180 and 240 DAP in the first and second crop. Initially $V_3$ and $N_3$ produced more tillers during both the years which were on par but significantly superior to all other treatments. The number of tillers produced by $V_3$ during first crop was 0.367 and during second crop was 0.47 and $N_3$ produced 0.23 and 0.27 number of tillers during first and second crop, respectively. During the second crop period at 60 DAP, $N_3$ and $F_3$ recorded same tiller number of 0.27.The treatment $C_1$ (coirpith compost 20.0 t ha$^{-1}$) and control did not produce any tillers in both years of experimentation. At 120 DAP also the same trend was noticed where $V_3$ and $N_3$ were on par and significantly superior during both the years. $V_3$ treated plants produced 2.20 and 2.28 number of tillers during first and second crop, respectively whereas $N_3$ recorded a tiller number 2.12 and 2.19 during first and second year of experimentation, respectively. On the other hand,$C_1$ produced less number of tillers during both years, the values being 0.767 during first crop and 0.89 during second crop. On the contrary, the control recorded the least number of tillers during first year (0.633) and second year (0.70). As the growth advanced, at 180 DAP, number of tillers produced were 2.36, 2.25 and 2.23 by the treatments $N_3$, $F_3$ and $V_3$, respectively, in the first year and they were significantly superior to other treatments. But during second year, the treatments $V_3$ and $N_3$ were significantly superior and produced a tiller number of 2.51 and 2.41, respectively. The control recorded least number of tillers during first year (0.187) and during second year (0.192). At 240 DAP during first year, $V_3$ (2.56) and $N_3$ (2.41) recorded significantly higher tiller count. But during second year, the treatment $V_3$ was significantly superior to all other treatments and produced 2.81 number of tillers. This was succeeded by $N_3$ (2.53). The control recorded the least number of tillers(0.98) at the final stage of growth also.

Table 6. Effect of organic manures on number of tillers in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | - | - | 0.790 | 1.000 | 1.090 | 1.060 | 1.170 | 1.090 |
| $F_2$-30.0 | 0.067 | 0.090 | 0.943 | 0.833 | 1.200 | 1.200 | 1.250 | 1.360 |
| $F_3$-40.0 | 0.167 | 0.270 | 1.970 | 1.050 | 2.250 | 2.310 | 2.290 | 2.390 |
| $V_1$-15.0 | 0.067 | 0.110 | 0.967 | 1.030 | 1.040 | 1.110 | 1.200 | 1.163 |
| $V_2$-20.0 | 0.133 | 0.190 | 1.050 | 1.170 | 1.143 | 1.270 | 1.260 | 1.460 |
| $V_3$-25.0 | 0.367 | 0.470 | 2.200 | 2.280 | 2.230 | 2.510 | 2.560 | 2.810 |
| $C_1$-20.0 | - | - | 0.767 | 0.890 | 1.130 | 0.966 | 1.440 | 1.030 |
| $C_2$-30.0 | 0.067 | 0.080 | 1.050 | 1.550 | 1.330 | 1.170 | 1.533 | 1.250 |
| $C_3$-40.0 | 0.100 | 0.120 | 1.470 | 2.000 | 1.830 | 1.910 | 2.150 | 2.280 |
| $N_1$-3.00 | 0.133 | 0.080 | 0.920 | 0.953 | 1.130 | 1.060 | 1.350 | 1.110 |
| $N_2$-4.50 | 0.166 | 0.180 | 1.330 | 2.170 | 1.460 | 1.250 | 1.680 | 1.430 |
| $N_3$-6.00 | 0.233 | 0.270 | 2.120 | 2.190 | 2.360 | 2.410 | 2.410 | 2.530 |
| Control | - | - | 0.633 | 0.700 | 0.850 | 0.928 | 1.030 | 0.980 |
| CD | 0.191 | 0.212 | 0.128 | 0.135 | 0.187 | 0.192 | 0.173 | 0.119 |
| SE | 0.655 | 0.089 | 0.098 | 0.180 | 0.170 | 0.130 | 0.160 | 0.110 |

CD Significant at 1 % level

### *4.2.1.3. Number of leaves*

The effect of different organic manures on the number of leaves at various growth stages during two years of experimentation are presented in Table 7. Perusal of the data clearly indicate that the various organic manures significantly influenced the number of leaves at all stages of growth period. At 60 DAP, during first year of experiment, $V_3$ produced the highest number of leaves (8.37) which was on par with $N_3$ (8.0) and were significantly superior to all other treatments. During second year also, at 60 DAP, $V_3$ was significantly superior compared to all other treatments with 9.83 leaves. This was succeeded by the treatment $N_3$ recording 9.32 number of leaves. The same trend was observed at 120 DAP also where $V_3$ was significantly superior and recorded a number of leaves of 13.92 and 14.70 during first and second year, respectively (Plate 5). During first year, treatments $N_3$, $F_3$ and $C_3$ were on par and gave 12.40, 12.18 and 11.86 number of leaves, respectively. But during second year, at 120 DAP, $V_3$ was succeeded by $N_3$ and recorded a number of leaves of 13.41. At 180 and 240 DAP, $V_3$ and $N_3$ recorded significantly superior mean value during both the years of experimentation. At 180 DAP, the number of leaves recorded by $V_3$ and $N_3$ were 14.47 and 13.98 during first year of experimentation, respectively. During second year $V_3$ and $N_3$ recorded 15.96 and 15.75 number of leaves, respectively. At final stage (240 DAP) also the same trend was obtained. The control recorded the least number of leaves in all growth stages.

### *4.2.1.4. Leaf area*

Effect of different types of organic manures on leaf area are clearly depicted in Table 8. Organic manures had significantly influenced the leaf area throughout the growth stages. At 60 DAP, the maximum leaf area was produced by $V_3$, which was significantly superior to all other treatments and recorded values of 2372.00 and 2379.33 $cm^2$ during first and second year, respectively.

Table 7. Effect of organic manures on number of leaves in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year |
| $F_1$-20.0 | 6.01 | 6.68 | 8.85 | 9.39 | 10.27 | 11.15 | 12.22 | 11.71 |
| $F_2$-30.0 | 6.72 | 7.84 | 10.34 | 10.58 | 11.70 | 13.25 | 12.43 | 14.12 |
| $F_3$-40.0 | 7.69 | 8.78 | 12.18 | 12.81 | 13.21 | 15.23 | 14.23 | 15.81 |
| $V_1$-15.0 | 6.24 | 7.18 | 8.32 | 9.85 | 9.67 | 12.25 | 11.38 | 13.21 |
| $V_2$-20.0 | 6.85 | 8.18 | 10.53 | 11.60 | 12.77 | 14.39 | 12.99 | 14.75 |
| $V_3$-25.0 | 8.37 | 9.83 | 13.92 | 14.70 | 14.47 | 15.96 | 15.05 | 17.77 |
| $C_1$-20.0 | 6.03 | 6.39 | 7.50 | 8.56 | 9.30 | 10.62 | 12.07 | 11.28 |
| $C_2$-30.0 | 6.28 | 7.38 | 9.73 | 10.20 | 10.67 | 13.13 | 12.67 | 13.56 |
| $C_3$-40.0 | 6.66 | 8.43 | 11.86 | 11.94 | 12.21 | 14.84 | 13.32 | 15.33 |
| $N_1$-3.00 | 6.67 | 6.96 | 8.43 | 9.28 | 10.35 | 11.57 | 11.68 | 12.63 |
| $N_2$-4.50 | 7.53 | 7.97 | 10.52 | 11.18 | 12.90 | 14.00 | 13.21 | 14.37 |
| $N_3$-6.00 | 8.00 | 9.32 | 12.40 | 13.41 | 13.98 | 15.75 | 14.99 | 16.28 |
| Control | 4.88 | 6.26 | 6.86 | 8.09 | 8.11 | 10.15 | 9.77 | 10.29 |
| CD | 0.442 | 0.114 | 0.987 | 0.378 | 1.060 | 0.221 | 1.090 | 0.153 |
| SE | 0.151 | 0.005 | 0.338 | 0.126 | 0.363 | 0.070 | 0.368 | 0.044 |

CD Significant at 1 %

Table 8. Effect of organic manures on leaf area (cm$^2$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year |
| $F_1$-20.0 | 1950.56 | 1963.80 | 1987.33 | 1988.67 | 3275.33 | 4235.33 | 4188.33 | 4984.68 |
| $F_2$-30.0 | 2042.31 | 2033.33 | 2059.27 | 2129.93 | 3367.67 | 4442.33 | 4176.33 | 5625.67 |
| $F_3$-40.0 | 2166.67 | 2178.67 | 2201.83 | 2250.17 | 4391.67 | 4663.68 | 5950.33 | 6059.67 |
| $V_1$-15.0 | 1129.50 | 1153.21 | 1185.66 | 1199.67 | 3279.33 | 4315.33 | 4765.00 | 5342.08 |
| $V_2$-20.0 | 2082.30 | 2138.97 | 2186.33 | 2206.33 | 3510.67 | 4549.68 | 5005.90 | 5847.93 |
| $V_3$-25.0 | 2372.00 | 2379.33 | 2394.67 | 2414.00 | 4808.34 | 4841.68 | 6188.73 | 6199.13 |
| $C_1$-20.0 | 1080.70 | 1117.67 | 1130.33 | 1190.33 | 3032.93 | 4145.33 | 4704.06 | 4804.07 |
| $C_2$-30.0 | 2036.33 | 2077.07 | 2079.57 | 2152.90 | 3199.50 | 4367.00 | 4968.50 | 5488.00 |
| $C_3$-40.0 | 2160.53 | 2166.53 | 2191.80 | 2254.47 | 3983.00 | 4600.00 | 5819.73 | 5929.33 |
| $N_1$-3.00 | 1862.33 | 1919.33 | 1880.33 | 1928.67 | 3465.33 | 4279.68 | 4920.66 | 5139.34 |
| $N_2$-4.50 | 2110.00 | 2115.67 | 2133.37 | 2186.70 | 3663.00 | 4507.00 | 5353.66 | 5725.60 |
| $N_3$-6.00 | 2251.33 | 2262.07 | 2271.20 | 2307.87 | 4787.67 | 4789.33 | 6053.33 | 6153.00 |
| Control | 988.30 | 1084.47 | 1031.67 | 1063.67 | 2913.53 | 3912.87 | 3830.33 | 3943.67 |
| CD | 54.17 | 43.62 | 55.23 | 73.26 | 74.73 | 47.98 | 25.96 | 62.63 |
| SE | 18.53 | 14.94 | 18.92 | 8.37 | 25.66 | 16.44 | 26.91 | 21.45 |

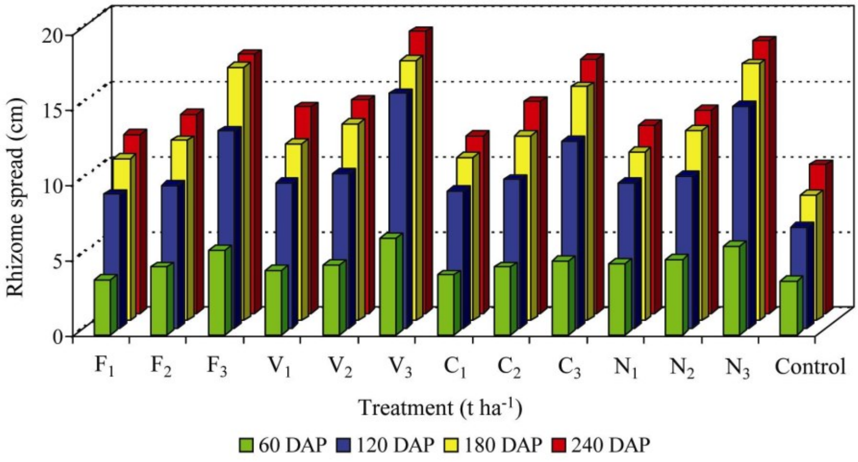
CD Significant at 1 %

At the same stage, treatment $V_3$ was followed by $N_3$ and recorded a leaf area of 2251.33 cm$^2$ in the first crop and 2262.07cm$^2$ in the second crop. The treatment $V_3$ was significantly superior to other treatments, during first and second year of experimentation at 120 DAP and recorded leaf area of 2394.67 and 2414.00cm$^2$, respectively. This was followed by treatment $N_3$ which recorded a leaf area of 2271.20 and 2307.87 cm$^2$ during first and second year, respectively. But at 180 DAP, the treatment $V_3$ was on par with $N_3$ the first year and gave values of 4808.34 and 4786.67 cm$^2$, respectively. This was followed by $F_3$ with a leaf area of 4391.67 cm$^2$. During second year also, $V_3$ was significantly superior and recorded maximum leaf area (4841.68 cm$^2$). This was followed by $N_3$ where the leaf area was 4789.33cm$^2$. This was succeeded by $F_3$ and $C_3$. At 240 DAP also during both the years, plants given the treatment $V_3$ performed best with maximum leaf area (Table 8). This was followed by treatment $N_3$ and $F_3$ which recorded leaf area of 6053.30 cm$^2$ and 5950.33cm$^2$, respectively. During second year at harvest stage, it was observed that $V_3$ was significantly superior but on par with $N_3$ recording a leaf area of 6199.13cm$^2$ and 6153.00 cm$^2$, respectively. This was followed by $F_3$, the leaf area recorded being 6059.67 cm$^2$. At this stage the control recorded the least leaf area of 3830.33 and 3943.67 cm$^2$, during first and second year, respectively.

#### *4.2.1.5. Rhizome spread*

The effect of various organic manure treatments and control on rhizome spread for two years of experimentation are presented in Table 9. There was significant variation in rhizome spread throughout the growth stages for both years (Fig 5). At 60 DAP, $V_3$ was superior and recorded a rhizome spread of 6.44 and 6.61 cm during first and second year, respectively. This was followed by $N_3$ and $F_3$ which were on par in both the years. The control was found to be inferior to all other treatments with a rhizome spread of 3.61 and 3.74 cm during first and second year, respectively.

First year of the study (2006-2007)



Second year of the study (2007-2008)

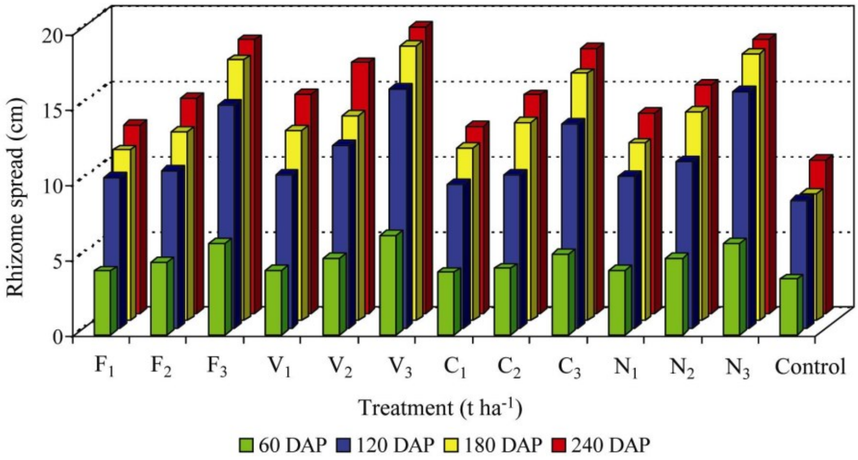


Fig. 5. Effect of organic manures on rhizome spread (cm) in *Curcuma aromatica* Salisb. during first and second year of study

Table 9. Effect of organic manures on rhizome spread. (cm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments ($t\ ha^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 3.70 | 4.27 | 8.87 | 9.95 | 10.76 | 11.32 | 11.85 | 12.45 |
| $F_2$-30.0 | 4.52 | 4.85 | 9.44 | 10.41 | 11.93 | 12.51 | 13.19 | 14.29 |
| $F_3$-40.0 | 5.66 | 6.07 | 13.05 | 14.77 | 16.80 | 17.30 | 17.15 | 18.14 |
| $V_1$-15.0 | 4.29 | 4.34 | 9.65 | 10.14 | 11.69 | 12.61 | 13.68 | 14.54 |
| $V_2$-20.0 | 4.65 | 5.13 | 10.26 | 12.11 | 13.05 | 13.62 | 14.14 | 16.63 |
| $V_3$-25.0 | 6.44 | 6.61 | 15.54 | 15.85 | 17.23 | 18.21 | 18.69 | 18.99 |
| $C_1$-20.0 | 4.00 | 4.19 | 9.07 | 9.53 | 10.83 | 11.43 | 11.75 | 12.37 |
| $C_2$-30.0 | 4.53 | 4.45 | 9.83 | 10.13 | 12.26 | 13.13 | 14.05 | 14.49 |
| $C_3$-40.0 | 4.93 | 5.38 | 12.38 | 13.53 | 15.50 | 16.40 | 16.85 | 17.56 |
| $N_1$-3.00 | 4.76 | 4.31 | 9.61 | 10.08 | 11.19 | 11.77 | 12.47 | 13.26 |
| $N_2$-4.50 | 5.00 | 5.12 | 10.05 | 11.07 | 12.60 | 13.88 | 13.45 | 15.13 |
| $N_3$-6.00 | 5.93 | 6.12 | 14.69 | 15.66 | 17.02 | 17.67 | 18.05 | 18.17 |
| Control | 3.61 | 3.74 | 6.67 | 8.48 | 8.34 | 8.42 | 9.84 | 10.13 |
| CD | 0.390 | 0.129 | 0.328 | 0.456 | 0.363 | 0.327 | 0.243 | 0.560 |
| SE | 1.134 | 0.044 | 0.111 | 0.084 | 0.122 | 0.114 | 0.077 | 0.189 |

CD Significant at 1% level

At 120 DAP, during first year, $V_3$ was significantly superior and recorded a rhizome spread of 15.54cm. This was followed by $N_3$ and $F_3$ where the rhizome spread was 14.69 and 13.05 cm, respectively. During the second year, at same stage, $V_3$ and $N_3$ were significantly superior recording a rhizome spread of 15.85 and 15.66 cm, respectively. This was followed by $F_3$ (14.77cm). The control recorded the least rhizome spread during first crop (6.67 cm) and second crop (8.48 cm ). Data taken at 180 DAP when analyzed showed that $V_3$ and $N_3$ were superior and on par recording rhizome spread of 17.23 and 17.02 cm, respectively in the first year. During second year at this stage, $V_3$ was significantly superior and recorded a rhizome spread of 18.21 cm. This was followed by $N_3$ where the rhizome spread was 17.67 cm. The control recorded the least rhizome spread of 8.34 and 8.42 cm during first and second year, respectively. At 240 DAP, $V_3$ was significantly superior recording a rhizome spread of 18.69 and 18.99 cm during first and second year, respectively. During first year, $V_3$ was followed by $N_3$ and $F_3$ recording a rhizome spread of 18.05 and 17.15cm, respectively. But during second year $N_3$ and $F_3$ were on par and the values were 18.17 and 18.14 cm, respectively. The control recorded the least rhizome spread of 9.84 and 10.13 cm during first and second year, respectively.

#### *4.2.1.6. Rhizome thickness*

The influence of various organic manure on rhizome thickness for both years of study are presented in Table 10. The various organic manures showed significant difference in rhizome thickness throughout the growth stages. At 60 DAP, during first year, $V_3$ was significantly superior compared to all other treatments and recorded a rhizome thickness of 1.57 cm. This was succeeded by treatments $N_3$ and $F_3$ which were on par recording a value of 1.36 and 1.33 cm, respectively. During second year, at 60 DAP, $V_3$ and $N_3$ recorded highest rhizome thickness of 1.49 and 1.47 cm, respectively which were on par. At 120 DAP, during first year, treatments $V_3$ was on par with $N_3$ and $F_3$, recording values of 1.67, 1.60 and 1.56 cm, respectively

Table 10. Effect of organic manures on rhizome thickness (cm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 1.16 | 1.25 | 1.37 | 1.46 | 1.41 | 1.60 | 1.58 | 1.70 |
| $F_2$-30.0 | 1.28 | 1.30 | 1.54 | 1.46 | 1.56 | 1.70 | 1.73 | 1.86 |
| $F_3$-40.0 | 1.33 | 1.36 | 1.56 | 1.63 | 1.83 | 1.95 | 1.99 | 2.27 |
| $V_1$-15.0 | 1.19 | 1.26 | 1.27 | 1.47 | 1.46 | 1.66 | 1.67 | 1.92 |
| $V_2$-20.0 | 1.25 | 1.27 | 1.47 | 1.58 | 1.67 | 1.78 | 1.84 | 1.94 |
| $V_3$-25.0 | 1.57 | 1.49 | 1.67 | 1.77 | 2.07 | 2.29 | 2.23 | 2.62 |
| $C_1$-20.0 | 1.00 | 1.02 | 1.22 | 1.32 | 1.38 | 1.39 | 1.53 | 1.58 |
| $C_2$-30.0 | 1.19 | 1.20 | 1.30 | 1.39 | 1.45 | 1.52 | 1.77 | 1.84 |
| $C_3$-40.0 | 1.30 | 1.38 | 1.42 | 1.61 | 1.77 | 1.87 | 1.90 | 2.09 |
| $N_1$-3.00 | 1.23 | 1.26 | 1.33 | 1.48 | 1.42 | 1.62 | 1.59 | 1.76 |
| $N_2$-4.50 | 1.25 | 1.27 | 1.40 | 1.50 | 1.6 | 1.68 | 1.80 | 1.91 |
| $N_3$-6.00 | 1.36 | 1.47 | 1.60 | 1.66 | 2.0 | 2.19 | 2.13 | 2.42 |
| Control | 0.99 | 1.03 | 1.09 | 1.13 | 1.13 | 1.23 | 1.25 | 1.35 |
| CD | 0.061 | 0.090 | 0.211 | 0.090 | 0.054 | 0.100 | 0.062 | 0.115 |
| SE | 0.017 | 0.031 | 0.017 | 0.031 | 0.017 | 0.031 | 0.017 | 0.045 |

CD Significant at 1% level

. During second year at same stage, $V_3$ was found significantly superior (1.77 cm) when compared to all other treatments. This was followed by $N_3$, $F_3$ and $C_3$ which were on par and the rhizome thickness observed were 1.13, 1.63 and 1.16 cm, respectively. At 180 DAP also, $V_3$ was significantly superior to all other treatments with a rhizome thickness of 2.07 cm during first year and 2.29 cm during second year of crop growth. This was followed by $N_3$ in first and second year of experiment where the rhizome thickness were 2.00 and 2.19 cm, respectively. At 240 DAP, too $V_3$ was superior and recorded the maximum rhizome thickness during first crop (2.23 cm) second crop (2.62 cm). This was followed by $N_3$ recording a rhizome thickness of 2.13 cm during first year and 2.42 cm during second year of experimentation. The control recorded the least value for rhizome thickness at all growth stages.

### *4.2.1.7. Root length*

The effect of various organic manures on root length is presented in Table 11. The effect of organic manures was significant at all stages of growth during both years. During first year, at 60 DAP, the treatment $V_3$ was found significantly superior compared to all other treatments and recorded the highest root length of 13.70 cm. This was succeeded by $N_3$ recording a root length of 13.08 cm. During second year, $V_3$ and $N_3$ were on par and significantly superior than other treatments and recorded a root length of 14.36 cm and 14.20 cm, respectively. $V_3$ was found significantly superior and recorded maximum root length at 120 DAP during first and second year with a value of 16.77 and 17.74 cm, respectively. This was followed by $N_3$ where the root length recorded were 16.17 and 17.35 cm during first and second year, respectively. At 180 DAP, $V_3$ (19.70 cm) was significantly superior and on par with $N_3$ (18.83 cm) during first year Root length recorded by $V_3$ was maximum (20.51 cm) during second year. At 240 DAP also $V_3$ recorded significantly the highest root length of 21.81 cm and 22.64 cm during the first and second year of experimentation, respectively.

Table 11. Effect of organic manures on root length (cm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 9.98 | 10.87 | 12.67 | 13.53 | 13.52 | 14.56 | 15.20 | 16.36 |
| $F_2$-30.0 | 10.68 | 11.72 | 13.10 | 14.08 | 14.40 | 16.16 | 17.02 | 17.38 |
| $F_3$-40.0 | 12.71 | 13.32 | 15.72 | 16.49 | 15.15 | 18.78 | 19.33 | 20.30 |
| $V_1$-15.0 | 11.10 | 11.89 | 13.17 | 14.56 | 14.59 | 15.48 | 16.27 | 16.61 |
| $V_2$-20.0 | 11.91 | 12.71 | 14.86 | 15.87 | 15.66 | 16.57 | 17.65 | 18.41 |
| $V_3$-25.0 | 13.70 | 14.36 | 16.77 | 17.74 | 19.70 | 20.51 | 21.81 | 22.64 |
| $C_1$-20.0 | 9.74 | 10.24 | 12.41 | 13.20 | 13.38 | 13.75 | 14.56 | 15.55 |
| $C_2$-30.0 | 10.17 | 10.65 | 12.94 | 14.02 | 15.06 | 15.68 | 16.21 | 17.26 |
| $C_3$-40.0 | 11.77 | 12.35 | 13.26 | 14.44 | 16.51 | 17.49 | 18.40 | 19.40 |
| $N_1$-3.00 | 11.56 | 11.71 | 13.15 | 14.0 | 14.25 | 15.08 | 16.15 | 17.27 |
| $N_2$-4.50 | 12.14 | 12.58 | 14.51 | 15.36 | 15.45 | 16.57 | 17.26 | 18.47 |
| $N_3$-6.00 | 13.08 | 14.20 | 16.17 | 17.35 | 18.83 | 19.68 | 20.72 | 21.55 |
| Control | 8.93 | 9.40 | 9.32 | 10.18 | 10.72 | 10.72 | 13.49 | 14.39 |
| CD | 0.212 | 0.355 | 0.188 | 0.352 | 2.750 | 0.407 | 0.208 | 0.298 |
| SE | 0.071 | 0.114 | 0.063 | 0.114 | 0.944 | 0.141 | 2.250 | 0.100 |

CD Significant at 1% level

This was succeeded by $N_3$ where the root length observed were 13.49 cm and 14.39 cm for first and second year of crop growth, respectively Control recorded the least root length during first and second year of study throughout all growth stages of the crop.

#### ***4.2.1.8. Root spread***

Table 12 presents the effect of various organic manures on root spread of the crop. The effect of organic manures was significant at all stages of growth during both years of study. At 60 DAP, during first year of experiment, $V_3$ was significantly superior among all other treatments and recorded the maximum root spread of 4.68 cm. This was followed by $N_3$ and $F_3$ where root spread were 4.26 and 4.06 cm, respectively. During second year, $V_3$ and $N_3$ were on par and recorded the maximum root spread of 4.89 cm by $V_3$ and 4.65 cm by $N_3$. At 120 DAP $V_3$ and $N_3$ were on par recording the maximum root spread of 6.28 and 6.08 cm, respectively, in the first year. This was followed by $F_3$ (5.18cm). During second year, $V_3$ was significantly superior and recorded the maximum root spread of 6.79 cm when compared to all other treatments. This was followed by $N_3$ where the root spread was 6.47 cm. At 180 DAP, during first and second years of experiment, $V_3$ was significantly superior which recorded a root spread of 10.62 cm and 11.64 cm, respectively. $V_3$ was followed by $N_3$ and $F_3$ and recorded a root spread of 10.38 and 9.88 cm, respectively in the first year. At 180 DAP, during second year, also the same trend was followed where $V_3$ was succeeded by $N_3$ and $F_3$ with a mean root spread of 11.40 and 10.51 cm, respectively. At the final stage (240 DAP) during first year and second year, $V_3$ was on par with $N_3$. $V_3$ recorded a root spread of 15.61 and 16.65 cm during first and second year, respectively, whereas $N_3$ recorded a value of 15.30 and 16.64cm during first and second year of experimentation, respectively. The control recorded a least root spread from the initial stage to the final harvest stages of the crop during both the years of study.

Table 12. Effect of organic manures on root spread (cm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 2.21 | 2.38 | 3.07 | 3.34 | 6.03 | 6.54 | 10.34 | 11.31 |
| $F_2$-30.0 | 3.17 | 3.71 | 3.61 | 4.34 | 6.75 | 7.14 | 12.07 | 13.15 |
| $F_3$-40.0 | 4.06 | 4.52 | 5.18 | 5.79 | 9.88 | 10.51 | 14.90 | 15.69 |
| $V_1$-15.0 | 2.33 | 2.77 | 3.12 | 3.87 | 6.47 | 6.76 | 10.59 | 11.50 |
| $V_2$-20.0 | 3.64 | 3.83 | 4.39 | 4.70 | 7.08 | 7.75 | 11.78 | 12.96 |
| $V_3$-25.0 | 4.68 | 4.89 | 6.28 | 6.79 | 10.62 | 11.64 | 15.61 | 16.65 |
| $C_1$-20.0 | 2.10 | 2.17 | 2.98 | 3.13 | 5.64 | 6.68 | 10.21 | 11.23 |
| $C_2$-30.0 | 2.38 | 2.52 | 4.10 | 4.24 | 6.98 | 7.06 | 10.69 | 11.44 |
| $C_3$-40.0 | 3.13 | 3.51 | 4.99 | 5.76 | 9.54 | 10.29 | 14.47 | 15.45 |
| $N_1$-3.00 | 2.31 | 2.63 | 4.06 | 4.14 | 6.23 | 6.66 | 10.53 | 11.69 |
| $N_2$-4.50 | 2.53 | 3.68 | 4.48 | 4.65 | 7.02 | 7.54 | 12.12 | 13.51 |
| $N_3$-6.00 | 4.26 | 4.65 | 6.08 | 6.47 | 10.38 | 11.40 | 15.30 | 16.64 |
| Control | 1.03 | 1.51 | 2.77 | 3.07 | 5.67 | 5.91 | 8.53 | 8.94 |
| CD | 0.286 | 0.268 | 0.242 | 0.209 | 0.146 | 0.205 | 0.322 | 0.358 |
| SE | 0.095 | 0.100 | 0.095 | 0.083 | 0.045 | 0.083 | 0.111 | 0.136 |

CD Significant at 1% level

### *4.2.1.9. Root weight*

The effect of various organic manures on root weight at different growth stages of the crop is presented in Table 13. At 60 DAP, root weight of plants in $V_3$ treated plots was significantly superior when compared to all other treatments. The root weight was found to be 0.676 and 0.833 g plant$^{-1}$ during the first and second year of study, respectively. This was followed by $N_3$ and $F_3$ (Table 13). At 120 DAP also $V_3$ was found to be significantly superior than other treatments during both the years .The root weight recorded by $V_3$ in first crop was 1.03 g plant$^{-1}$ and second crop was 1.19 g plant$^{-1}$. At the same stage, $N_3$ was followed by $V_3$ which recorded a root weight of 0.90 g plant$^{-1}$ during first year and 0.963 g plant$^{-1}$ during second year. This was succeeded by $F_3$ and $C_3$ (Table 13). The same trend was observed at 180 DAP as well, where $V_3$ was significantly superior recording a root weight of 1.54 and 1.55 g plant $^{-1}$ during first and second year, respectively. This was followed by $N_3$ where the weight of roots observed were 1.27 g plant $^{-1}$ during first year and 1.33 g plant$^{-1}$ during second year of experimentation. At 240 DAP also $V_3$ was significantly superior and recorded values of 1.76 g plant$^{-1}$ and 1.95 g plant$^{-1}$ in first and second year, respectively. This was followed by $N_3$ with root weight of 1.56 g plant $^{-1}$ and 1.80 g plant $^{-1}$ during first and second year, respectively. During first year, $N_3$ was followed by $F_3$ and $C_3$ where the root weight recorded were 1.243 and 1.124 g plant$^{-1}$, respectively. But in second year, $F_3$ and $C_3$ were on par recording a root weight of 1.143 and 1.13 g plant$^{-1}$, respectively. The control recorded least root weight throughout the growth stages.

### *4.2.1.10. Number of fingers*

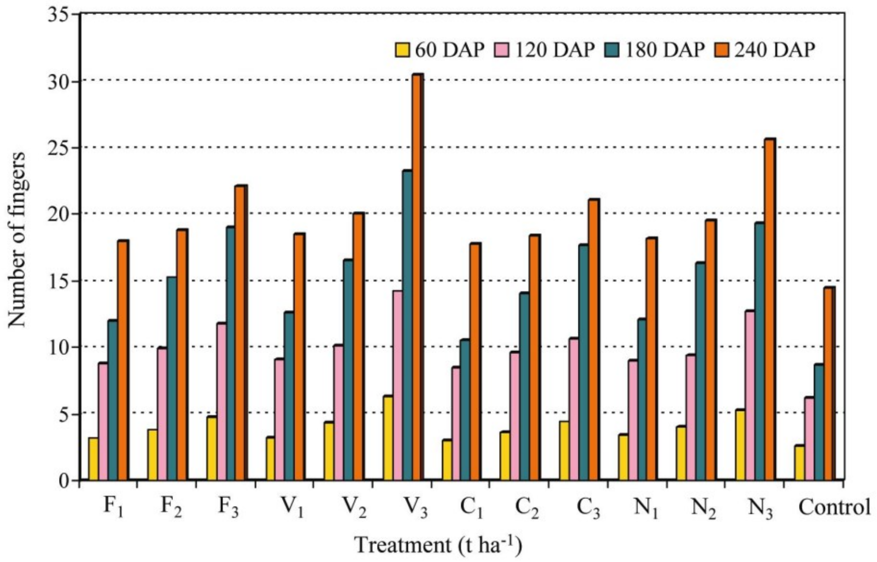
The influence of different levels of various organic manures on number of fingers are presented in Table 14. Organic manures significantly influenced the number of fingers in both the years of experimentation (Fig 6).

Table 13. Effect of organic manures on root weight (gm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 0.293 | 0.343 | 0.376 | 0.467 | 0.570 | 0.630 | 0.670 | 0.720 |
| $F_2$-30.0 | 0.417 | 0.483 | 0.530 | 0.637 | 0.730 | 0.823 | 0.957 | 0.993 |
| $F_3$-40.0 | 0.507 | 0.643 | 0.840 | 0.927 | 1.020 | 1.060 | 1.243 | 1.143 |
| $V_1$-15.0 | 0.233 | 0.367 | 0.466 | 0.620 | 0.576 | 0.650 | 0.850 | 0.930 |
| $V_2$-20.0 | 0.456 | 0.580 | 0.686 | 0.757 | 0.880 | 0.930 | 1.110 | 1.610 |
| $V_3$-25.0 | 0.676 | 0.833 | 1.030 | 1.193 | 1.540 | 1.550 | 1.760 | 1.950 |
| $C_1$-20.0 | 0.203 | 0.293 | 0.307 | 0.380 | 0.450 | 0.580 | 0.620 | 0.710 |
| $C_2$-30.0 | 0.253 | 0.320 | 0.350 | 0.467 | 0.530 | 0.630 | 0.780 | 0.830 |
| $C_3$-40.0 | 0.436 | 0.51 | 0.763 | 0.823 | 0.970 | 1.030 | 1.123 | 1.130 |
| $N_1$-3.00 | 0.313 | 0.410 | 0.417 | 0.530 | 0.627 | 0.723 | 0.750 | 0.810 |
| $N_2$-4.50 | 0.523 | 0.537 | 0.607 | 0.673 | 0.780 | 0.820 | 1.08 | 1.120 |
| $N_3$-6.00 | 0.536 | 0.563 | 0.900 | 0.963 | 1.270 | 1.330 | 1.560 | 1.800 |
| Control | 0.089 | 0.133 | 0.170 | 0.203 | 0.273 | 0.203 | 0.483 | 0.550 |
| CD | 0.025 | 0.070 | 0.036 | 0.109 | 0.026 | 0.070 | 0.025 | 0.157 |
| SE | 0.017 | 0.026 | 0.031 | 0.031 | 0.017 | 0.017 | 0.017 | 0.054 |

CD Significant at 1% level

First year of the study (2006-2007)



Second year of the study (2007-2008)

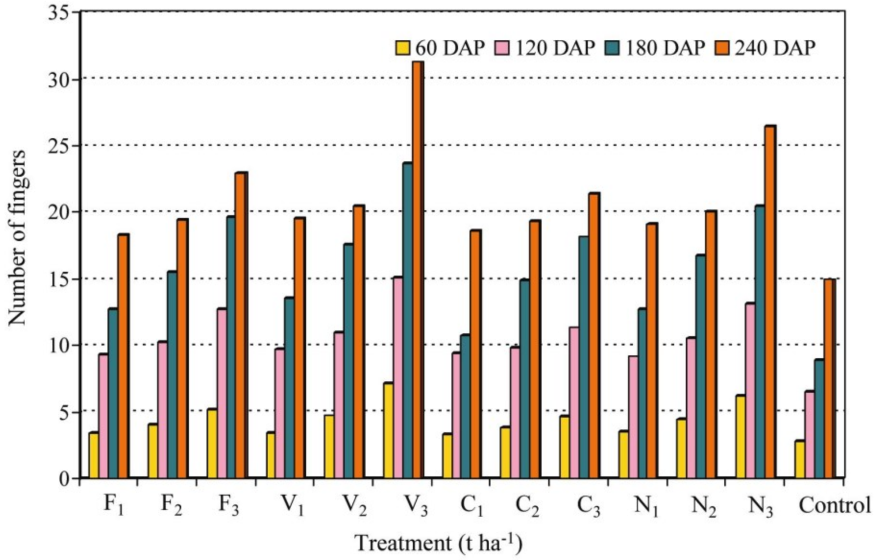


Fig. 6. Effect of organic manures on number of fingers in *Curcuma aromatica* Salisb. during first and second year of study

Table 14. Effect of organic manures on number of fingers in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|
| | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year | Ist Year | IInd Year | |
| $F_1$-20.0 | 3.14 | 3.36 | 8.81 | 9.25 | 11.98 | 12.71 | 17.96 | 18.25 | 18.11 |
| $F_2$-30.0 | 3.75 | 3.98 | 9.90 | 10.21 | 15.23 | 15.44 | 18.83 | 19.37 | 19.10 |
| $F_3$-40.0 | 4.70 | 5.16 | 11.80 | 12.65 | 18.96 | 19.59 | 22.14 | 22.95 | 22.55 |
| $V_1$-15.0 | 3.18 | 3.43 | 9.07 | 9.73 | 12.63 | 13.54 | 18.52 | 19.50 | 19.01 |
| $V_2$-20.0 | 4.30 | 4.68 | 10.13 | 10.90 | 16.49 | 17.56 | 19.99 | 20.43 | 20.21 |
| $V_3$-25.0 | 6.30 | 7.10 | 14.19 | 15.07 | 23.20 | 23.63 | 30.51 | 31.24 | 30.88 |
| $C_1$-20.0 | 2.99 | 3.26 | 8.44 | 9.39 | 10.50 | 10.77 | 17.76 | 18.60 | 18.80 |
| $C_2$-30.0 | 3.59 | 3.78 | 9.58 | 9.83 | 14.05 | 14.84 | 18.36 | 19.35 | 18.86 |
| $C_3$-40.0 | 4.38 | 4.60 | 10.63 | 11.30 | 17.63 | 18.12 | 21.05 | 21.39 | 21.22 |
| $N_1$-3.00 | 3.36 | 3.54 | 8.98 | 9.13 | 12.09 | 12.73 | 18.15 | 19.08 | 18.62 |
| $N_2$-4.50 | 4.04 | 4.45 | 9.38 | 10.57 | 16.28 | 16.77 | 19.48 | 20.04 | 19.76 |
| $N_3$-6.00 | 5.23 | 6.14 | 12.68 | 13.13 | 19.29 | 20.45 | 25.61 | 26.46 | 26.04 |
| Control | 2.58 | 2.76 | 6.15 | 6.52 | 8.63 | 8.85 | 14.44 | 14.92 | 29.36 |
| CD | 0.223 | 0.181 | 0.475 | 0.427 | 0.801 | 0.804 | 0.600 | 0.681 | NS |
| SE | 0.071 | 0.054 | 0.164 | 0.054 | 0.274 | 0.275 | 0.205 | 0.233 | - |

CD Significant at 1% level

$V_3$ was found to be significantly superior and recorded the maximum number of fingers throughout the different growth stages of the crop. At 60 DAP, $V_3$ was superior and recorded a value of 6.30 during first crop and 7.10 during second crop. This was followed by $N_3$ where the number of fingers were 5.23 during first year and 6.14 during second year .$N_3$ was succeeded by $F_3$ (Table 14). As the plants grow and at 120 DAP, $V_3$ was significantly superior when compared to all other treatments and gave a number of fingers of 14.19 and 15.07 during first and second year, respectively. This was followed by treatment $N_3$ and $F_3$. At 180 DAP, treatment $V_3$ was significantly superior than other treatments in recording number of fingers. The number of fingers recorded by $V_3$ during first year was 23.20 and during second year was 23.63. This was followed by $N_3$ with 19.29 and 20.45 number of fingers during first and second year of experiment, respectively At this stage the control recorded least number of fingers of 8.63 during first year and 8.85 fingers during second year. At 240 DAP $V_3$ was significantly superior and recorded maximum number of fingers of 30.51 and 31.24 during first and second year of experiment, respectively. At 240 DAP, $N_3$ recorded number of fingers of 25.61 and 26.46 in first crop and second crop, respectively. This was followed by treatments $F_3$ and $C_3$ and $V_2$ in both first and second year of study (Table 15). The control recorded the least number of fingers during first crop (14.44) and second crop (14.92) at the final stage of crop growth. The pooled data analyzed for this character was found to be non significant.

### 4.2.2. Yield and yield components

#### *4.2.2.1. Rhizome yield (fresh)*

The influence of different sources of organic manures on fresh rhizome yield is presented in Table 15.

Table 15. Effect of organic manures on fresh rhizome yield ( g plant$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

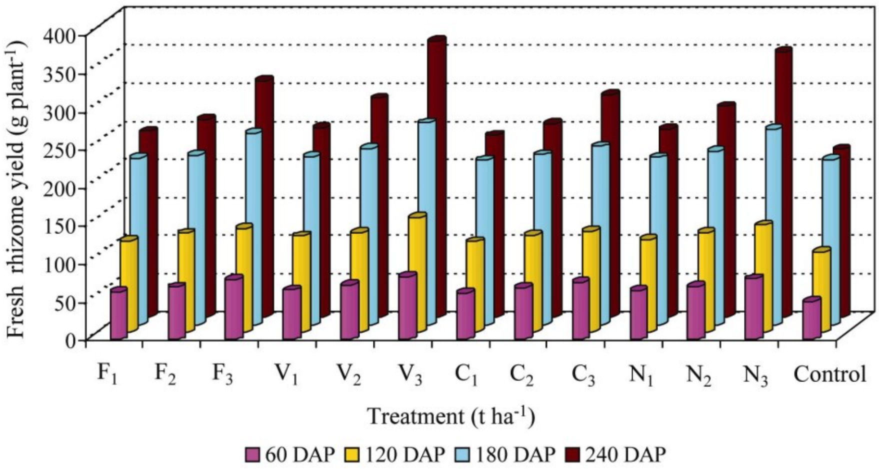
| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$Year | |
| $F_1$-20.0 | 62.79 | 63.90 | 120.37 | 123.71 | 218.51 | 244.15 | 243.98 | 255.64 | 249.81 |
| $F_2$-30.0 | 69.21 | 70.23 | 130.09 | 130.65 | 222.30 | 259.76 | 259.43 | 260.81 | 260.12 |
| $F_3$-40.0 | 78.85 | 79.70 | 136.62 | 136.87 | 251.21 | 310.26 | 309.91 | 347.66 | 328.79 |
| $V_1$-15.0 | 65.19 | 66.95 | 126.44 | 126.74 | 220.89 | 221.18 | 248.67 | 227.34 | 238.00 |
| $V_2$-20.0 | 71.43 | 72.45 | 131.24 | 131.52 | 231.39 | 287.54 | 287.27 | 291.18 | 289.23 |
| $V_3$-25.0 | 82.97 | 86.45 | 150.79 | 150.89 | 262.88 | 363.22 | 364.95 | 396.33 | 379.64 |
| $C_1$-20.0 | 60.56 | 61.40 | 118.86 | 119.03 | 216.14 | 238.64 | 238.99 | 245.91 | 242.32 |
| $C_2$-30.0 | 68.21 | 69.13 | 127.45 | 127.77 | 222.86 | 254.54 | 254.48 | 278.14 | 256.31 |
| $C_3$-40.0 | 75.69 | 76.18 | 132.94 | 133.17 | 233.73 | 292.29 | 291.86 | 307.81 | 299.84 |
| $N_1$-3.00 | 64.48 | 65.21 | 122.22 | 122.50 | 219.49 | 246.42 | 246.28 | 268.33 | 257.31 |
| $N_2$-4.50 | 69.89 | 71.36 | 130.31 | 130.78 | 227.62 | 277.17 | 276.38 | 280.46 | 278.42 |
| $N_3$-6.00 | 80.15 | 80.81 | 140.45 | 140.55 | 257.16 | 348.19 | 347.91 | 377.63 | 362.77 |
| Control | 50.42 | 50.73 | 105.27 | 105.53 | 216.52 | 220.78 | 220.25 | 225.64 | 222.95 |
| CD | 1.367 | 1.050 | 3.449 | 4.302 | 3.300 | 9.540 | 9.430 | 10.140 | 11.130 |
| SE | 0.467 | 0.357 | 1.181 | 1.473 | 1.131 | 3.270 | 3.230 | 3.760 | 2.590 |

CD Significant at 1% level

Among the various organic manures tried, the fresh rhizome yield was found to be highly significant at all growth stages of the crop (Fig 7). At 60 DAP, $V_3$ was found to be significantly superior when compared to all other treatments during both the years. The fresh rhizome yield recorded by $V_3$ was 82.97 g plant$^{-1}$ during first year and 86.45 g plant$^{-1}$ in second year. $V_3$ was followed by $N_3$ and $F_3$ which were on par recording a fresh rhizome yield of 80.15 and 78.85 g plant$^{-1}$, respectively in the first year. During second year $V_3$ was succeeded by $N_3$ where rhizome yield observed was 80.81g plant$^{-1}$. $N_3$ was followed by $F_3$ and $C_2$ which recorded a fresh rhizome yield of 79.70 g plant$^{-1}$ and 76.18 plant$^{-1}$, respectively. $C_1$ recorded a lower fresh rhizome yield of 60.56 and 61.40 g plant$^{-1}$ for first and second year, respectively. The control recorded the least fresh rhizome yield of 50.42 and 50.73 g plant$^{-1}$ during first and second year of crop growth, respectively. At 120 DAP, the fresh rhizome yield observed was maximum in $V_3$ in first year (150.79 ) and also at second year ( 150.89 g plant$^{-1}$) of experimentation. $V_3$ was succeeded by $N_3$ where the fresh rhizome yield was 140.45 g plant$^{-1}$ for first crop and 140.55 g plant$^{-1}$ for second crop. $C_1$ recorded the least fresh rhizome yield of 118.86 and 119.03 g plant$^{-1}$ during first and second year of experimentation, respectively. The fresh rhizome yield obtained from control plots were the least in both the years of study.

At 180 DAP also the fresh rhizome yield was maximum from $V_3$ treated plots which recorded 262.88 g plant$^{-1}$ for first crop and 363.22 g plant$^{-1}$ for second crop. This was followed by treatment $N_3$ and $F_3$ in both the years (Table 15). Here also the control recorded the least fresh rhizome yield of 216.52 g plant$^{-1}$ and 220.78 g plant$^{-1}$ during first and second year, respectively. At the harvest stage (240 DAP) the same trend was noticed and $V_3$ recorded a maximum fresh rhizome yield of 364.95 and 396.33 g plant$^{-1}$ during first and second year of experimentation, respectively. This was followed by $N_3$ and $F_3$ in recording fresh rhizome yield. At the final

First year of the study (2006-2007)



Second year of the study (2007-2008)

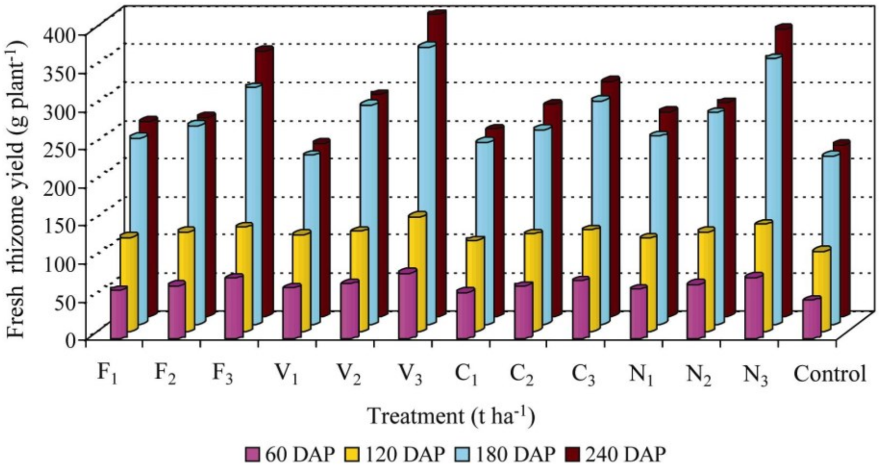


Fig. 7. Effect of organic manures on fresh rhizome yield (g plant$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

stage, $N_3$ recorded a fresh rhizome yield of 347.91 and 377.63 g plant$^{-1}$ during first and second year respectively, whereas $F_3$ recorded a fresh rhizome yield of 309.91g plant$^{-1}$ during first year and 347.66g plant$^{-1}$ during second year. As in the previous stages, at the final stage also, $C_1$ recorded lowest fresh rhizome yield of 238.64 and 245.91g plant$^{-1}$ during first and second year, respectively. At the final harvest stage, the control recorded the least fresh rhizome yield of 220.25 and 225.64 g plant$^{-1}$ during first and second year, respectively (Plate 6).

The data on fresh rhizome yield obtained from first and second year of experimentation were pooled and the mean yield is presented in Table 15. Pooled analysis showed that there were significant differences in fresh rhizome yield during both the years. The pooled mean showed that $V_3$ was significantly superior to all other organic manure treatments and recorded at fresh rhizome yield of 379.64 g plant$^{-1}$. This was closely followed by $N_3$ (362.77g plant$^{-1}$), $F_3$ (328.79g plant$^{-1}$), $C_3$ (299.84g plant$^{-1}$) and $V_2$ (289.23 g plant$^{-1}$). The pooled analysis also showed that $V_1$ recorded the lowest fresh rhizome yield of 238.0g plant$^{-1}$ which was inferior to all other treatments, with the control giving the least yield (222.95g plant$^{-1}$).

#### *4.2.2.2. Rhizome yield (dry)*

Table 16 represents the effect of different levels of various organic manures on dry rhizome yield, which was found to be significant at all growth stages of the crop in first and second year of the study. At 60 DAP, in the first year, $V_3$ was significantly superior when compared to all other treatments and recorded a dry rhizome yield of 18.27 g plant $^{-1}$. This was followed by $N_3$ and $F_3$ and both recorded the same dry rhizome yield of 15.61g plant$^{-1}$. During second year also at 60 DAP, $V_3$ was significantly superior with a dry rhizome yield of 19.61g plant$^{-1}$. This was followed by $N_3$ (17.82 g plant$^{-1}$) and $F_3$ (16.86 g plant$^{-1}$). At this growth stage, the control recorded the lowest dry rhizome yield of 10.50 g plant$^{-1}$ and 11.23 g plant$^{-1}$ in the first and second year, respectively.

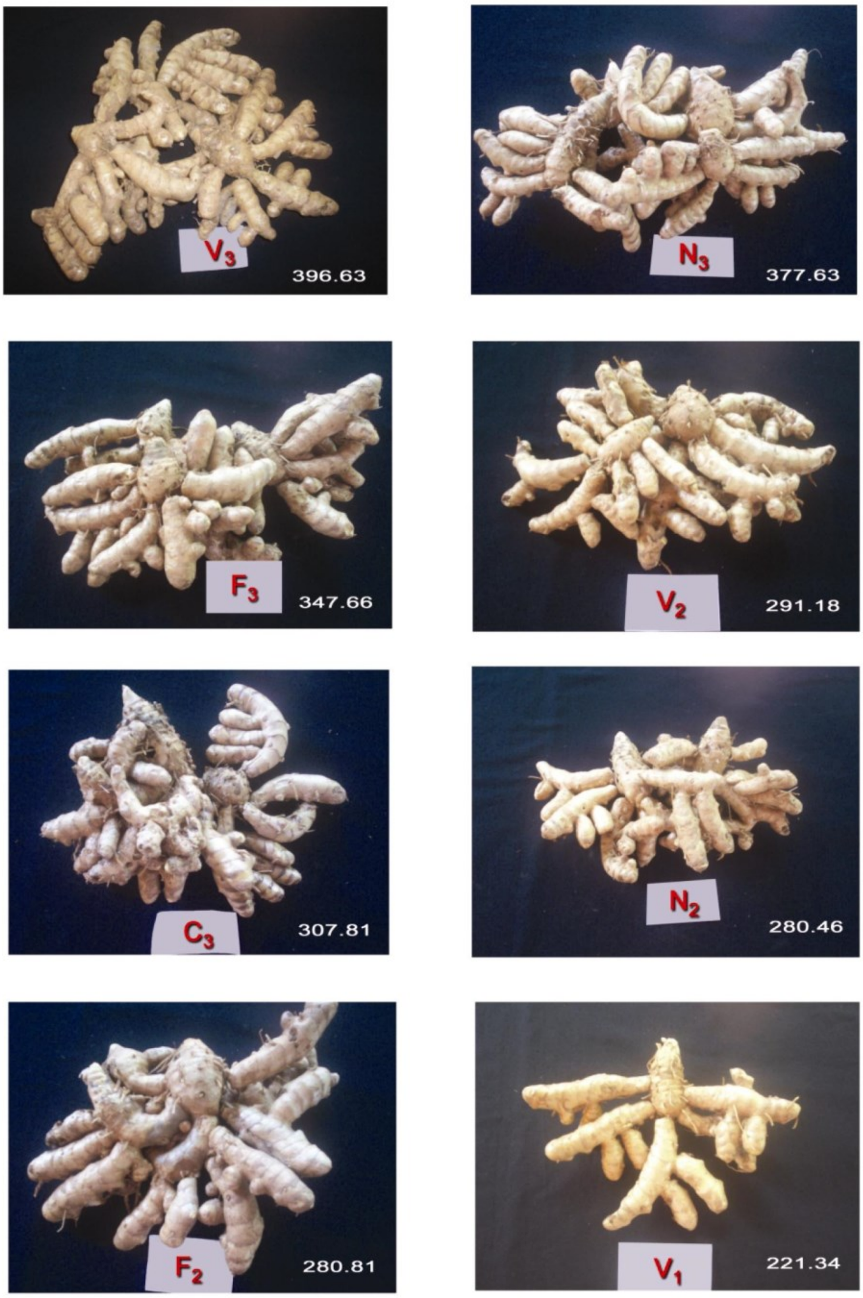


Plate 6. Effect of organic manures on rhizome yield (g plant$^{-1}$) in *Curcuma aromatica* salisb. (second crop)

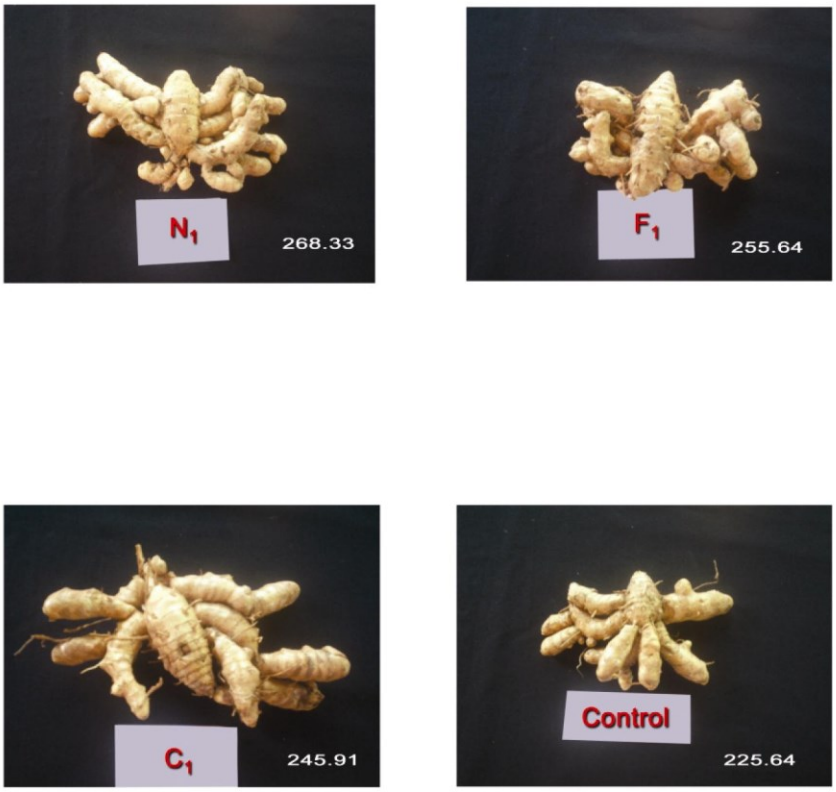


Plate 6. (Contd....)

Table 16. Effect of organic manures on dry rhizome yield (g plant$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 12.26 | 13.37 | 24.48 | 25.54 | 43.83 | 44.63 | 46.09 | 47.44 | 46.77 |
| $F_2$-30.0 | 13.24 | 14.39 | 26.17 | 27.54 | 44.96 | 45.62 | 51.40 | 52.71 | 52.05 |
| $F_3$-40.0 | 15.61 | 16.86 | 27.36 | 28.55 | 49.47 | 50.12 | 61.32 | 62.25 | 61.79 |
| $V_1$-15.0 | 12.42 | 13.50 | 24.95 | 25.62 | 44.28 | 44.77 | 47.49 | 48.66 | 48.08 |
| $V_2$-20.0 | 14.00 | 15.22 | 27.19 | 28.14 | 47.26 | 45.19 | 55.20 | 57.40 | 56.30 |
| $V_3$-25.0 | 18.27 | 19.61 | 29.65 | 32.70 | 54.30 | 56.15 | 69.66 | 72.69 | 71.18 |
| $C_1$-20.0 | 11.27 | 12.21 | 23.28 | 24.52 | 42.58 | 43.74 | 45.06 | 46.49 | 45.77 |
| $C_2$-30.0 | 13.08 | 14.37 | 25.47 | 26.77 | 45.33 | 46.37 | 48.74 | 49.39 | 49.04 |
| $C_3$-40.0 | 14.19 | 15.36 | 26.62 | 27.40 | 48.36 | 49.20 | 57.65 | 58.48 | 58.07 |
| $N_1$-3.00 | 12.83 | 13.69 | 24.51 | 25.79 | 44.69 | 45.76 | 47.78 | 48.74 | 48.26 |
| $N_2$-4.50 | 14.11 | 15.32 | 26.26 | 27.45 | 46.33 | 47.29 | 55.33 | 56.35 | 55.84 |
| $N_3$-6.00 | 15.61 | 17.82 | 29.36 | 30.28 | 52.37 | 53.31 | 70.43 | 71.06 | 70.75 |
| Control | 10.50 | 11.23 | 17.49 | 17.65 | 37.96 | 38.60 | 44.34 | 45.13 | 44.74 |
| CD | 0.847 | 0.805 | 2.220 | 1.052 | 1.792 | 2.320 | 1.880 | 1.860 | 1.870 |
| SE | 0.289 | 0.275 | 0.758 | 0.688 | 0.614 | 2.097 | 0.641 | 0.640 | 0.890 |

CD Significant at 1% level

$V_3$ recorded a higher rhizome yield of 29.65 g plant$^{-1}$, when the yield data were taken at 120 DAP in the first year but was on par with $N_3$ (29.36 g plant$^{-1}$). This was followed by $F_3$, $C_3$ treatments with a dry rhizome yield of 27.36 and 26.62 g plant$^{-1}$, respectively. During second year $V_3$ was significantly superior to all other treatments at the same stages and recorded a dry rhizome yield of 32.70g plant$^{-1}$. This was followed by $N_3$ and $F_3$ which recorded a rhizome yield of 30.28 and 28.55 g plant$^{-1}$, respectively. At this stage, the control recorded the lowest dry rhizome yield of 17.49 g plant$^{-1}$ and 17.65 g plant$^{-1}$ in the first and second year, respectively. At 180 DAP $V_3$ gave significantly superior dry rhizome yield of 54.30 and 56.15 g plant$^{-1}$ during first and second year, respectively. This was followed by $N_3$ in both years (Table 16). The control recorded lowest value of 37.96 and 38.60 g plant$^{-1}$ during first and second year, respectively. But at 240 DAP $N_3$ and $V_3$ was significantly superior to all other treatments but on par in the first year and recorded dry rhizome yield of 70.40 and 69.66 g plant$^{-1,}$ respectively. This was followed by $V_3$ in the first year (69.66 g plant$^{-1}$) and $N_3$ (71.06g plant$^{-1}$) in the second year. The control recorded the lowest value in both the years.

The dry rhizome yield obtained from first and second year of experimentation were pooled, statistically analyzed and the mean yield is presented in Table 16. There were significant differences among the various treatments with respect to dry rhizome yield during both the years. The pooled mean showed that $V_3$ and $N_3$ were on par and significantly superior to all other treatments and recorded a dry rhizome yield of 71.18 and 70.75 g plant$^{-1}$ respectively. This was followed by $F_3$ with a pooled dry yield of 61.79g plant$^{-1}$. The pooled analysis also revealed that as in individual analysis, control recorded the least dry rhizome yield of 44.74 g plant$^{-1}$.

### *4.2.2.3. Top yield*

Top yield of kasthuri turmeric at 120 DAP and 180 DAP for first and second year are depicted in Table 17. Top yield recorded at 120 DAP when analyzed, $V_3$ was found to be significantly superior to all other treatments in the first year. The top yield recorded by $V_3$ was 27.18 g plant$^{-1}$. This was followed by $N_3$ and recorded a top yield of 26.11 g plant$^{-1}$. During second year, $V_3$ and $N_3$ were on par recording top yield of 27.83 and 27.45 g plant$^{-1}$, respectively. At 180 DAP also $V_3$ treatment was found to be significantly superior recording a top yield of 21.83 g plant$^{-1}$during first year. This was followed by $N_3$ which recorded a top yield of 20.73 g plant$^{-1}$. At second year also, at the same stage of growth, $V_3$ recorded the highest top yield (23.75 g plant$^{-1}$) which was significantly superior to all other treatments. This was followed by $N_3$ with a top yield of 22.06g plant$^{-1}$. The control recorded lowest top yield when compared to the different treatments at all growth stages.

### *4.2.2.4. Crop duration*

The data on crop duration for the first and second year of experimentation are depicted in Table 18.

Significant differences were observed among various levels of different organic manures in crop duration. The crop took minimum number of days for attaining maturity when the treatment $V_3$ was given and gave values of 221.43 days and 222.58 days in the first and second year, respectively. This was followed by $F_3$ (223.43) and $N_3$ (224.52) which were on par with each other in the first year. During second year of experiment $V_3$ was followed by $N_3$ which took 223.13 days for attaining maturity. In both the years the control took more number of days to harvest (i.e) a high crop duration of 232.23 days and 234.13 days during the first and second year, respectively.

Table 17. Effect of organic manures on top yield (g plant-1) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments ($t\ ha^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I<sup>st</sup> Year | II<sup>nd</sup> Year | I<sup>st</sup> Year | II<sup>nd</sup> Year |
| $F_1$-20.0 | 16.42 | 17.11 | 12.26 | 13.52 |
| $F_2$-30.0 | 20.75 | 21.69 | 15.61 | 16.80 |
| $F_3$-40.0 | 24.81 | 26.20 | 19.01 | 20.03 |
| $V_1$-15.0 | 19.50 | 20.48 | 14.69 | 16.06 |
| $V_2$-20.0 | 21.84 | 22.99 | 17.22 | 18.23 |
| $V_3$-25.0 | 27.18 | 27.83 | 21.83 | 23.75 |
| $C_1$-20.0 | 15.74 | 16.79 | 12.43 | 13.52 |
| $C_2$-30.0 | 19.21 | 20.41 | 13.57 | 14.76 |
| $C_3$-40.0 | 22.62 | 23.68 | 18.29 | 19.39 |
| $N_1$-3.00 | 17.53 | 18.35 | 16.82 | 18.07 |
| $N_2$-4.50 | 21.38 | 22.44 | 18.37 | 19.37 |
| $N_3$-6.00 | 26.11 | 27.45 | 20.73 | 22.06 |
| Control | 11.51 | 12.31 | 11.45 | 12.72 |
| CD | 1.041 | 0.926 | 1.560 | 1.569 |
| SE | 0.341 | 0.317 | 0.533 | 0.538 |

CD Significant at 1% level

Table 18. Effect of organic manures on crop duration (days) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatment (t ha$^{-1}$) | Experiment I | Experiment II |
|---|---|---|
| $F_1$-20 .0 | 229.00 | 229.83 |
| $F_2$-30 .0 | 227.42 | 228.27 |
| $F_3$-40 .0 | 223.43 | 224.60 |
| $V_1$-15.0 | 227.36 | 228.23 |
| $V_2$-20.0 | 226.70 | 227.27 |
| $V_3$ -25.0 | 221.43 | 222.58 |
| $C_1$-20 .0 | 229.43 | 228.39 |
| $C_2$-30.0 | 228.03 | 227.53 |
| $C_3$-40.0 | 226.50 | 226.47 |
| $N_1$-3.00 | 226.23 | 226.80 |
| $N_2$-4.50 | 225.95 | 225.43 |
| $N_3$-6.00 | 224.52 | 223.13 |
| Control | 232.23 | 234.13 |
| CD | 0.885 | 2.529 |
| SE | 0.303 | 0.866 |

CD Significant at 1% level

### 4.2.3. Physiological parameters

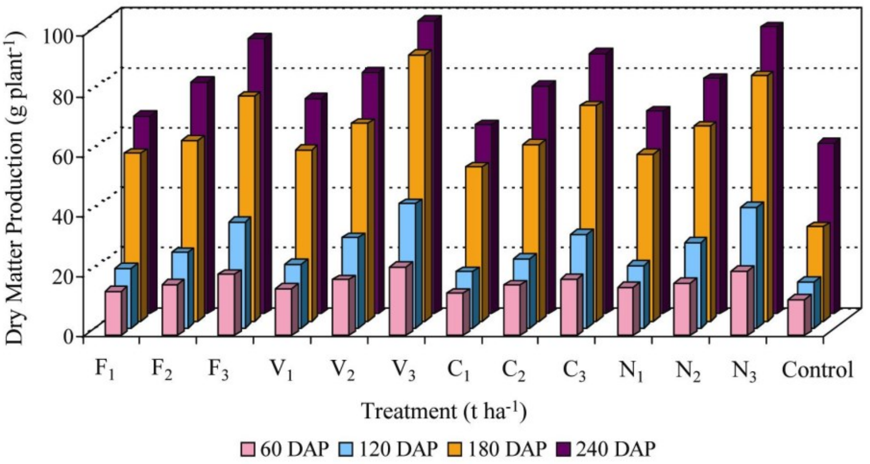
#### *4.2.3.1. Dry Matter Production (DMP)*

The dry matter production recorded at various stages of growth during first and second year are presented in Table 19. During first year, at 60 DAP $V_3$ produced the highest DMP (22.84 g plant$^{-1}$), which was found to be significantly superior (Fig 8). This was followed by $N_3$ (21.57 g plant$^{-1}$) and $F_3$ 20.40 g plant$^{-1}$. During second year $V_3$ and $N_3$ were on par and significantly superior and recorded DMP of 29.79 and 22.65 g plant$^{-1}$), respectively. As growth enhanced and observations taken at 120 DAP, the plants given $V_3$ and $N_3$ gave significantly higher DMP were on par. $V_3$ produced a DMP of 41.42 g plant$^{-1}$ during first year and 43.07 g plant$^{-1}$ during second year of experimentation, but $N_3$ gave values of 40.47 g plant$^{-1}$ and 41.59 g plant$^{-1}$ during first and second year respectively. At 180 DAP also $V_3$ gave a maximum value of DMP during first year (88.54 g plant$^{-1}$) and second year (89.39 g plant$^{-1}$) which were superior to all other treatments. This was followed by $N_3$ and $F_3$ in both the years. At the final stage of growth ( 240 DAP) during both the years $V_3$ and $N_3$ were superior and recorded a DMP of 97.49 and 95.45 g plant$^{-1}$ during first year of experiment, respectively. During second year, $V_3$ recorded 99.48 and $N_3$ 97.44 g plant$^{-1}$ DMP. The control recorded the least DMP in all the growth stages.

#### *4.2.3.2. Leaf area index (LAI)*

The effect of organic manures on Leaf Area Index was significant at 60, 120, 180 and 240 DAP at both years of experiment (Table 20). During first year, at 60 DAP, $V_3$ recorded maximum LAI of 2.64 which was significantly superior to all other treatments. This was followed by $N_3$ and $F_3$ recording a LAI of 2.50 and 2.41, respectively.

First year of the study (2006-2007)



Second year of the study (2007-2008)

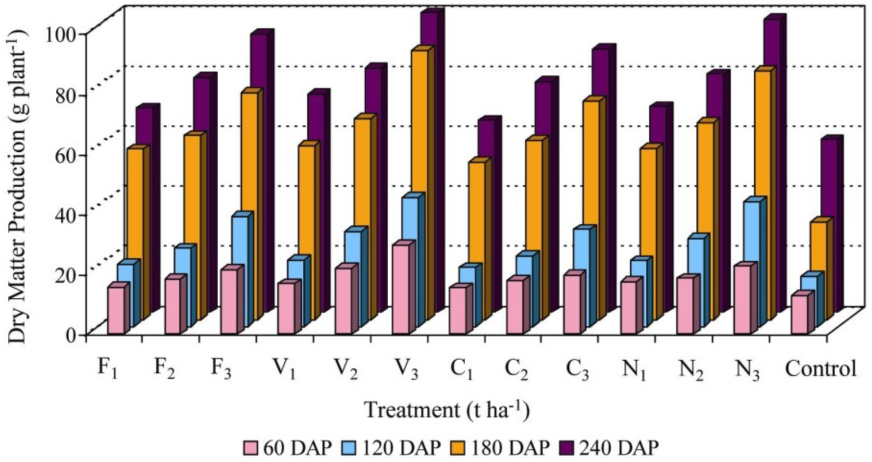


Fig. 8. Effect of organic manures on Dry Matter Production (g plant$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

Table 19. Effect of organic manures on dry matter production.(g plant$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 14.89 | 15.82 | 19.89 | 20.91 | 55.76 | 56.77 | 65.70 | 67.73 | 66.72 |
| $F_2$-30.0 | 17.08 | 18.35 | 25.23 | 26.18 | 60.11 | 61.21 | 76.98 | 77.98 | 72.08 |
| $F_3$-40.0 | 20.40 | 21.52 | 35.53 | 36.76 | 74.74 | 75.57 | 91.56 | 92.39 | 77.48 |
| $V_1$-15.0 | 15.73 | 16.81 | 21.32 | 22.40 | 56.80 | 57.78 | 71.59 | 72.57 | 96.98 |
| $V_2$-20.0 | 18.63 | 21.90 | 30.27 | 31.72 | 65.67 | 66.74 | 80.31 | 81.20 | 80.76 |
| $V_3$-25.0 | 22.84 | 29.79 | 41.42 | 43.07 | 88.54 | 89.39 | 97.49 | 99.48 | 98.49 |
| $C_1$-20.0 | 14.12 | 15.37 | 18.86 | 19.74 | 51.31 | 52.47 | 62.86 | 63.81 | 63.33 |
| $C_2$-30.0 | 16.89 | 17.89 | 23.06 | 23.65 | 58.61 | 59.58 | 75.73 | 76.62 | 76.18 |
| $C_3$-40.0 | 18.98 | 19.89 | 31.36 | 32.37 | 71.60 | 72.61 | 86.57 | 87.48 | 87.03 |
| $N_1$-3.00 | 16.03 | 17.58 | 20.85 | 22.01 | 55.46 | 56.98 | 67.27 | 68.25 | 67.76 |
| $N_2$-4.50 | 17.60 | 18.69 | 28.48 | 29.42 | 64.85 | 65.64 | 78.16 | 79.17 | 78.67 |
| $N_3$-6.00 | 21.57 | 22.65 | 40.47 | 41.59 | 81.52 | 82.76 | 95.45 | 97.44 | 91.44 |
| Control | 11.98 | 13.01 | 15.39 | 16.84 | 31.42 | 32.43 | 56.60 | 57.41 | 57.00 |
| CD | 0.689 | 8.280 | 1.120 | 1.151 | 1.804 | 1.185 | 3.240 | 3.353 | 3.190 |
| SE | 0.237 | 2.837 | 0.385 | 0.394 | 0.618 | 0.634 | 1.109 | 1.134 | 1.650 |

CD Significant at 1% level

Table 20. Effect of organic manures on leaf area index (LAI) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments ($t\ ha^{-1}$) | 60 DAP | | 120 DAP | | 180 DAP | | 240 DAP | |
|---|---|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 2.16 | 2.46 | 2.20 | 2.50 | 3.65 | 3.71 | 4.65 | 5.05 |
| $F_2$-30.0 | 2.26 | 2.63 | 2.28 | 2.65 | 3.74 | 3.81 | 5.52 | 5.64 |
| $F_3$-40.0 | 2.41 | 2.81 | 2.44 | 2.96 | 4.87 | 4.91 | 6.56 | 6.74 |
| $V_1$-15.0 | 1.30 | 1.35 | 1.31 | 1.41 | 3.63 | 3.66 | 5.26 | 5.40 |
| $V_2$-20.0 | 2.28 | 2.55 | 2.43 | 2.65 | 3.90 | 3.69 | 5.54 | 5.66 |
| $V_3$-25.0 | 2.64 | 2.88 | 2.66 | 3.11 | 5.44 | 5.60 | 6.85 | 6.96 |
| $C_1$-20.0 | 1.20 | 1.50 | 1.91 | 1.52 | 3.37 | 3.45 | 5.22 | 5.29 |
| $C_2$-30.0 | 2.23 | 2.54 | 2.31 | 2.55 | 3.55 | 3.69 | 5.52 | 5.71 |
| $C_3$-40.0 | 2.28 | 2.67 | 2.43 | 2.67 | 4.42 | 4.61 | 6.46 | 6.69 |
| $N_1$-3.00 | 2.07 | 2.05 | 2.28 | 2.13 | 3.85 | 3.91 | 5.46 | 5.61 |
| $N_2$-4.50 | 2.34 | 2.36 | 2.36 | 2.40 | 4.06 | 4.20 | 5.94 | 6.00 |
| $N_3$-6.00 | 2.50 | 2.97 | 2.52 | 3.02 | 5.17 | 5.28 | 6.72 | 6.83 |
| Control | 1.11 | 1.20 | 1.14 | 1.23 | 3.22 | 3.31 | 4.25 | 4.38 |
| CD | 0.105 | 0.388 | 0.324 | 0.276 | 0.136 | 0.292 | 0.045 | 0.128 |
| SE | 0.032 | 0.134 | 0.032 | 0.055 | 0.045 | 0.010 | 0.014 | 0.100 |

CD Significant at 1% level

During second year, $N_3$ recorded the highest LAI (2.97) which was on par with $V_3$ (2.88) and $F_3$ (2.81). At 120 DAP, $V_3$ and $N_3$ were found on par where the LAI was 2.66, and 2.52, respectively in the first year. During second year also $V_3$ recorded maximum LAI with a mean value of 3.11. However, $V_3$ was on par with $N_3$ and $F_3$ recording a LAI of 3.02 and 2.96, respectively. At 180 DAP also the treatment $V_3$ recorded highest LAI of 5.44 and was found significantly superior to all other treatments. This was followed by $N_3$ and $F_3$ which were on par. $V_3$ was found significantly superior recording LAI of 5.6 in the second crop as well. This was followed by $N_3$, $F_3$ and $C_3$ recording a LAI of 5.28, 4.91 and 4.61, respectively. At the final harvesting stage also (240 DAP) $V_3$ was found to be significantly superior to other treatments in both the years of crop growth.$V_3$ recorded a LAI of 6.85 during first year and 6.96 during second year. This was followed by $N_3$ and $F_3$, where LAI recorded were 6.72 and 6.56 during first year of experimentation, respectively. During second year also, $V_3$ was followed by $N_3$ which was on par with $F_3$ and LAI recorded were 6.83 and 6.74, respectively. The control recorded the least LAI of 4.25 and 4.38 during first and second year, respectively.

### *4.2.3.3. Crop growth rate (CGR)*

Table 21 shows the effect of various treatments on the crop growth rate for both years of experimentation. Significant variations could be observed in CGR. During first and second year, of experimentation, between 60-120 DAP and 120-180 DAP generally an increasing trend in CGR was noticed from initial phase. However, at the final stage (180-240 DAP) CGR was lower. During first year between 60-120 DAP $V_3$ was on par with $N_3$ and the CGR was 3.619 $gm^{-2}$ $day^{-1}$ and 3.484 $gm^{-1}$ $day^{-1}$, respectively. This was followed by $F_3$ recording CGR of 2.792 $gm^{-1}$ $day^{-1}$. During second year between 60-120 DAP $N_3$ was on par with $V_3$ recording CGR of 4.104 $gm^{-1}$ $day^{-1}$ and 4.040 $gm^{-1}$ $day^{-1}$, respectively.

Table 21. Effect of organic manure of crop growth rate (CGR) (gm$^{-2}$ day$^{-1}$) in *Curcuma aromatica* Salisb.during first and second year of study

| Treatments (t ha$^{-1}$) | 60 -120 DAP | | 120-180 DAP | | 180-240 DAP | |
|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 0.915 | 1.060 | 4.879 | 4.800 | 1.998 | 1.468 |
| $F_2$-30.0 | 1.501 | 1.650 | 4.884 | 4.710 | 2.229 | 2.130 |
| $F_3$-40.0 | 2.792 | 3.230 | 5.007 | 5.540 | 2.235 | 2.560 |
| $V_1$-15.0 | 1.046 | 1.060 | 3.481 | 3.015 | 2.517 | 1.536 |
| $V_2$-20.0 | 2.067 | 2.330 | 5.029 | 4.550 | 2.642 | 1.675 |
| $V_3$-25.0 | 3.619 | 4.040 | 5.793 | 6.619 | 4.013 | 1.880 |
| $C_1$-20.0 | 0.857 | 0.949 | 4.954 | 3.110 | 2.251 | 1.552 |
| $C_2$-30.0 | 1.115 | 1.158 | 5.177 | 4.600 | 2.374 | 2.120 |
| $C_3$-40.0 | 2.166 | 2.515 | 5.286 | 5.230 | 2.483 | 2.168 |
| $N_1$-3.00 | 0.887 | 0.784 | 4.549 | 4.010 | 1.619 | 1.846 |
| $N_2$-4.50 | 2.001 | 1.968 | 4.879 | 4.320 | 1.675 | 2.359 |
| $N_3$-6.00 | 3.484 | 4.104 | 4.930 | 5.840 | 1.806 | 2.350 |
| Control | 0.626 | 0.714 | 1.549 | 1.280 | 1.476 | 1.450 |
| CD | 0.280 | 0.594 | 0.795 | 0.399 | 0.613 | 0.516 |
| SE | 0.097 | 0.202 | 0.272 | 0.138 | 0.209 | 0.173 |

CD Significant at 1% level

This was followed by $F_3$ and $C_3$ the values being, 2.515 and 2.330 $gm^{-2}$ $day^{-1}$, respectively. Between 120-180 DAP the CGR recorded by $V_3$ (5.793 $gm^{-2}$ $day^{-}1$) was on par with $C_3$ and $C_2$ the values being 5.286 and 5.177 $gm^{-2}$ $day^{-1}$, in the first year, respectively. During second year also between 120-180 DAP $V_3$ was significantly superior and recorded the highest CGR of 6.619 $gm^{-2}$ $day^{-1}$. This was followed by $N_3$, where the CGR recorded was 5.840 $gm^{-2}$ $day^{-1}$. $V_3$ was significantly superior and recorded the highest CGR of 4.013 $gm^{-2}$ $day^{-1}$ between 180-240 DAP in the first year. On the contrary during second year $F_3$ was on par with $N_2$ and $N_3$ recording CGR of 2.56, 2.36 and 2.35 $gm^{-2}$ $day^{-1}$, respectively. The control recorded the least value at all stages of growth.

### *4.2.3.4. Relative growth rate (RGR)*

The effect of various organic manures on relative growth rate is presented in Table 22. RGR showed an increasing trend between 60-120 DAP and 120-180 DAP, but decreased between 180-240 DAP. Between 60-120 DAP $V_3$ and $N_3$ recorded the same RGR of 0.011 g $day^{-1}$ during first and second year of crop growth which were significantly superior. This was followed by $F_3$ during the same period, for both the years. Between 60-120 DAP, the control and $N_1$ were on par with $C_1$ and $F_1$ during first year of experimentation. During the same growth stage between 60-120 DAP the control and $C_1$ recorded the same RGR (0.004 g $day^{-1}$). During first year between 120-180 DAP $V_3$, $F_3$ and $N_3$ recorded the same value (0.017 g $day^{-1}$). The control recorded low RGR (0.002 g $day^{-1}$). During second year between 120-180 DAP the mean value of RGR recorded by $V_3$ was 0.023 g $day^{-1}$. However $V_3$ was on par with $F_3$ (0.017 g $day^{-1}$) and $C_3$ (0.0163g $day^{-1}$). Control recorded the lowest RGR (0.011 g $day^{-1}$). During first year between 180-240 DAP $F_3$, $V_3$, $C_3$ and $N_3$ recorded the same RGR of 0.004 g $day^{-1}$. The control recorded lowest RGR (0.002 g $day^{-1}$). But the RGR was found significantly superior for $N_3$ during second year and recorded highest mean value of 0.0095 g $day^{-1}$ which was on par with $F_3$, $C_1$ and $F_2$.

Table 22. Effect of organic manures on relative growth rate (RGR) (g day$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 -120 DAP | | 120-180 DAP | | 180-240 DAP | |
|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| F$_1$-20.0 | 0.005 | 0.005 | 0.015 | 0.012 | 0.002 | 0.003 |
| F$_2$-30.0 | 0.007 | 0.006 | 0.016 | 0.014 | 0.003 | 0.003 |
| F$_3$-40.0 | 0.009 | 0.001 | 0.017 | 0.018 | 0.004 | 0.004 |
| V$_1$-15.0 | 0.005 | 0.005 | 0.013 | 0.013 | 0.002 | 0.002 |
| V$_2$-20.0 | 0.008 | 0.008 | 0.016 | 0.016 | 0.003 | 0.003 |
| V$_3$-25.0 | 0.011 | 0.010 | 0.017 | 0.023 | 0.004 | 0.004 |
| C$_1$-20.0 | 0.005 | 0.004 | 0.012 | 0.013 | 0.003 | 0.003 |
| C$_2$-30.0 | 0.005 | 0.005 | 0.140 | 0.015 | 0.003 | 0.003 |
| C$_3$-40.0 | 0.008 | 0.008 | 0.016 | 0.016 | 0.004 | 0.003 |
| N$_1$-3.00 | 0.004 | 0.004 | 0.013 | 0.013 | 0.003 | 0.003 |
| N$_2$-4.50 | 0.008 | 0.008 | 0.014 | 0.015 | 0.004 | 0.003 |
| N$_3$-6.00 | 0.011 | 0.010 | 0.017 | 0.016 | 0.010 | 0.009 |
| Control | 0.004 | 0.004 | 0.002 | 0.011 | 0.002 | 0.003 |
| CD | 0.001 | 0.001 | 0.001 | 0.008 | 0.001 | 0.096 |
| SE | 0.004 | 0.004 | 0.004 | 0.002 | 0.004 | 0.006 |

CD Significant at 1% level

### *4.2.3.5. Net assimilation rate (NAR)*

The results on effect of various organic manures on NAR are presented in Table 23. Significant variations were observed with respect to NAR. In the first year between 60-120 DAP the treatment $N_3$ (1.390 g day$^{-1}$) recorded the highest NAR which was on par with $V_3$ (1.369g day$^{-1}$). This was followed by $C_3$ which recorded a mean NAR values (0.948 g day$^{-1}$) which was on par with $V_2$ (0.908 g day$^{-1}$). The control recorded lower CGR value of 0.115 g day$^{-1}$. During second year, $V_3$ was (1.403) superior but on par with $N_3$ (1.382 g day$^{-1}$). This was followed by $F_3$ (1.143 g day$^{-1}$). Control recorded the lowest NAR of 0.429 g day$^{-1}$. Between 120-180 DAP $V_3$ recorded the highest mean value with respect to NAR during first year (2.650 g day$^{-1}$ ) which was on par with $C_3$ (2.598 g day$^{-1}$), during the first year of experimentation .The control recorded least value. During the second year also, $V_3$ recorded highest NAR of 2.138 g day$^{-1}$ which was on par with $V_2$ (2.128 g day$^{-1}$). But during first year between 180-240 DAP the NAR was significantly superior in $N_3$ (1.244 g day$^{-1}$) when compared to all other treatments The treatments $C_3$ and $N_2$ were on par recording a CGR of 0.699 and 0.692 g day$^{-1}$, respectively. During second year the NAR was significantly superior in the case of $C_3$ (0.570 g day$^{-1}$) which was on par with $F_3$ (0.557 g day$^{-1}$) and $V_3$ (0.510 g day$^{-1}$). At this stage, the control recorded lowest NAR of 0.44 and 0.31 g day$^{-1}$ in the first and second year respectively.

### *4.2.3.6. Leaf area duration (LAD)*

Table 24 shows the effect of various organic manures on LAD at different growth stages, which showed significant variations. Between 60-120 DAP during both the years $V_3$ and $N_3$ were on par and recorded the highest LAD of 159 and 150.50 days. The control recorded lowest LAD (67.70). But during second year $N_3$ and $V_3$ were found on par with values of 179.80 and 179.70, respectively. The control recorded least LAD (72.9).

Table 23. Effect of organic manures on net assimilation rate (NAR) (g day$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60-120 DAP | | 120-180 DAP | | 180-240 DAP | |
|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| F$_1$-20.0 | 0.564 | 0.594 | 2.072 | 1.776 | 0.459 | 0.396 |
| F$_2$-30 .0 | 0.423 | 0.627 | 2.142 | 1.871 | 0.542 | 0.523 |
| F$_3$-40.0 | 0.663 | 1.143 | 2.272 | 1.921 | 0.674 | 0.557 |
| V$_1$-15.0 | 0.805 | 0.793 | 2.072 | 1.728 | 0.271 | 0.274 |
| V$_2$-20.0 | 0.908 | 0.916 | 2.180 | 2.128 | 0.572 | 0.463 |
| V$_3$-25.0 | 1.369 | 1.403 | 2.650 | 2.138 | 0.613 | 0.510 |
| C$_1$-20.0 | 0.500 | 0.632 | 2.172 | 1.838 | 0.498 | 0.423 |
| C$_2$-30.0 | 0.714 | 0.455 | 2.245 | 1.957 | 0.509 | 0.477 |
| C$_3$-40.0 | 0.948 | 0.941 | 2.598 | 2.047 | 0.699 | 0.570 |
| N$_1$-3.00 | 0.429 | 0.384 | 1.938 | 1.804 | 0.469 | 0.398 |
| N$_2$-4.50 | 0.855 | 0.684 | 2.092 | 1.881 | 0.692 | 0.440 |
| N$_3$-6.00 | 1.390 | 1.382 | 2.158 | 1.934 | 1.244 | 0.447 |
| Control | 0.115 | 0.429 | 1.360 | 1.046 | 0.440 | 0.310 |
| CD | 0.126 | 0.126 | 0.117 | 0.115 | 0.155 | 0.135 |
| SE | 0.045 | 0.017 | 0.036 | 0.045 | 0.164 | 0.045 |

CD Significant at 1% level

Table 24. Effect of organic manure on leaf area duration (LAD) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 60 -120 DAP | | 120-180 DAP | | 180-240 DAP | |
|---|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| F$_1$-20.0 | 131.00 | 148.90 | 175.60 | 186.30 | 249.00 | 262.80 |
| F$_2$-30.0 | 136.30 | 158.30 | 180.50 | 193.70 | 277.70 | 283.50 |
| F$_3$-40.0 | 145.70 | 173.20 | 219.40 | 236.20 | 343.80 | 349.70 |
| V$_1$-15.0 | 78.40 | 82.40 | 148.50 | 153.00 | 267.00 | 272.70 |
| V$_2$-20.0 | 141.10 | 155.70 | 189.70 | 189.50 | 283.10 | 279.70 |
| V$_3$-25.0 | 159.00 | 179.70 | 242.90 | 261.30 | 368.70 | 376.70 |
| C$_1$-20.0 | 93.50 | 90.60 | 158.50 | 149.00 | 257.50 | 262.20 |
| C$_2$-30.0 | 136.10 | 152.70 | 175.80 | 187.00 | 272.10 | 281.80 |
| C$_3$-40.0 | 141.60 | 160.30 | 205.60 | 218.40 | 326.50 | 339.00 |
| N$_1$-3.00 | 130.50 | 125.20 | 183.90 | 181.00 | 279.30 | 285.40 |
| N$_2$-4.50 | 140.50 | 142.60 | 192.60 | 197.80 | 300.30 | 305.90 |
| N$_3$-6.00 | 150.50 | 179.80 | 230.60 | 249.00 | 356.90 | 363.20 |
| Control | 67.70 | 72.90 | 131.00 | 136.10 | 224.30 | 230.70 |
| CD | 9.907 | 13.190 | 10.080 | 5.600 | 4.131 | 12.920 |
| SE | 3.394 | 4.520 | 3.454 | 1.921 | 1.415 | 4.430 |

CD Significant at 1% level

At first and second year between 120-180 DAP $V_3$ was found significantly superior and recorded highest LAD of 242.90 and 261.3, respectively. This was followed by $N_3$ where the LAD recorded was 230.60 and 249.0 during first and second crop, respectively. At this stage the control recorded lowest LAD of 131.0 and 136.1 during first and second year, respectively. At 180-240 DAP also $V_3$ was found significantly superior and recorded highest LAD of 368.70, 376.70 during first and second year, respectively. This was followed by $N_3$ and $F_3$ which showed higher LAD values of 356.90 and 363.2, respectively. The control recorded lowest LAD ( 224.30) during first crop and (230.7 ) second crop of the study.

### *4.2.3.7. Rhizome : shoot ratio*

Table 25 shows the effect of various organic manure treatments on rhizome shoot ratio. The rhizome shoot ratio was significant at various growth stages during both years. At 120 DAP $C_3$ was significantly superior where the rhizome shoot ratio was 1.86 in the first year. This was followed by $V_3$ (1.67) and $N_3$ (1.48.). But during the second year, $V_3$ recorded the highest rhizome shoot ratio of 1.73 which was significantly superior compared to all other treatments. This was followed by $N_3$ and $F_3$ where rhizome shoot ratio were 1.65 and 1.46, respectively. On the contrary, at 180 DAP, $N_3$ was found to be significantly superior and recorded a rhizome shoot ratio of 3.17 and 3.18 during first year and second year respectively. This was followed by $V_3$ and the rhizome shoot ratio recorded was 3.02 and 3.12 during first and second year, respectively The control recorded the lowest rhizome shoot ratio of 1.12 and 1.13 during the first and second year, respectively.

### *4.2.3.8. Harvest index*

Table 26 shows the effect of various organic manures on harvest index during first and second year of experimentation. It was found that organic manures had significant influence on harvest index.

Table 25. Effect of organic manures on rhizome: shoot ratio in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 1.19 | 1.19 | 2.32 | 2.36 |
| $F_2$-30.0 | 1.19 | 1.20 | 3.00 | 3.09 |
| $F_3$-40.0 | 1.34 | 1.46 | 3.27 | 3.33 |
| $V_1$-15.0 | 1.15 | 1.16 | 2.24 | 2.32 |
| $V_2$-20.0 | 1.19 | 1.24 | 2.53 | 2.61 |
| $V_3$-25.0 | 1.67 | 1.73 | 3.02 | 3.12 |
| $C_1$-20.0 | 1.14 | 1.15 | 2.22 | 2.25 |
| $C_2$-30.0 | 1.21 | 1.27 | 2.30 | 2.31 |
| $C_3$-40.0 | 1.86 | 1.33 | 2.61 | 2.73 |
| $N_1$-3.00 | 1.15 | 1.23 | 2.25 | 2.31 |
| $N_2$-4.50 | 1.20 | 1.25 | 2.45 | 2.54 |
| $N_3$-6.00 | 1.48 | 1.65 | 3.17 | 3.18 |
| Control | 0.633 | 0.708 | 1.120 | 1.130 |
| CD | 0.02 | 0.03 | 0.02 | 0.03 |
| SE | 0.010 | 0.032 | 0.008 | 0.032 |

CD Significant at 1% level

Table 26. Effect of organic manures on harvest index (HI) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments<br>(t $ha^{-1}$) | 240 DAP | |
|---|---|---|
| | I<sup>st</sup> Year | II<sup>nd</sup> Year |
| $F_1$-20.0 | 0.590 | 0.646 |
| $F_2$-30.0 | 0.664 | 0.680 |
| $F_3$-40.0 | 0.754 | 0.781 |
| $V_1$-15.0 | 0.617 | 0.651 |
| $V_2$-20.0 | 0.714 | 0.753 |
| $V_3$-25.0 | 0.838 | 0.854 |
| $C_1$-20.0 | 0.569 | 0.584 |
| $C_2$-30.0 | 0.655 | 0.666 |
| $C_3$-40.0 | 0.732 | 0.753 |
| $N_1$-3.00 | 0.605 | 0.615 |
| $N_2$-4.50 | 0.693 | 0.714 |
| $N_3$-6.00 | 0.786 | 0.791 |
| Control | 0.565 | 0.578 |
| CD | 0.01 | 0.02 |
| SE | 0.001 | 0.055 |

CD Significant at 1% level.

During first year, at 240 DAP, $V_3$ recorded highest mean harvest index value of 0.838 and significantly superior. This was followed by $N_3$ (0.786). The control recorded lowest harvest index value of 0.565. During second year also the $V_3$ recorded the highest harvest index value (0.854) and was significantly superior. The control recorded the lowest harvest index of 0.578.

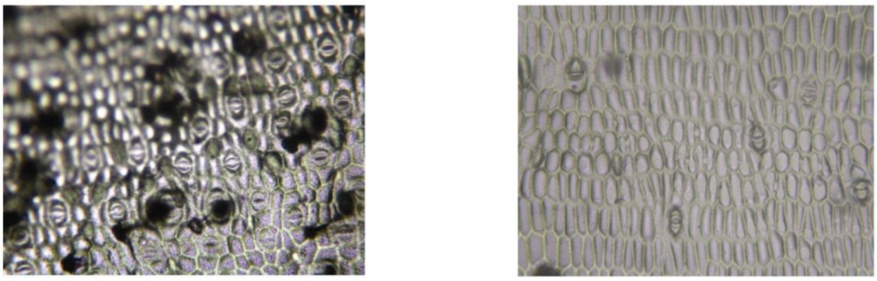
## 4.2.4. Anatomical characters

### *4.2.4.1. Leaf cuticle thickness*

Effect of organic manures on leaf cuticle thickness at 120 and 180 DAP are depicted in Table 27. Organic manures had significant influence in leaf cuticle thickness in the first and second year of experimentation. During first year, $N_3$ and $V_3$ were on par recording a leaf cuticle thickness of 0.37 µm and 0.35µm, respectively. But during second year, $N_3$ was found significantly superior and recorded the highest leaf cuticle thickness of 0.39µm. This was followed by $V_3$ with a leaf cuticle thickness of 0.36µm. $F_3$ and $C_3$ recorded the same value (0.33µm). At 180 DAP the same trend was followed for the first and second year. Highest leaf cuticle thickness was for $V_3$ (0.49µm) which was on par with $N_3$ (0.48µm). The control recorded the least value, at all growth stages.

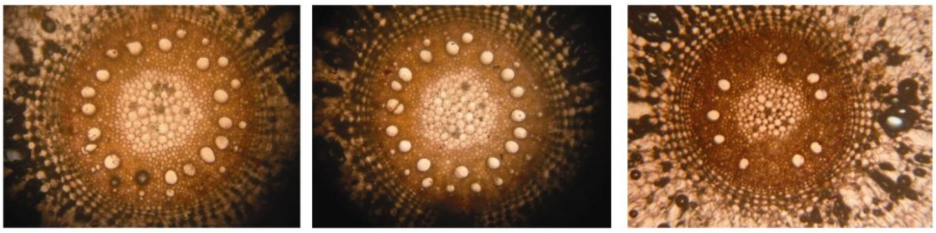
### *4.2.4.2. Number of vascular bundles (rhizome)*

Effect of organic manure on number of vascular bundles in rhizome at 120 and 180 DAP are presented in Table 28. Organic manures had significant effect in number of vascular bundles (rhizome) in the first and second year of experimentation (Plate 7). During first and second year at 120 DAP, $V_3$ observed the maximum number of vascular bundles in rhizome 14.35, and 14.61, respectively. At 180 DAP during first year $V_3$ was significantly superior and recorded a number of vascular bundles (16.64). This was followed by $N_3$ 15.55. During second year $V_3$ and $N_3$ were on par the value being 16.75 and 16.67, respectively. The control recorded least number of vascular bundles in rhizome (8.67).



Stomatal count ($V_3$)

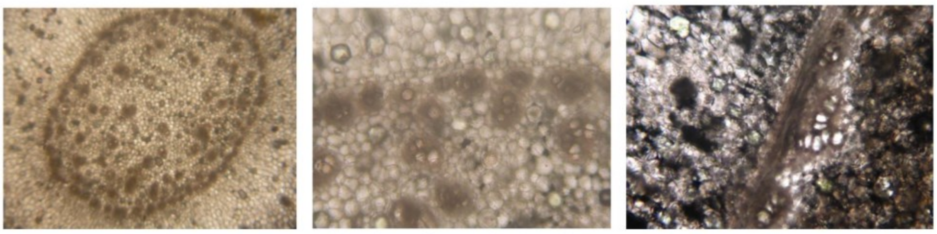
Control



Number of vascular bundles in root ($V_3$)

Number of vascular bundles in root ($N_3$)

Control



Number of vascular bundles in rhizome ($V_3$)

Number of vascular bundles in rhizome ($N_3$)

Control

Plate 7. Effect of organic manures on anatomical characters in *Curcuma aromatica* Salisb.

Table 27. Effect of organic manures on leaf cuticle thickness (µm) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 0.21 | 0.23 | 0.32 | 0.34 |
| $F_2$-30.0 | 0.26 | 0.27 | 0.40 | 0.41 |
| $F_3$-40.0 | 0.32 | 0.33 | 0.45 | 0.47 |
| $V_1$-15.0 | 0.22 | 0.24 | 0.35 | 0.36 |
| $V_2$-20.0 | 0.28 | 0.29 | 0.42 | 0.43 |
| $V_3$-25.0 | 0.35 | 0.36 | 0.49 | 0.49 |
| $C_1$-20.0 | 0.19 | 0.21 | 0.32 | 0.33 |
| $C_2$-30.0 | 0.25 | 0.26 | 0.38 | 0.39 |
| $C_3$-40.0 | 0.31 | 0.33 | 0.44 | 0.46 |
| $N_1$-3.00 | 0.24 | 0.26 | 0.32 | 0.36 |
| $N_2$-4.50 | 0.27 | 0.28 | 0.40 | 0.41 |
| $N_3$-6.00 | 0.37 | 0.39 | 0.48 | 0.48 |
| Control | 0.16 | 0.17 | 0.29 | 0.29 |
| CD | 0.020 | 0.002 | 0.020 | 0.010 |
| SE | 0.005 | 0.003 | 0.005 | 0.011 |

CD Significant at 1% level

Table 28. Effect of organic manures on number of vascular bundles (rhizome) in *Curcuma aromatica* Salisb.during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 8.81 | 8.94 | 10.04 | 10.50 |
| $F_2$-30.0 | 9.18 | 9.35 | 10.51 | 10.65 |
| $F_3$-40.0 | 11.65 | 11.81 | 14.45 | 14.86 |
| $V_1$-15.0 | 8.81 | 8.96 | 10.25 | 10.61 |
| $V_2$-20.0 | 10.26 | 10.63 | 12.33 | 12.56 |
| $V_3$-25.0 | 14.35 | 14.61 | 16.64 | 16.75 |
| $C_1$-20.0 | 7.93 | 8.06 | 9.99 | 10.28 |
| $C_2$-30.0 | 8.89 | 8.97 | 10.44 | 10.70 |
| $C_3$-40.0 | 10.51 | 10.74 | 12.65 | 12.78 |
| $N_1$-3.00 | 8.82 | 8.94 | 10.09 | 10.54 |
| $N_2$-4.50 | 9.98 | 10.06 | 11.70 | 11.88 |
| $N_3$-6.00 | 13.15 | 13.52 | 15.55 | 16.67 |
| Control | 7.47 | 7.80 | 8.45 | 8.67 |
| CD | 0.070 | 0.120 | 0.207 | 0.126 |
| SE | 0.017 | 0.014 | 0.057 | 0.045 |

CD Significant at 1% level

### *4.2.4.3. Number of vascular bundles in roots*

Table 29 represents the effect of organic manures on number of vascular bundles in roots at 120 and 180 DAP, during first and second year of experimentation. The effect of various organic manures was found significant on number of vascular bundles in roots (Plate 7). At first year at 120 DAP $V_3$ was significantly superior and recorded the highest number of vascular bundles (roots) of 13.57. During second year at 120 DAP $V_3$ was found significantly superior compared to all other treatments recording a value of 13.72. This was followed by $N_3$ (12.91). During first year at 180 DAP $V_3$ was significantly superior and recorded maximum number of vascular bundles in roots (15.66) which was followed by $N_3$ (13.34) and $F_3$ (12.63). During second year also the same trend was followed. $V_3$ was significantly superior and produced highest number of vascular bundles in roots (15.78). This was followed by $N_3$ and $F_3$ which recorded a value of (13.57, 12.78, respectively). The control recorded least number of vascular bundles in roots (10.79).

### *4.2.4.4. Stomatal frequency (abaxial)*

Table 30 represents the effect of organic manures on stomatal frequency at 120 and 180 DAP for both years. Organic manures had significant effect on stomatal frequency (abaxial). During first year at 120 DAP $N_3$ was on par with $V_3$ and $F_3$ which were significantly superior and recorded a stomatal frequency (abaxial) of 651.41, 622.14 and 614.66, respectively. During second year $V_3$ was on par with $F_3$ and $V_2$ and significantly superior. The stomatal frequency (abaxial) was recorded (690.34, 616.08 and 588.59, respectively). At 180 DAP, $V_3$ was found to be significantly superior compared to all other treatments and the stomatal frequency observed was 691.65, during first year. This was followed by $N_3$ and $V_2$, the values being 682.17 and 666.66, respectively.

Table 29. Effect of organic manures on number of vascular bundles on (roots) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 9.57 | 9.78 | 11.04 | 11.17 |
| $F_2$-30.0 | 10.60 | 10.80 | 11.07 | 11.24 |
| $F_3$-40.0 | 11.63 | 11.82 | 12.63 | 12.78 |
| $V_1$-15.0 | 10.60 | 10.82 | 11.08 | 11.49 |
| $V_2$-20.0 | 10.87 | 11.05 | 11.32 | 11.62 |
| $V_3$-25.0 | 13.57 | 13.72 | 15.66 | 15.78 |
| $C_1$-20.0 | 9.60 | 9.77 | 10.95 | 11.09 |
| $C_2$-30.0 | 10.60 | 10.75 | 11.03 | 11.36 |
| $C_3$-40.0 | 10.73 | 11.09 | 11.34 | 11.42 |
| $N_1$-3.00 | 10.80 | 10.89 | 11.02 | 11.39 |
| $N_2$-4.50 | 10.90 | 11.17 | 11.12 | 11.42 |
| $N_3$-6.00 | 12.77 | 12.91 | 13.34 | 13.57 |
| Control | 9.23 | 9.41 | 10.69 | 10.79 |
| CD | 0.350 | 0.442 | 0.030 | 0.030 |
| SE | 0.114 | 0.440 | 0.440 | 0.077 |

CD Significant at 1% level

Table 30. Effect of organic manures on stomatal frequency (abaxial) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| F$_1$-20.0 | 565.29 | 478.06 | 579.04 | 490.80 |
| F$_2$-30.0 | 575.42 | 566.28 | 594.43 | 595.47 |
| F$_3$-40.0 | 614.66 | 616.08 | 625.36 | 626.47 |
| V$_1$-15.0 | 530.82 | 515.97. | 511.49 | 522.34 |
| V$_2$-20.0 | 587.22 | 588.59 | 554.73 | 588.87 |
| V$_3$-25.0 | 622.14 | 690.34 | 691.65 | 692.69 |
| C$_1$-20.0 | 476.94 | 499.30 | 489.44 | 512.49 |
| C$_2$-30.0 | 565.29 | 557.31 | 554.73 | 555.79 |
| C$_3$-40.0 | 593.36 | 594.40 | 612.27 | 613.31 |
| N$_1$-3.00 | 461.63 | 522.79 | 602.23 | 580.58 |
| N$_2$-4.50 | 581.38 | 576.83 | 666.66 | 603.29 |
| N$_3$-6.00 | 651.41 | 582.46 | 682.17 | 683.38 |
| Control | 349.47 | 462.40 | 466.31 | 500.66 |
| CD | 145.39 | 105.34 | 2.35 | 26.56 |
| SE | 49.810 | 36.089 | 0.806 | 9.099 |

CD Significant at 1% level

During second year at 180 DAP $V_3$ and $N_3$ were on par and significantly superior recording stomatal frequency of 692.69 and 683.38, respectively. This was followed by $F_3$ (626.47). The control plot recorded lowest stomatal frequency (abaxial) (Plate 7).

#### *4.2.4.5. Stomatal frequency (adaxial)*

Significant difference among the treatments was noticed in stomatal frequency (adaxial) throughout the growth period (Table 31). During first and second year at 120 DAP $V_3$ was significantly superior and recorded highest stomatal frequency (adaxial) 2297.87. This was succeeded by $N_3$ and $F_3$ giving a values of 2014.77 and 2003.46, respectively. During first and second year at 180 DAP $V_3$ was found significantly superior, recording a stomatal frequency of 2314.97 and 2316.65, respectively. This was followed by $C_3$ which recorded a value of 2100.83 and 2102.33 during first and second year, respectively. The control recorded the least value throughout the growth stages.

### 4.2.5. Biochemical characters

#### *4.2.5.1. Rhizome*

##### 4.2.5.1.1. Curcumin content

Table 32 represents the effect of organic manures on curcumin content at 120 and 240 DAP for both years. Curcumin content was found significant at 120 and 240 DAP during both the years of experimentation (Fig 9). During first year at 120 DAP $V_3$ was significantly superior and recorded maximum curcumin content of 0.065 per cent. This was followed by $N_3$ and $F_3$ recording a curcumin content of 0.061 per cent and $F_3$ 0.057 per cent. At second year the same trend was followed where $V_3$ was significantly superior and recorded the highest curcumin content of 0.076 per cent. This was followed by $N_3$ and $F_3$ recording a curcumin content of 0.071 and 0.057 per cent, respectively.

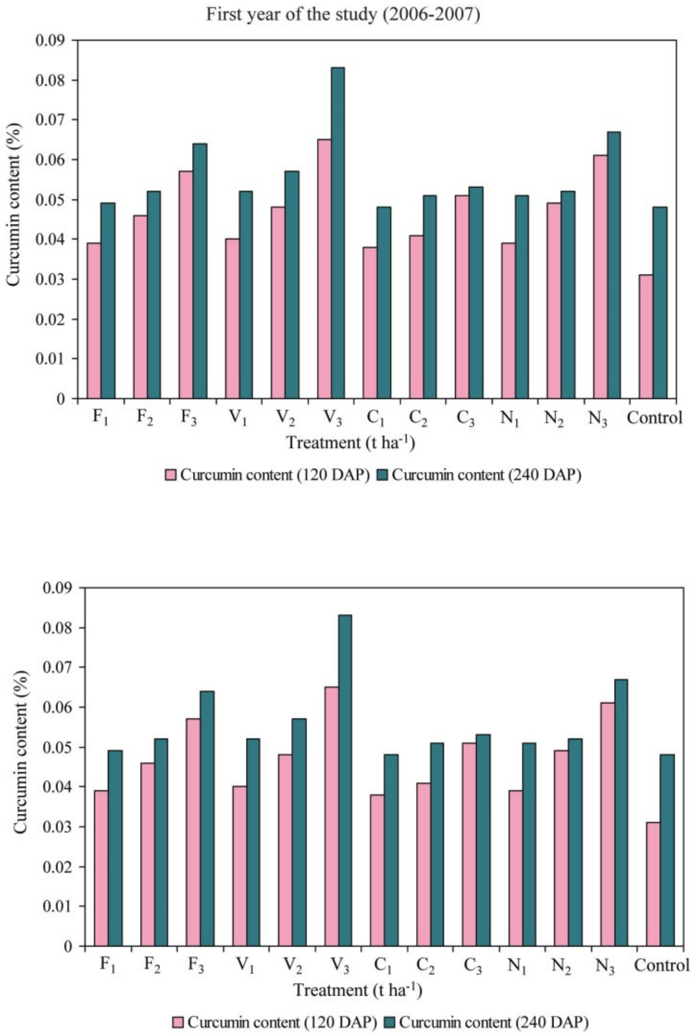


Fig. 9. Effect of organic manures on curcumin content (%) in *Curcuma aromatica* Salisb. during first and second year of study

Table 31. Effect of organic manures on stomatal frequency (adaxial) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year |
| $F_1$-20.0 | 1181.03 | 1187.12 | 1192.93 | 1194.24 |
| $F_2$-30.0 | 1181.61 | 1190.07 | 1200.03 | 1201.96 |
| $F_3$-40.0 | 2003.46 | 2004.49 | 2016.16 | 2017.40 |
| $V_1$-15.0 | 1183.83 | 1192.66 | 1188.11 | 1189.47 |
| $V_2$-20.0 | 1194.68 | 1195.99 | 1198.67 | 1199.66 |
| $V_3$-25.0 | 2297.87 | 2298.99 | 2314.97 | 2316.65 |
| $C_1$-20.0 | 1181.82 | 1183.75 | 1184.88 | 1186.56 |
| $C_2$-30.0 | 1186.06 | 1187.72 | 1192.97 | 1193.53 |
| $C_3$-40.0 | 1197.64 | 1198.74 | 2100.83 | 2102.33 |
| $N_1$-3.00 | 1191.44 | 1193.22 | 1198.95 | 1199.53 |
| $N_2$-4.50 | 1194.32 | 1196.31 | 2014.22 | 2018.58 |
| $N_3$-6.00 | 2014.77 | 2016.31 | 2039.97 | 2041.07 |
| Control | 1160.87 | 1162.37 | 1174.60 | 1171.32 |
| CD | 2.918 | 3.768 | 4.011 | 3.370 |
| SE | 1.000 | 1.288 | 1.374 | 1.153 |

CD Significant at 1% level

Table 32. Effect of organic manures on curcumin content (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 0.039 | 0.046 | 0.049 | 0.056 | 0.048 |
| $F_2$-30.0 | 0.046 | 0.057 | 0.052 | 0.059 | 0.054 |
| $F_3$-40.0 | 0.057 | 0.064 | 0.064 | 0.069 | 0.062 |
| $V_1$-15.0 | 0.040 | 0.061 | 0.052 | 0.063 | 0.054 |
| $V_2$-20.0 | 0.048 | 0.062 | 0.057 | 0.064 | 0.062 |
| $V_3$-25.0 | 0.065 | 0.076 | 0.083 | 0.092 | 0.079 |
| $C_1$-20.0 | 0.038 | 0.056 | 0.048 | 0.060 | 0.048 |
| $C_2$-30.0 | 0.041 | 0.057 | 0.051 | 0.062 | 0.052 |
| $C_3$-40.0 | 0.051 | 0.059 | 0.053 | 0.067 | 0.058 |
| $N_1$-3.00 | 0.039 | 0.047 | 0.051 | 0.062 | 0.049 |
| $N_2$-4.50 | 0.049 | 0.063 | 0.052 | 0.060 | 0.052 |
| $N_3$-6.00 | 0.061 | 0.071 | 0.067 | 0.089 | 0.075 |
| Control | 0.031 | 0.041 | 0.048 | 0.049 | 0.043 |
| CD | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 |
| SE | 0.017 | 0.047 | 0.547 | 0.044 | 0.047 |

CD Significant at 1% level

During first year and second year at 240 DAP $V_3$ was significantly superior. The curcumin content recorded during first crop (0.083 %) and second crop (0.092%). This was followed by $N_3$ where the curcumin content was 0.067 and 0.089 per cent, respectively. This was followed by $F_3$ during both the years. The control recorded the least value.

The pooled mean for curcumin content is presented in Table 32. There was significant influence in curcumin content during both the years. The pooled mean recorded by $V_3$ gave maximum curcumin content (0.079%). This was closely followed by $N_3$ (0.075%). The pooled mean of $F_3$ and $V_2$ recorded the same curcumin content of 0.062 per cent.. This was followed by $C_3$ (0.058%) and $F_2$ (0.54%). The pooled mean for control was 0.43 per cent.

#### 4.2.5.1.2. Volatile oil

Table 33 depicts the effect of different organic manures on volatile oil at 120 and 240 DAP during both years of experimentation. During first year at 120 DAP $V_3$ was significantly superior where the volatile oil content was 5.25 per cent (Fig 10). This was followed by $F_3$ and $N_3$ which were on par where the volatile oil content was 5.14 and 5.13 per cent, respectively. During second year also $V_3$ was significantly superior and the volatile oil observed was 5.44 per cent. This was followed by $N_3$ and $F_3$ where the volatile content was 5.32 and 5.22 per cent, respectively. During first year at 240 DAP $V_3$ was significantly superior in recording the maximum volatile oil content (6.58%). This was followed by $N_3$ and $F_3$ recording volatile content of 6.12 and 6.04 per cent, respectively. During the second year at the same stage $V_3$ was significantly superior and the volatile content was maximum and recorded a value of 6.73 per cent. This was followed by $N_3$ (6.27 %) and $F_3$ (6.15 %). The control recorded least volatile oil content throughout the growth stages.

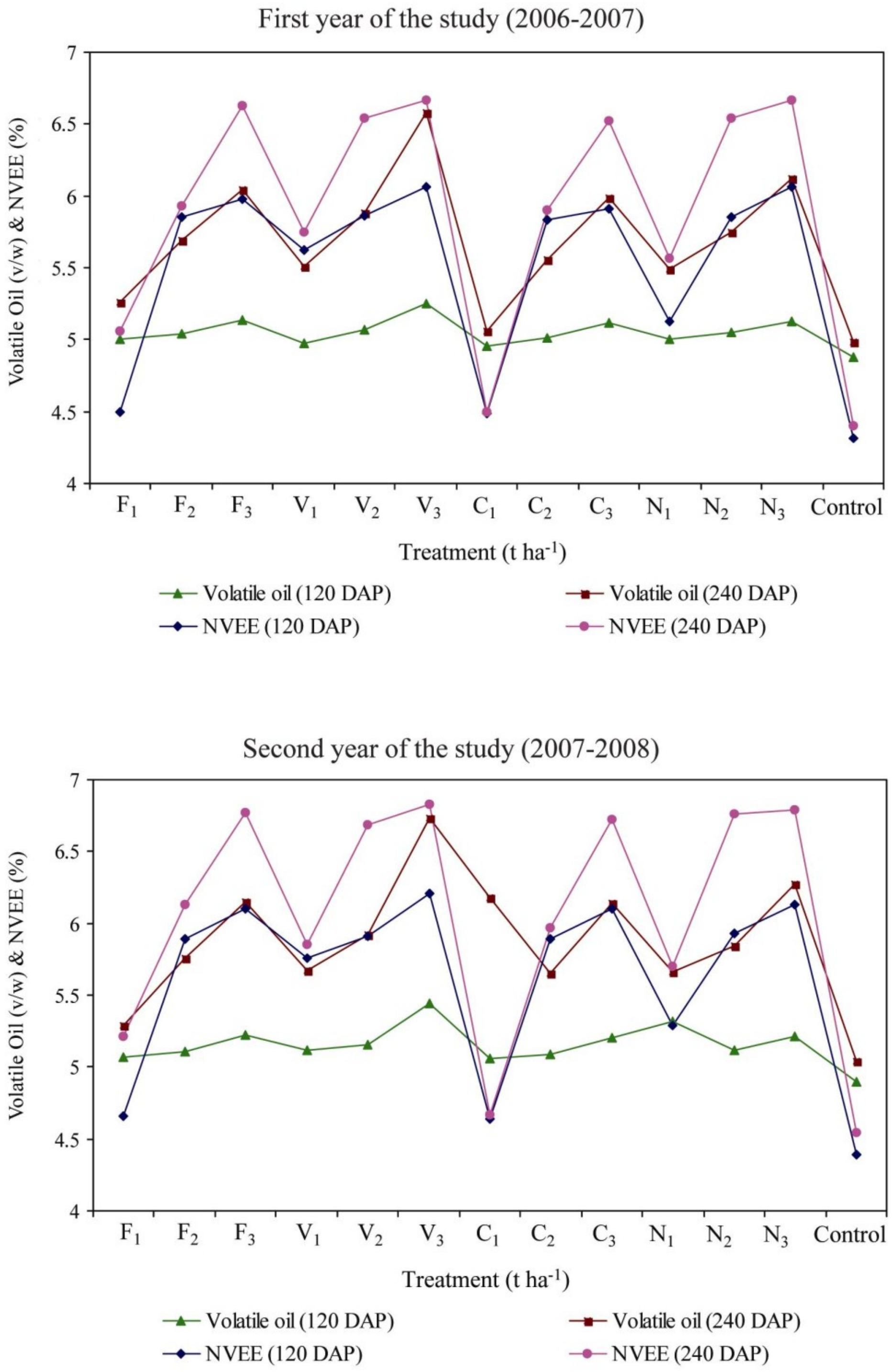


Fig. 10. Effect of organic manures on volatile oil (v/w) and NVEE (%) in *Curcuma aromatica* Salisb. during first and second year of study

Table 33. Effect of organic manures on volatile oil (v/w) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 5.00 | 5.07 | 5.26 | 5.29 | 5.16 |
| $F_2$-30.0 | 5.04 | 5.11 | 5.69 | 5.76 | 5.40 |
| $F_3$-40.0 | 5.14 | 5.22 | 6.04 | 6.15 | 5.64 |
| $V_1$-15.0 | 4.97 | 5.12 | 5.51 | 5.67 | 5.32 |
| $V_2$-20.0 | 5.07 | 5.16 | 5.88 | 5.92 | 5.49 |
| $V_3$-25.0 | 5.25 | 5.44 | 6.58 | 6.73 | 6.00 |
| $C_1$-20.0 | 4.96 | 5.06 | 5.06 | 6.18 | 5.05 |
| $C_2$-30.0 | 5.01 | 5.09 | 5.56 | 5.65 | 5.33 |
| $C_3$-40.0 | 5.12 | 5.20 | 5.99 | 6.14 | 5.49 |
| $N_1$-3.00 | 5.00 | 5.12 | 5.49 | 5.66 | 5.36 |
| $N_2$-4.50 | 5.05 | 5.21 | 5.75 | 5.84 | 5.44 |
| $N_3$-6.00 | 5.13 | 5.32 | 6.12 | 6.27 | 5.69 |
| Control | 4.88 | 4.90 | 4.98 | 5.04 | 4.94 |
| CD | 0.030 | 0.080 | 0.026 | 0.063 | 0.070 |
| SE | 0.032 | 0.031 | 0.026 | 0.026 | 0.026 |

CD Significant at 1% level

The pooled data for volatile oil content is presented in Table 33. There was significant influence in volatile oil content. The pooled mean of $V_3$ recorded the maximum volatile oil content (6.0 %). and was superior to all other treatments. This was closely followed by $N_3$ where the volatile oil content was 5.69 per cent. This was followed by $F_3$ (5.64 %) and $C_3$ (5.49 %). The control recorded least volatile oil content (4.94 %).

#### 4.2.5.1.3. Non volatile ether extract (NVEE)

The effect of organic manures on NVEE at 120 and 240 DAP, are presented in Table 34. Effect of different organic manures on NVEE was significant at 120 DAP and 240 DAP (Fig 10). During first year at 120 DAP $V_3$ and $N_3$ recorded the same value (6.06 %). During the second year at 120 DAP NVEE was found significantly superior in $V_3$ treatment (6.21 %) which was on par with $N_3$ (6.13 %). During first year at 240 DAP $V_3$ and $N_3$ treatment recorded the same value for NVEE (6.67%). Similarly during second year at 240 DAP $V_3$, $N_3$ and $F_3$ were on par recording values $V_3$ (6.83, 6.79 and 6.77%), respectively. The control recorded the least NVEE throughout the growth stages.

The pooled mean for NVEE is presented in Table 34. There was significant difference in NVEE pooled data. The pooled mean of $V_3$ recorded the maximum NVEE content of 6.44 per cent. The pooled mean for NVEE recorded by $V_3$ was on par with $N_3$ (6.41%), $F_3$ (6.37%) and $C_3$ (6.32%). Among the organic manures the pooled mean of $C_1$ recorded less NVEE (4.58 %). The pooled mean of control was the least (4.41%).

#### 4.2.5.1.4. Crude fibre

The effect of organic manures on crude fibre content at 120 DAP and 240 DAP during both years of experimentation are depicted in Table 35.

Table 34. Effect of organic manures on NVEE (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 4.50 | 4.66 | 5.06 | 5.21 | 4.86 |
| $F_2$-30.0 | 5.85 | 5.89 | 5.93 | 6.13 | 5.95 |
| $F_3$-40.0 | 5.98 | 6.10 | 6.63 | 6.77 | 6.37 |
| $V_1$-15.0 | 5.62 | 5.76 | 5.75 | 5.85 | 5.75 |
| $V_2$-20.0 | 5.86 | 5.91 | 6.54 | 6.68 | 6.25 |
| $V_3$-25.0 | 6.06 | 6.21 | 6.67 | 6.83 | 6.44 |
| $C_1$-20.0 | 4.49 | 4.64 | 4.50 | 4.67 | 4.58 |
| $C_2$-30.0 | 5.83 | 5.89 | 5.90 | 5.97 | 5.90 |
| $C_3$-40.0 | 5.91 | 6.10 | 6.52 | 6.72 | 6.32 |
| $N_1$-3.00 | 5.13 | 5.29 | 5.57 | 5.70 | 5.42 |
| $N_2$-4.50 | 5.85 | 5.93 | 6.54 | 6.76 | 6.27 |
| $N_3$-6.00 | 6.06 | 6.13 | 6.67 | 6.79 | 6.41 |
| Control | 4.32 | 4.39 | 4.40 | 4.54 | 4.41 |
| CD | 0.268 | 0.256 | 0.040 | 0.080 | 0.120 |
| SE | 0.000 | 0.087 | 0.000 | 0.026 | 0.177 |

CD Significant at 1% level

Table 35. Effect of organic manures on crude fibre (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 2.70 | 2.80 | 3.08 | 3.26 | 3.01 |
| $F_2$-30.0 | 2.51 | 2.82 | 2.93 | 3.23 | 2.76 |
| $F_3$-40.0 | 2.37 | 2.59 | 2.83 | 3.02 | 2.48 |
| $V_1$-15.0 | 2.64 | 2.62 | 2.63 | 2.70 | 2.61 |
| $V_2$-20.0 | 2.47 | 2.44 | 2.52 | 2.61 | 2.91 |
| $V_3$-25.0 | 2.13 | 2.21 | 2.47 | 2.51 | 2.33 |
| $C_1$-20.0 | 2.77 | 2.85 | 3.16 | 3.11 | 2.45 |
| $C_2$-30.0 | 2.74 | 2.63 | 3.11 | 3.19 | 2.94 |
| $C_3$-40.0 | 2.51 | 2.78 | 2.83 | 2.91 | 2.72 |
| $N_1$-3.00 | 2.54 | 2.59 | 3.02 | 2.72 | 2.69 |
| $N_2$-4.50 | 2.45 | 2.66 | 2.61 | 3.11 | 2.73 |
| $N_3$-6.00 | 2.32 | 2.39 | 2.51 | 2.61 | 2.45 |
| Control | 2.84 | 2.90 | 3.14 | 3.44 | 3.09 |
| CD | 0.020 | 0.050 | 0.020 | 0.060 | 0.050 |
| SE | 0.026 | 0.055 | 0.026 | 0.017 | 0.032 |

CD Significant at 1% level

The effect of various organic manures on crude fibre was significant at 120 and 240 DAP during both the years of experimentation. During first year at 120 DAP $V_3$ was found highly significant and recorded the least crude fibre content (2.13%). This was followed by $N_3$ recording at crude fibre content of 2.32 per cent. At second year of 120 DAP, $V_3$ was found highly significant and recorded a crude fibre content of 2.21 per cent. This was followed by $N_3$ (2.39%). During first year at 240 DAP $V_3$ was significantly superior, the crude fibre content was 2.47 per cent. This was followed by $N_3$ where $N_3$ and $V_2$ were on par recording crude fibre content of 2.51 and 2.52 per cent. During second year at 240 DAP the treatment $V_3$ was significantly superior and recorded the crude fibre content 2.51 per cent. $N_3$ and $V_2$ recorded the same value (2.61%).

The pooled mean data for crude fibre was statistically significant. The pooled mean of $V_3$ recorded the least crude fibre (2.33 %) and was superior. This was followed by $N_3$ (2.45%) and $F_3$ (2.48 %). The control recorded highest value of crude fibre (3.09%).

### 4.2.5.1.5. Starch

The effect of organic manures on starch content at 120 and 240 DAP at both years are presented in Table 36. Organic manures showed significant effects at 120 and 240 DAP. During first year at 120 DAP it t was found that $V_3$ and $N_3$ were on par recording the maximum starch content of 21.46 per cent where $V_3$ was on par with $N_3$ During second year at 120 DAP $V_3$ recorded the maximum starch content (21.75 %) and was superior among other treatments This was followed by $N_3$ and $F_3$ recording starch content of 21.61 and 21.46 per cent, respectively. During first year at 240 DAP, $V_3$ recorded the highest starch content (22.61 %) and was significantly superior. This was followed by $N_3$ (22.44 %) and $F_3$ (22.22 %). During second year at 240 DAP $V_3$ was significantly superior and recorded the maximum starch content of 22.72 per cent. The control recorded least starch content throughout the crop growth stages.

Table 36. Effect of organic manures on starch content (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| $F_1$-20.0 | 20.11 | 20.22 | 20.63 | 21.56 | 20.25 |
| $F_2$-30.0 | 20.68 | 20.75 | 21.46 | 21.33 | 21.11 |
| $F_3$-40.0 | 21.26 | 21.46 | 22.22 | 21.09 | 21.82 |
| $V_1$-15.0 | 20.45 | 20.66 | 20.97 | 22.34 | 20.79 |
| $V_2$-20.0 | 20.97 | 21.19 | 21.87 | 22.61 | 21.49 |
| $V_3$-25.0 | 21.46 | 21.75 | 22.61 | 22.72 | 22.13 |
| $C_1$-20.0 | 20.07 | 20.18 | 20.60 | 21.75 | 20.37 |
| $C_2$-30.0 | 20.55 | 20.65 | 21.22 | 21.93 | 20.93 |
| $C_3$-40.0 | 21.10 | 21.24 | 21.98 | 22.08 | 21.60 |
| $N_1$-3.00 | 20.25 | 20.35 | 20.89 | 20.65 | 20.60 |
| $N_2$-4.50 | 20.82 | 20.93 | 21.67 | 20.76 | 21.29 |
| $N_3$-6.00 | 21.45 | 21.61 | 22.44 | 20.92 | 22.03 |
| Control | 19.98 | 20.14 | 20.14 | 20.21 | 20.20 |
| CD | 0.020 | 0.125 | 0.030 | 0.060 | 0.140 |
| SE | 0.010 | 0.045 | 0.010 | 0.067 | 0.161 |

CD Significant at 1% level

The pooled data for starch content is presented in Table 36. There was significant influence in pooled mean of starch content. The pooled mean of $V_3$ recorded the maximum starch content 22.13 per cent which was superior but on par with $N_3$ (22.03 %) This was closely followed by $F_3$ where the pooled mean of starch was 21.82 per cent. The control recorded least pooled mean (20.20 %).

### 4.2.5.1.6. Total carbohydrates

The effect of organic manure on total carbohydrates at 120 DAP and 240 DAP are presented in Table 37.

Total carbohydrates was significant by application of various organic manures. During first year at 120 DAP $V_3$ was on par with $N_3$ (1.68 and 1.67 %), respectively. $N_3$ was on par with $F_3$.During second year at 120 DAP $V_3$ was on par with $C_3$ where $V_3$ recorded total carbohydrates of 1.80 per cent and $C_3$ recorded a value of 1.76 per cent. The treatment $N_3$ and $F_3$ recorded the same value (1.74 %). During first and year at 240 DAP the same trend was observed in crop growth as in previous case where $V_3$ was found significantly superior and the total carbohydrate content recorded was 1.75 per cent during first year and 1.87 per cent during second year of experimentation. This was followed by $N_3$ and $F_3$ during both the years. Total carbohydrates recorded by $N_3$ during first year was 1.71 and during second year was 1.81 per cent. The control recorded the least total carbohydrates content.

The pooled mean for total carbohydrates is presented in Table 37.There was significant influence in total carbohydrates. The pooled mean for $V_3$ recorded maximum total carbohydrates 1.77 per cent and was superior. This was followed by $N_3$ which recorded total carbohydrates of 1.74 per cent. The control recorded least value of 1.40 per cent of total carbohydrates.

Table 37. Effect of organic manures on total carbohydrates (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| F$_1$-20.0 | 1.21 | 1.32 | 1.45 | 1.52 | 1.45 |
| F$_2$-30.0 | 1.55 | 1.64 | 1.55 | 1.61 | 1.47 |
| F$_3$-40.0 | 165 | 1.74 | 1.68 | 1.73 | 1.67 |
| V$_1$-15.0 | 1.25 | 1.38 | 1.48 | 1.63 | 1.41 |
| V$_2$-20.0 | 1.61 | 1.73 | 1.65 | 1.74 | 1.65 |
| V$_3$-25.0 | 1.68 | 1.80 | 1.75 | 1.87 | 1.77 |
| C$_1$-20.0 | 1.20 | 1.23 | 1.40 | 1.51 | 1.47 |
| C$_2$-30.0 | 1.34 | 1.42 | 1.50 | 1.60 | 1.66 |
| C$_3$-40.0 | 1.62 | 1.76 | 1.65 | 1.72 | 1.70 |
| N$_1$-3.00 | 1.24 | 1.34 | 1.48 | 1.58 | 1.45 |
| N$_2$-4.50 | 1.58 | 1.68 | 1.62 | 1.74 | 1.63 |
| N$_3$-6.00 | 1.67 | 1.74 | 1.71 | 1.81 | 1.74 |
| Control | 1.19 | 1.27 | 1.21 | 1.29 | 1.40 |
| CD | 0.0200 | 0.040 | 0.020 | 0.030 | 0.027 |
| SE | 0.005 | 0.012 | 0.005 | 0.007 | 0.031 |

CD Significant at 1% level

#### 4.2.5.1.7. Protein

The effect of various organic manures on protein content at 120 and 240 DAP during both years of experimentation are presented in Table 38.

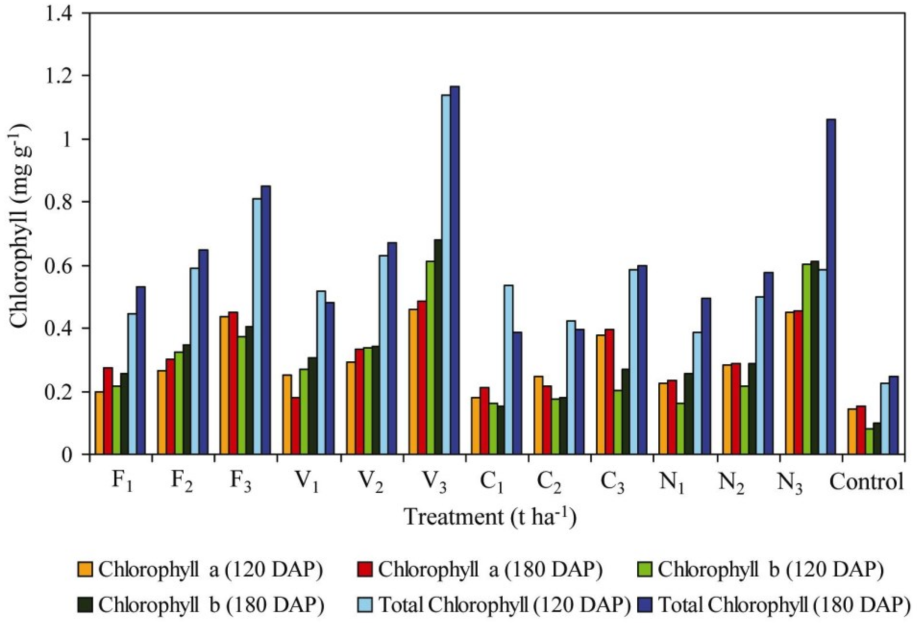
During first year at 120 DAP $V_3$ was significantly superior and recorded the highest protein content (5.88 %). This was succeeded by $N_3$ (5.78 %) and $F_3$ (5.74 %). During second year $V_3$ was significantly superior and recorded a protein content of 5.88 per cent. $N_3$ was on par with $F_3$, where the protein content recorded was 5.83 and 5.80 per cent, respectively. During first year at 240 DAP $V_3$ was significantly superior where the protein content was (6.98 %). This was followed by $N_3$ and $F_3$ which recorded protein content (6.86 and 6.81 %) respectively. At second year at 240 DAP the $V_3$ was significantly superior compared to all other treatments. The protein content observed by $V_3$ was 7.07 per cent. This was followed by $N_3$ and $V_2$ which recorded the same value (6.92 %). The protein content of control was less throughout the crop growth.

The pooled mean for protein was found significantly superior. The pooled mean in $V_3$ was 6.40 per cent protein which recorded the maximum value. This was followed by $N_3$ (6.3%), $C_3$ (6.25 %) and $F_3$ (6.21 %) protein. The pooled mean in protein for control was 5.36 per cent.

### *4.2.5.2. Leaf*

#### 4.2.5.2.1. Chlorophyll 'a'

The effect of different organic manures on chlorophyll ‘a’ content in leaves at 120 and 180 DAP is presented in Table 39 (Fig.11). Chlorophyll ‘a’ content in leaves varied significantly with different levels of organic manures. Plants which received $V_3$ treatment was found significantly superior and produced maximum chlorophyll ‘a’ content during both the years of experiment. The value recorded at 120 DAP was 0.458 mg $g^{-1}$ and 0.467 mg $g^{-1}$ during first and second year of experimentation, respectively.


First year of the study (2006-2007)

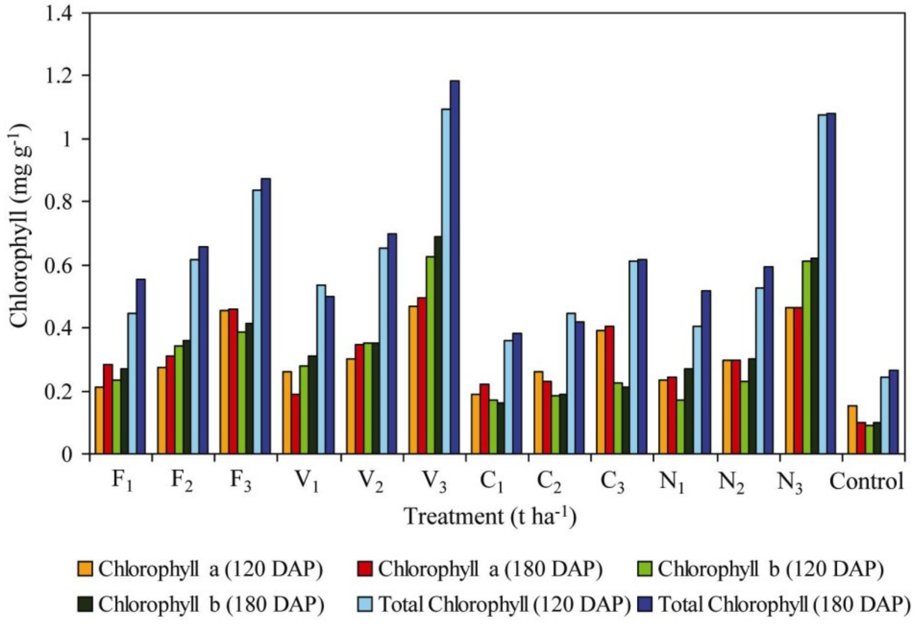

Second year of the study (2007-2008)

Fig. 11. Effect of organic manures on chlorophyll a, b and total chlorophyll (mg g$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

Table 38. Effect of organic manures on protein (%) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | 120 DAP | | 240 DAP | | Pooled mean |
|---|---|---|---|---|---|
| | I$^{st}$ Year | II$^{nd}$ Year | I$^{st}$ Year | II$^{nd}$ Year | |
| F$_1$-20.0 | 5.31 | 5.41 | 6.12 | 6.25 | 6.01 |
| F$_2$-30.0 | 5.53 | 5.60 | 6.61 | 6.72 | 6.16 |
| F$_3$-40.0 | 5.74 | 5.80 | 6.81 | 6.89 | 6.21 |
| V$_1$-15.0 | 5.41 | 5.58 | 6.21 | 6.31 | 6.03 |
| V$_2$-20.0 | 5.65 | 5.72 | 6.70 | 6.92 | 6.28 |
| V$_3$-25.0 | 5.88 | 5.88 | 6.98 | 7.07 | 6.40 |
| C$_1$-20.0 | 5.29 | 5.39 | 6.03 | 6.09 | 5.83 |
| C$_2$-30.0 | 5.47 | 5.53 | 6.55 | 6.62 | 6.07 |
| C$_3$-40.0 | 5.70 | 5.79 | 6.75 | 6.80 | 6.25 |
| N$_1$-3.00 | 5.32 | 5.42 | 6.21 | 6.32 | 6.02 |
| N$_2$-4.50 | 5.57 | 5.63 | 6.62 | 6.70 | 6.08 |
| N$_3$-6.00 | 5.78 | 5.83 | 6.86 | 6.92 | 6.35 |
| Control | 5.21 | 5.30 | 5.45 | 5.51 | 5.36 |
| CD | 0.020 | 0.041 | 0.020 | 0.075 | 0.030 |
| SE | 0.017 | 0.044 | 0.005 | 0.026 | 0.026 |

CD Significant at 1% level

Table 39. Effect of organic manures on chlorophyll ‘a’ (mg $g^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t $ha^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | I<sup>st</sup> Year | II<sup>nd</sup> Year | I<sup>st</sup> Year | II<sup>nd</sup> Year |
| $F_1$-20.0 | 0.197 | 0.212 | 0.273 | 0.283 |
| $F_2$-30.0 | 0.264 | 0.274 | 0.301 | 0.311 |
| $F_3$-40.0 | 0.438 | 0.453 | 0.449 | 0.459 |
| $V_1$-15.0 | 0.250 | 0.260 | 0.178 | 0.188 |
| $V_2$-20.0 | 0.292 | 0.302 | 0.335 | 0.345 |
| $V_3$-25.0 | 0.458 | 0.467 | 0.486 | 0.496 |
| $C_1$-20.0 | 0.179 | 0.191 | 0.210 | 0.220 |
| $C_2$-30.0 | 0.248 | 0.259 | 0.218 | 0.228 |
| $C_3$-40.0 | 0.380 | 0.390 | 0.397 | 0.407 |
| $N_1$-3.00 | 0.224 | 0.236 | 0.235 | 0.245 |
| $N_2$-4.50 | 0.285 | 0.297 | 0.286 | 0.296 |
| $N_3$-6.00 | 0.448 | 0.462 | 0.453 | 0.463 |
| Control | 0.144 | 0.153 | 0.151 | 0.161 |
| CD | 0.003 | 0.002 | 0.002 | 0.002 |
| SE | 0.01 | 0.01 | 0.01 | 0.01 |

CD Significant at 1% level

The best treatment after $V_3$ was $N_3$ where the chlorophyll 'a' content was 0.448 mg $g^{-1}$ during first year and 0.462 mg $g^{-1}$ during second year. This was succeeded by $F_3$, 0.438 mg $g^{-1}$ for the first crop and 0.453 mg $g^{-1}$ for the second crop. The leaves of $V_3$ treated plants gave significantly superior chlorophyll 'a' content of 0.486 mg $g^{-1}$ and 0.496 mg $g^{-1}$ during first and second year, respectively at 180 DAP. This was followed by $N_3$ which recorded chlorophyll 'a' content of 0.453 mg $g^{-1}$ during first crop and 0.463 mg $g^{-1}$ during second crop. The leaves of control plants recorded the least chlorophyll 'a' content at the above two stages of crop growth.

#### 4.2.5.2.2. Chlorophyll 'b'

Table 40 shows the effect of various organic manures on chlorophyll 'b' content at different growth stages. Perusal of the data on chlorophyll 'b' content clearly indicate that various organic manures significantly influenced the chlorophyll 'b' content at all stages of growth (Fig.11). It was observed that $V_3$ was significantly superior and recorded a chlorophyll ‘b’ content of 0.612 mg $g^{-1}$ during first year and 0.627 mg $g^{-1}$ during second year, whereas $N_3$ recorded 0.602 and 0.614mg $g^{-1}$ during first and second year, respectively. At 180 DAP the chlorophyll 'b' content was significantly influenced by $V_3$ in both the years. In the first year it was 0.679mg $g^{-1}$ and in second year, the value was 0.689 mg $g^{-1}$.$V_3$ was succeeded by $N_3$ giving a value of 0.611mg $g^{-1}$ (first crop) and 0.619mg $g^{-1}$ (second crop). The control recorded least value during the above two stages.

#### 4.2.5.2.3. Total chlorophyll

The effect of various organic manures on total chlorophyll, content is depicted in Table 41.

Table 40. Effect of organic manures on chlorophyll ‘b’ (mg $g^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t $ha^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | $I^{st}$ Year | $II^{nd}$ Year | $I^{st}$ Year | $II^{nd}$ Year |
| $F_1$-20.0 | 0.214 | 0.232 | 0.256 | 0.271 |
| $F_2$-30.0 | 0.326 | 0.342 | 0.348 | 0.358 |
| $F_3$-40.0 | 0.374 | 0.386 | 0.404 | 0.413 |
| $V_1$-15.0 | 0.268 | 0.277 | 0.304 | 0.312 |
| $V_2$-20.0 | 0.338 | 0.351 | 0.340 | 0.352 |
| $V_3$-25.0 | 0.612 | 0.627 | 0.679 | 0.689 |
| $C_1$-20.0 | 0.160 | 0.170 | 0.152 | 0.161 |
| $C_2$-30.0 | 0.175 | 0.186 | 0.178 | 0.190 |
| $C_3$-40.0 | 0.204 | 0.224 | 0.272 | 0.211 |
| $N_1$-3.00 | 0.163 | 0.171 | 0.257 | 0.272 |
| $N_2$-4.50 | 0.216 | 0.229 | 0.288 | 0.300 |
| $N_3$-6.00 | 0.602 | 0.614 | 0.611 | 0.619 |
| Control | 0.080 | 0.089 | 0.097 | 0.105 |
| CD | 0.060 | 0.069 | 0.029 | 0.025 |
| SE | 0.017 | 0.017 | 0.010 | 0.024 |

CD Significant at 1% level

Table 41. Effect of organic manures on total chlorophyll (mg $g^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t $ha^{-1}$) | 120 DAP | | 180 DAP | |
|---|---|---|---|---|
| | $I^{st}$ Year | $II^{nd}$ Year | $I^{st}$ Year | $II^{nd}$ Year |
| $F_1$-20.0 | 0.447 | 0.444 | 0.529 | 0.554 |
| $F_2$-30.0 | 0.590 | 0.616 | 0.649 | 0.659 |
| $F_3$-40.0 | 0.812 | 0.838 | 0.853 | 0.872 |
| $V_1$-15.0 | 0.518 | 0.537 | 0.482 | 0.501 |
| $V_2$-20.0 | 0.630 | 0.653 | 0.672 | 0.697 |
| $V_3$-25.0 | 1.137 | 1.094 | 1.164 | 1.185 |
| $C_1$-20.0 | 0.537 | 0.361 | 0.387 | 0.381 |
| $C_2$-30.0 | 0.423 | 0.445 | 0.396 | 0.418 |
| $C_3$-40.0 | 0.587 | 0.614 | 0.599 | 0.618 |
| $N_1$-3.00 | 0.387 | 0.407 | 0.493 | 0.517 |
| $N_2$-4.50 | 0.501 | 0.526 | 0.575 | 0.596 |
| $N_3$-6.00 | 1.050 | 1.076 | 1.064 | 1.082 |
| Control | 0.224 | 0.242 | 0.247 | 0.266 |
| CD | 0.030 | 0.060 | 0.070 | 0.080 |
| SE | 0.031 | 0.024 | 0.024 | 0.097 |

CD Significant at 1% level.

The total chlorophyll in leaves of treatment plants and control were analyzed at 120 DAP and 180 days after planting. The effect of various organic manures on total chlorophyll was significant (Fig.11). At 120 DAP, the total chlorophyll was maximum in $V_3$ treated plants recording a value of 1.137 and 1.094 mg $g^{-1}$, in the first and second year, respectively. $N_3$ which succeeded $V_3$, recorded a value of 1.050 mg $g^{-1}$during first year and 1.076 mg $g^{-1}$ during second year. As in the previous case at 180 DAP also $V_3$ was significantly superior and recorded maximum total chlorophyll content of 1.164 and 1.185 mg $g^{-1}$ during first and second year, respectively. $V_3$ was followed by $N_3$ which gave a value of 1.064 and 1.082 mg $g^{-1}$ during first and second year, respectively. The control recorded least total chlorophyll content of 0.224 and 0.242 mg $g^{-1}$ in the first year and second year at 120 DAP. The same effect was observed at 180 DAP also, the values being 0.247 and 0.266 mg $g^{-1}$ during first and second year of study, respectively.

### 4.2.6. Soil analysis

#### *4.2.6.1. Soil physical properties*

#### 4.2.6.1.1. Bulk density

The data on bulk density of soil before the experiment and after the experiment during first year of the crop, second year and residual crop are presented in Table 42.

It was found that vermicompost, Farm yard manure, Neem cake, coirpith compost lowered the bulk density. After the first crop, when analysed, highest bulk density was observed in the control plot (1.55 g $cc^{-1}$). But this was on par with $C_2$ (1.54 g $cc^{-1}$) whereas least and same bulk density (1.51 g $cc^{-1}$) was recorded by $V_3$ and $N_3$. At the end of second year of experiment, bulk density was found to be significant and reduced from the first year. The control recorded the maximum bulk density (1.52 g $cc^{-1}$).

Table 42. Effect of organic manures on bulk density (gm $cc^{-1}$) during first, second year and after residual crop

| Treatments (t $ha^{-1}$) | Initial | $I^{st}$ Year | $II^{nd}$ Year | Residual crop |
|---|---|---|---|---|
| $F_1$-20.0 | 1.53 | 1.53 | 1.50 | 1.46 |
| $F_2$-30.0 | 1.55 | 1.53 | 1.49 | 1.43 |
| $F_3$-40.0 | 1.56 | 1.52 | 1.47 | 1.39 |
| $V_1$-15.0 | 1.53 | 1.53 | 1.50 | 1.43 |
| $V_2$-20.0 | 1.55 | 1.52 | 1.49 | 1.40 |
| $V_3$-25.0 | 1.53 | 1.51 | 1.45 | 1.37 |
| $C_1$-20.0 | 1.52 | 1.53 | 1.52 | 1.47 |
| $C_2$-30.0 | 1.55 | 1.54 | 1.51 | 1.44 |
| $C_3$-40.0 | 1.53 | 1.52 | 1.49 | 1.40 |
| $N_1$-3.00 | 1.54 | 1.52 | 1.50 | 1.45 |
| $N_2$-4.50 | 1.57 | 1.53 | 1.49 | 1.41 |
| $N_3$-6.00 | 1.56 | 1.51 | 1.45 | 1.38 |
| Control | 1.54 | 1.55 | 1.52 | 1.50 |
| CD | 0.03 | 0.01 | 0.02 | 0.01 |
| SE | 0.012 | 0.014 | 0.005 | 0.012 |

CD Significant at 1% level

The least bulk density was recorded by $V_3$ and $N_3$ with the same value (1.45 g $cc^{-1}$) and was significantly superior. After residual crop when the soil samples were analysed $V_3$ and $N_3$ showed a reduced bulk density of 1.37 and 1.38 g $cc^{-1}$, respectively which were on par. $F_3$ was on par with $N_3$ in (1.39 g $cc^{-1}$) during residual crop. The bulk density recorded by control plots after the residual crop was high (1.50 g $cc^{-1}$) whereas $F_3$ and $N_3$ were on par and recorded a minimum bulk density of 1.39 and 1.38 g $cc^{-1}$, respectively. The bulk density decreased due to the application of organic manures, whereas the control recorded highest bulk density.

### 4.2.6.1.2. Water holding capacity

The influence of organic manures on water holding capacity of the soil before and after the main experiments and residual crop are presented in Table 43.

At the end of first year of experiment maximum water holding capacity of soil was observed in $V_3$ (29.76 %). $N_3$ also recorded high water holding capacity (29.72 %). But the control recorded a water holding capacity of 24.62 per cent only. At the end of second year of field experiment, the water holding capacity increased where $V_3$ was found to be superior when compared to all other treatments (30.67 %). This was closely followed by $N_3$ where the water holding capacity was 30.63 per cent. The control recorded a low water holding capacity (26.87 %). The water holding capacity of $V_3$ was further increased to 32.65 per cent when analysed at the final stage and was significantly superior compared to other treatments. This was succeeded by $F_3$ and $N_3$. The soil in control plots measured the least water holding capacity of 29.90 per cent when analysed after harvesting the residual crop.

Table 43. Effect of organic manures on water holding capacity (%) during first, second year and after residual crop

| Treatments ($t\ ha^{-1}$) | Initial | I$^{rst}$ Year | II$^{nd}$ Year | Residual crop |
|---|---|---|---|---|
| $F_1$-20.0 | 22.76 | 28.22 | 29.15 | 31.04 |
| $F_2$-30.0 | 23.07 | 28.97 | 29.86 | 31.12 |
| $F_3$-40.0 | 24.03 | 29.57 | 30.59 | 31.95 |
| $V_1$-15.0 | 22.91 | 28.71 | 29.51 | 30.25 |
| $V_2$-20.0 | 23.62 | 29.51 | 30.22 | 31.56 |
| $V_3$-25.0 | 25.47 | 29.76 | 30.67 | 32.65 |
| $C_1$-20.0 | 22.73 | 28.03 | 29.01 | 29.96 |
| $C_2$-30.0 | 23.03 | 28.88 | 29.75 | 30.68 |
| $C_3$-40.0 | 23.97 | 29.46 | 30.43 | 31.76 |
| $N_1$-3.00 | 22.89 | 28.57 | 29.31 | 30.90 |
| $N_2$-4.50 | 23.45 | 29.12 | 29.96 | 31.12 |
| $N_3$-6.00 | 24.28 | 29.72 | 30.63 | 31.90 |
| Control | 22.37 | 24.62 | 26.87 | 29.98 |
| CD | 0.030 | 0.030 | 0.022 | 0.031 |
| SE | 0.011 | 0.011 | 0.007 | 0.921 |

CD Significant at 1% level

### *4.2.6.2. Soil chemical properties*

#### 4.2.6.2.1. Soil pH

The data on soil pH, before the experimentation, after the first and second crop and after the residual crop are presented in Table 44.

The application of various organic manures resulted in significant change in soil pH. At the end of first year of the experiment, there was a gradual decrease in soil pH among treatments. In $V_3$, the soil pH was reduced from 7.05 to 6.37 and in $N_3$ from 7.0 to 6.4. In control, the pH ,was reduced from 7.08 the initial state to 6.65 after the first year of experiment. At the end of second year there was no significant difference. At the end of residual crop it was seen that $V_3$ was significantly superior where the pH was reduced from 7.05 (initial) to 5.41. This was followed by $V_2$ where the pH was reduced to 5.61.

#### 4.2.6.2.2. Electrical Conductivity (EC)

The effect of various organic manures on EC before the first experiment, after the first and second crop and also after the residual crop are presented in Table 45.

The EC measured at the end of first experiment was found significant. EC increased due to organic manure application. Treatments $N_3$ and $F_3$ were found superior and recorded the same value (0.387 $dsm^{-1}$). This was closely followed by $V_3$ where the EC was increased from 0.336 in the initial stage to 0.380 $dsm^{-1}$. The control recorded least EC value of 0.317 $dsm^{-1}$. At the end of second year, treatment $V_3$ was superior and recorded the maximum EC (0.547 $dsm^{-1}$). This was followed by treatments $N_3$ (0.537 $dsm^{-1}$) and $F_3$ (0.527 $dsm^{-1}$). The control recorded least EC of 0.447 $dsm^{-1}$. $V_3$ was also found significantly superior and gave the highest EC value of 0.747 $dsm^{-1}$ at the end of residual crop. This was followed by $N_3$ and $F_3$, with an EC value of 0.707 and 0.647 $dsm^{-1}$, respectively.

Table 44. Effect of organic manures on soil pH during first, second year and after residual crop

| Treatments (t ha$^{-1}$) | Initial | I$^{rst}$ Year | II$^{nd}$ Year | Residual crop |
|---|---|---|---|---|
| $F_1$-20.0 | 6.56 | 6.60 | 6.20 | 6.01 |
| $F_2$-30.0 | 6.53 | 6.20 | 4.02 | 5.90 |
| $F_3$-40.0 | 6.66 | 6.62 | 6.06 | 5.79 |
| $V_1$-15.0 | 6.46 | 6.30 | 6.00 | 5.81 |
| $V_2$-20.0 | 7.00 | 6.40 | 6.10 | 5.61 |
| $V_3$-25.0 | 7.05 | 6.37 | 5.73 | 5.41 |
| $C_1$-20.0 | 6.41 | 6.36 | 6.20 | 6.09 |
| $C_2$-30.0 | 6.56 | 6.46 | 6.23 | 6.03 |
| $C_3$-40.0 | 6.68 | 6.65 | 6.41 | 6.01 |
| $N_1$-3.00 | 6.50 | 6.30 | 6.08 | 5.94 |
| $N_2$-4.50 | 7.24 | 7.10 | 6.28 | 5.85 |
| $N_3$-6.00 | 7.00 | 6.40 | 6.01 | 5.83 |
| Control | 7.08 | 6.65 | 6.42 | 6.12 |
| CD | 0.104 | 0.151 | NS | 0.040 |
| SE | 0.036 | 0.047 | --- | 0.044 |

CD Significant at 1% level. NS Non Significant

Table 45. Effect of organic manures on electrical conductivity (EC) ($dsm^{-1}$) during first, second year and after residual crop

| Treatments ($t\ ha^{-1}$) | Initial | $I^{rst}$ Year | $II^{nd}$ Year | Residual crop |
|---|---|---|---|---|
| $F_1$-20.0 | 0.297 | 0.347 | 0.477 | 0.486 |
| $F_2$-30.0 | 0.297 | 0.367 | 0.497 | 0.547 |
| $F_3$-40.0 | 0.320 | 0.387 | 0.527 | 0.647 |
| $V_1$-15.0 | 0.313 | 0.357 | 0.487 | 0.507 |
| $V_2$-20.0 | 0.316 | 0.377 | 0.507 | 0.587 |
| $V_3$-25.0 | 0.336 | 0.380 | 0.547 | 0.747 |
| $C_1$-20.0 | 0.293 | 0.343 | 0.467 | 0.487 |
| $C_2$-30.0 | 0.296 | 0.357 | 0.487 | 0.537 |
| $C_3$-40.0 | 0.326 | 0.377 | 0.517 | 0.607 |
| $N_1$-3.00 | 0.317 | 0.357 | 0.477 | 0.497 |
| $N_2$-4.50 | 0.307 | 0.367 | 0.507 | 0.547 |
| $N_3$-6.00 | 0.327 | 0.387 | 0.537 | 0.707 |
| Control | 0.277 | 0.317 | 0.447 | 0.467 |
| CD | 0.009 | 0.009 | 0.001 | 0.001 |
| SE | 0.005 | 0.031 | 0.005 | 0.005 |

CD Significant at 1% level

The value for control was 0.467 dsm$^{-1}$ which was least. Thus at the end of residual crop the electrical conductivity showed an increasing trend.

### 4.2.6.2.3. Organic carbon

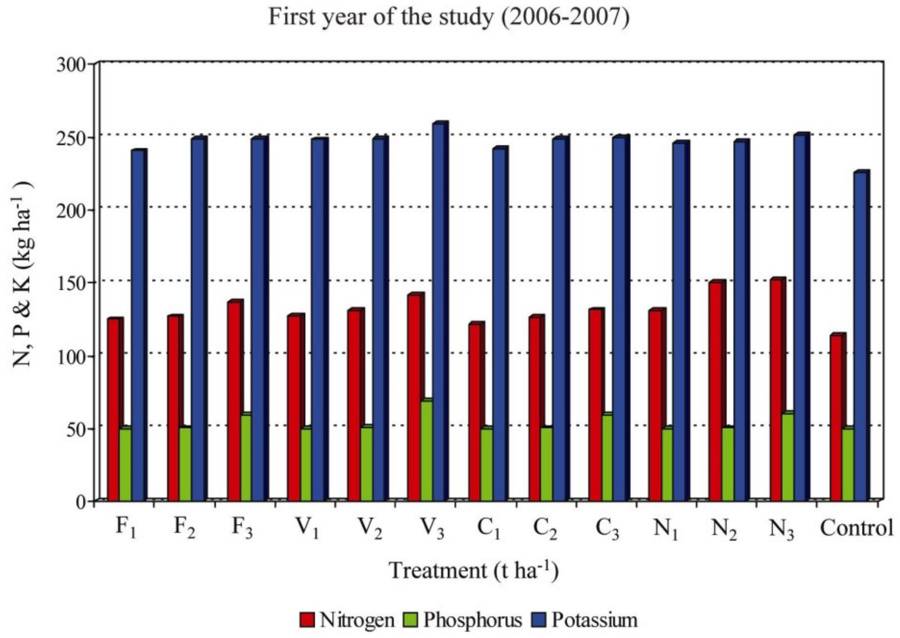
The organic carbon content of the soil before and after the first and second year of study and after the residual crop are presented in Table 46.

Different levels of organic manures showed significant variation in the organic carbon content of soil. At the end of first year, the organic carbon content was reduced in treatment $V_3$ from initial value (0.586 %) to 0.433 per cent and was highly significant. $N_3$ recorded an organic carbon of 0.44 per cent and $F_3$ (0.45%) and control (0.58%). At the end of second year, organic carbon content in $V_3$ was 0.29 per cent which was on par with $N_3$ (0.30%). The control recorded organic carbon content of 0.41 per cent. After the end of residual crop the least organic carbon content was noticed in $N_3$ (0.18%) which was on par with $F_3$ (0.19%) and $V_3$ (0.20%) whereas the control recorded 0.3 per cent of organic carbon.

### 4.2.6.2.4. Available Nitrogen

The available nitrogen content of soil before starting the experiment, after the first and second crop and after the residual crop is depicted in Table 47.

The available nitrogen content before the first year of experiment was generally low which increased after each experiment in plots where organic manures were given (Fig.12). At end of first year $N_3$ was significantly superior when compared to other treatments (152.04 Kg ha$^{-1}$). This was followed by $N_2$ which recorded an available nitrogen content of 150.07 Kg ha$^{-1}$, whereas the control recorded the least (113.44 Kg ha$^{-1}$).


First year of the study (2006-2007)

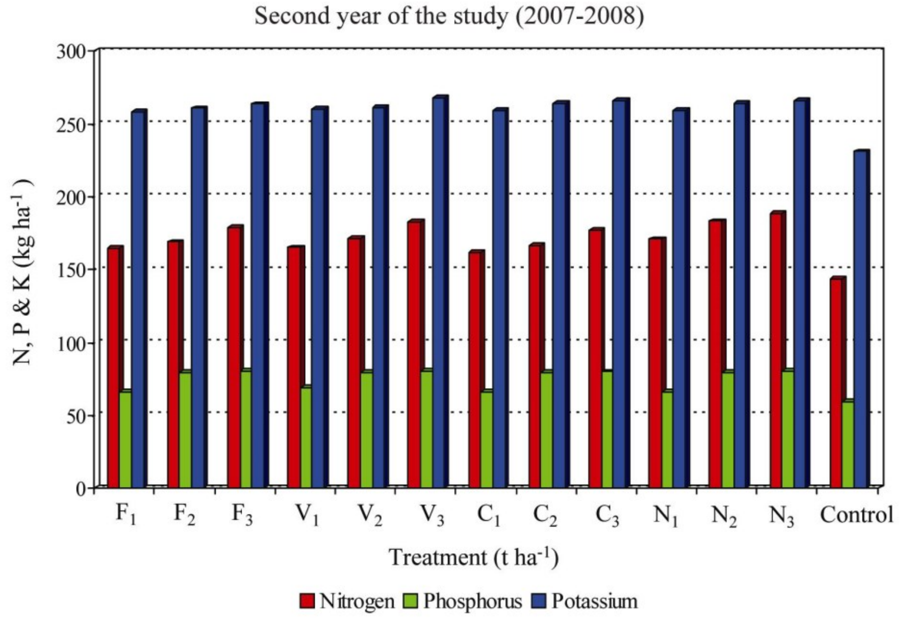

Second year of the study (2007-2008)

Fig. 12. Effect of organic manures on available nitrogen, phosphorus and potassium during first and second year of study

Table 46. Effect of organic manures on organic carbon (%) during first, second and after residual crop

| Treatments ($t\ ha^{-1}$) | Initial | I$^{rst}$ Year | II$^{nd}$ Year | Residual crop |
|---|---|---|---|---|
| $F_1$-20.0 | 0.616 | 0.550 | 0.41 | 0.25 |
| $F_2$-30.0 | 0.707 | 0.550 | 0.37 | 0.23 |
| $F_3$-40.0 | 0.507 | 0.450 | 0.32 | 0.19 |
| $V_1$-15.0 | 0.547 | 0.536 | 0.38 | 0.26 |
| $V_2$-20.0 | 0.616 | 0.510 | 0.32 | 0.21 |
| $V_3$-25.0 | 0.586 | 0.433 | 0.29 | 0.20 |
| $C_1$-20.0 | 0.593 | 0.583 | 0.41 | 0.27 |
| $C_2$-30.0 | 0.613 | 0.570 | 0.37 | 0.25 |
| $C_3$-40.0 | 0.627 | 0.510 | 0.33 | 0.21 |
| $N_1$-3.00 | 0.603 | 0.550 | 0.39 | 0.25 |
| $N_2$-4.50 | 0.657 | 0.520 | 0.33 | 0.21 |
| $N_3$-6.00 | 0.547 | 0.44 | 0.30 | 0.18 |
| Control | 0.616 | 0.58 | 0.41 | 0.30 |
| CD | 0.003 | 0.020 | 0.010 | 0.020 |
| SE | 0.173 | 0.054 | 0.054 | 0.031 |

CD Significant at 1% level

Table 47. Effect of organic manures on available nitrogen. (kg ha$^{-1}$) during first, second year and after residual crop

| Treatments (t ha$^{-1}$) | Initial | I$^{rst}$ Year | II$^{nd}$ Year | Residual crop | Pooled mean |
|---|---|---|---|---|---|
| $F_1$-20.0 | 111.90 | 124.63 | 164.44 | 181.41 | 147.59 |
| $F_2$-30.0 | 112.22 | 126.58 | 168.61 | 183.06 | 147.61 |
| $F_3$-40.0 | 112.55 | 136.54 | 179.03 | 191.77 | 154.97 |
| $V_1$-15.0 | 110.79 | 127.36 | 164.84 | 181.55 | 146.14 |
| $V_2$-20.0 | 112.94 | 131.24 | 171.27 | 190.27 | 151.43 |
| $V_3$-25.0 | 113.15 | 141.34 | 182.65 | 195.98 | 158.28 |
| $C_1$-20.0 | 111.00 | 121.56 | 161.84 | 181.51 | 143.98 |
| $C_2$-30.0 | 112.26 | 125.76 | 166.51 | 182.72 | 146.81 |
| $C_3$-40.0 | 112.95 | 131.42 | 176.39 | 188.89 | 152.41 |
| $N_1$-3.00 | 112.07 | 131.01 | 170.46 | 186.69 | 150.06 |
| $N_2$-4.50 | 112.34 | 150.07 | 183.00 | 192.49 | 150.48 |
| $N_3$-6.00 | 112.87 | 152.04 | 187.85 | 198.67 | 162.85 |
| Control | 111.62 | 113.44 | 143.57 | 161.14 | 132.44 |
| CD | 1.962 | 1.284 | 2.067 | 1.397 | 2.340 |
| SE | 0.673 | 0.439 | 0.707 | 0.478 | 0.512 |

CD Significant at 1% level

The available nitrogen content gradually increased at the end of second year of experiment. Here, the treatment $N_3$ was significantly superior and recorded the maximum available nitrogen content in soil (187.85 Kg $ha^{-1}$). This was followed by $N_2$ (183.0 Kg $ha^{-1}$), $V_3$ (182.65 Kg $ha^{-1}$) and $F_3$ (179.03 Kg $ha^{-1}$). The control recorded least available Nitrogen content of 143.57 Kg $ha^{-1}$ at the end of second year. But after harvesting the residual crop, when the soil was analysed, this was found to increase from the initial value and $N_3$ was significantly superior (198.67 Kg $ha^{-1}$). This was followed by $N_2$ (192.49 Kg $ha^{-1}$) and $V_3$ (195.98 Kg $ha^{-1}$). The lowest available nitrogen content value was recorded by $F_1$ (181.41 Kg $ha^{-1}$), whereas the control recorded the least value (161.14 Kg $ha^{-1}$).

The pooled results revealed that the available nitrogen content was significant. When analysis done mean values of $N_3$ was found significantly superior with the highest available nitrogen content (162.85 Kg $ha^{-1}$). This was followed by $V_3$ (158.28 Kg $ha^{-1}$) $F_3$ (154.97 Kg $ha^{-1}$) and $V_2$ (151.43 Kg $ha^{-1}$) whereas the for control plots recorded least pooled mean (132.44 Kg $ha^{-1}$) with respect to available nitrogen content in soil.

### 4.2.6.2.5. Available phosphorus

The effect of different organic manures on the available phosphorus content of the soil before, after the first and second year of experiment and after the residual crop are indicated in the Table 48 (Fig.12).

At the end of first year $V_3$ was superior and recorded the maximum available phosphorus content of 68.91 Kg$ha^{-1}$ followed by $N_3$ with 60.41 Kg $ha^{-1}$. The control recorded least value of only 49.82 Kg $ha^{-1}$ .But at the end of second year of study the mean value showed that $V_3$ and $N_3$ were on par and recorded an available phosphorus content of 80.63 Kg $ha^{-1}$ and 80.62 Kg $ha^{-1}$, respectively. This was followed by $F_3$ (80.26 Kg $ha^{-1}$) and the control recorded least available phosphorus content (59.63 Kg $ha^{-1}$).

Table 48. Effect of organic manures on available $P_2O_5$ (kg ha$^{-1}$) during first, second year and residual crop

| Treatments (t ha$^{-1}$) | Initial | I$^{rst}$ Year | II$^{nd}$ Year | Residual crop | Pooled mean |
|---|---|---|---|---|---|
| $F_1$-20.0 | 41.20 | 49.82 | 65.77 | 66.73 | 58.85 |
| $F_2$-30.0 | 42.01 | 50.22 | 79.47 | 79.37 | 62.78 |
| $F_3$-40.0 | 43.32 | 59.69 | 80.26 | 80.98 | 66.06 |
| $V_1$-15.0 | 41.94 | 49.97 | 68.79 | 69.37 | 57.52 |
| $V_2$-20.0 | 42.43 | 50.60 | 79.47 | 80.06 | 63.14 |
| $V_3$-25.0 | 48.90 | 68.91 | 80.62 | 83.70 | 70.53 |
| $C_1$-20.0 | 40.89 | 49.75 | 65.69 | 66.25 | 55.65 |
| $C_2$-30.0 | 41.74 | 50.28 | 79.07 | 79.34 | 62.60 |
| $C_3$-40.0 | 42.31 | 59.52 | 79.82 | 80.56 | 65.55 |
| $N_1$-3.00 | 41.24 | 49.77 | 65.93 | 68.96 | 56.48 |
| $N_2$-4.50 | 41.62 | 50.27 | 79.61 | 79.88 | 62.85 |
| $N_3$-6.00 | 45.60 | 60.41 | 80.63 | 80.96 | 66.90 |
| Control | 39.11 | 49.82 | 59.63 | 61.57 | 52.53 |
| CD | 0.483 | 0.010 | 0.219 | 0.351 | 1.380 |
| SE | 0.005 | 0.242 | 0.054 | 0.118 | 0.144 |

CD Significant at 1% level

At the end of residual crop as well, $V_3$ was significantly superior and recorded an available phosphorus content of 83.70 kg $ha^{-1}$.But $V_3$ was on par with $F_3$ and $N_3$ the values recorded being 80.98 and 80.96 kg $ha^{-1}$, respectively, On the contrary the control recorded the least content of available phosphorus (61.57 kg $ha^{-1}$).

The pooled mean for available phosphorus is also presented in Table 48. There was significant influence in available phosphorus by various organic manures. $V_3$ recorded the maximum available phosphorus content (70.53 kg $ha^{-1}$) at the end of experiment, which was superior to all other treatments. This was closely followed by $N_3$ (66.9 kg $ha^{-1}$), $F_3$ (66.06 Kg $ha^{-1}$) and $C_3$ (65.55 kg $ha^{-1}$) which were, on par whereas the control recorded least pooled mean value (52.53 kg $ha^{-1}$).

### 4.2.6.2.6. Available potassium

The effect of various organic manures on the available potassium content of the soil before the experiment, after the first, second crop and residual crop are provided in Table 49 (Fig.12).

At the end of first year of experiment $V_3$ was significantly superior and recorded $K_2O$ content of 258.74 kg $ha^{-1}$. The control recorded 225.17 kg $ha^{-1}$. At the end of second year the available potassium status was found to increase. The treatment $V_3$ was found significantly superior with an increased available potassium content of 267.80 kg $ha^{-1}$, followed by $N_3$ (265.71 kg $ha^{-1}$). The control recorded least available potassium content (230.71 kg $ha^{-1}$) at the end of second year also. There was a high content of available potassium after taking the residual crop and $V_3$ recorded the highest mean value of 280.75 kg $ha^{-1}$ which was on par with $F_3$ and $C_3$.The available potassium content in $F_3$ and $C_3$ were 280.58 and 280.53 kg $ha^{-1}$, respectively. The control after the residual crop recorded the least available potassium content of 241.21 kg $ha^{-1}$.

Table 49. Effect of organic manures on available $K_2O$ (kg $ha^{-1}$) during first, second year and after residual crop

| Treatments (t $ha^{-1}$) | Initial | $I^{rst}$ Year | $II^{nd}$ Year | Residual crop | Pooled mean |
|---|---|---|---|---|---|
| $F_1$-20.0 | 208.62 | 240.26 | 258.04 | 259.75 | 241.67 |
| $F_2$-30.0 | 214.93 | 248.28 | 260.19 | 275.82 | 249.80 |
| $F_3$-40.0 | 217.58 | 248.71 | 263.12 | 280.58 | 252.50 |
| $V_1$-15.0 | 211.38 | 247.81 | 260.07 | 268.62 | 246.97 |
| $V_2$-20.0 | 214.98 | 248.27 | 260.96 | 280.48 | 251.17 |
| $V_3$-25.0 | 218.51 | 258.74 | 267.80 | 280.75 | 256.45 |
| $C_1$-20.0 | 208.47 | 241.27 | 258.80 | 258.18 | 241.68 |
| $C_2$-30.0 | 215.42 | 248.19 | 263.98 | 270.63 | 249.55 |
| $C_3$-40.0 | 215.61 | 249.56 | 265.61 | 280.53 | 252.82 |
| $N_1$-3.00 | 208.50 | 245.61 | 258.80 | 268.52 | 245.36 |
| $N_2$-4.50 | 214.73 | 246.39 | 263.98 | 279.78 | 251.22 |
| $N_3$-6.00 | 217.10 | 251.46 | 265.61 | 280.11 | 253.50 |
| Control | 206.38 | 225.17 | 230.71 | 241.21 | 225.87 |
| CD | 2.291 | 1.343 | 2.064 | 0.421 | 2.350 |
| SE | 0.784 | 0.460 | 0.707 | 0.145 | 0.439 |

CD Significant at 1% level

The pooled mean data on available potassium after the termination of all experiments was found to be significant. The pooled mean obtained from $V_3$ gave maximum available potassium content (256.45 kg $ha^{-1}$) at the end of the experiment. This was followed by $N_3$ (253.50 kg $ha^{-1}$), $C_3$ (252.82 kg $ha^{-1}$) and $F_3$ (252.56 kg $ha^{-1}$) which were on par. The pooled mean also showed that available potassium content was least in control (225.87 kg $ha^{-1}$).

### 4.2.7. Plant analysis

#### *4.2.7.1. Uptake of nitrogen*

The effects of various organic manures on the uptake of nitrogen by kasthuri turmeric plants during first and second year of experiment are presented in Table 50.

The effect of various organic manures on the uptake of nitrogen in plants was significant in both the years. At the end of first experiment, when the plant samples were analysed, the uptake of N was found to be significantly superior in $V_3$ (91.65 kg $ha^{-1}$) when compared to all other treatments. This was followed by $N_3$ and $F_3$ which were on par the value recorded being 90.31 kg $ha^{-1}$ and 90.07 kg $ha^{-1}$, respectively. The control recorded least value of 77.37 kg $ha^{-1}$ of N. During second year also $V_3$ recorded maximum uptake of nitrogen of 94.70 kg $ha^{-1}$. This was followed by $N_3$.

The pooled analysis (Table 50) showed that there was significant influence in the uptake of N. The treatment $V_3$ recorded the highest uptake of N (93.18 kg $ha^{-1}$) which was on par with $N_3$ (91.99 kg $ha^{-1}$). The control recorded the least pooled mean value for uptake of N (78.71 kg $ha^{-1}$).

Table 50. Effect of organic manures on uptake of nitrogen (kg ha$^{-1}$) *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | I$^{st}$ Year | II$^{nd}$ Year | Pooled mean |
|---|---|---|---|
| $F_1$-20.0 | 86.07 | 90.27 | 88.17 |
| $F_2$-30.0 | 87.39 | 91.67 | 89.53 |
| $F_3$-40.0 | 90.07 | 93.12 | 91.60 |
| $V_1$-15.0 | 86.12 | 90.63 | 88.38 |
| $V_2$-20.0 | 87.35 | 92.65 | 90.00 |
| $V_3$-25.0 | 91.65 | 94.70 | 93.18 |
| $C_1$-20.0 | 86.01 | 90.31 | 88.16 |
| $C_2$-30.0 | 86.26 | 91.56 | 88.91 |
| $C_3$-40.0 | 88.64 | 91.97 | 90.31 |
| $N_1$-3.00 | 86.79 | 90.35 | 88.57 |
| $N_2$-4.50 | 88.16 | 92.47 | 90.32 |
| $N_3$-6.00 | 90.31 | 93.67 | 91.99 |
| Control | 77.37 | 80.05 | 78.71 |
| CD | 0.820 | 0.379 | 1.110 |
| SE | 0.281 | 0.001 | 0.017 |

CD Significant at 1% level

### *4.2.7.2. Uptake of phosphorus*

The data on uptake of phosphorus at the end of both the years of experiment are presented in Table 51.

The treatment $V_3$ resulted in higher uptake of P (15.88 kg ha$^{-1}$) which was on par with $N_3$ (15.75 kg ha$^{-1}$ ) after completing the first year study. Samples of $C_1$ recorded a low uptake of P (12.83 kg ha$^{-1}$) and in control the uptake was the least (10.25 kg ha$^{-1}$). At the end of second year also the uptake of P was maximum for $V_3$ (17.85 kg ha$^{-1}$) which was significantly superior. This was followed by $N_3$ (17.67 kg ha$^{-1}$), whereas $N_2$ and $F_3$ recorded the same value (17.25 kg ha$^{-1}$). The uptake of P was least in the plants given no treatment (control).

The pooled mean for uptake of P is presented in Table 51. There was significant influence in uptake of P during both the years. The pooled mean data revealed that $V_3$ recorded the maximum P uptake (16.87 kg ha$^{-1}$) which was on par with $N_3$, $F_3$ and $C_3$ which in turn recorded values of 16.71, 16.49 and 16.30 kg ha$^{-1}$, respectively. Among various organic manures $C_1$ treated plants recorded a lower uptake of P and the least in control. (10.76 kg ha$^{-1}$).

### *4.2.7.3. Uptake of potassium*

The data on the uptake of potassium after each experiment are presented in Table 52.

Application of different organic manures significantly favoured the uptake of potassium. $C_3$ resulted in significantly higher plant uptake of potassium (103.21 kg ha$^{-1}$) which was on par with $N_3$ (103.13 kg ha$^{-1}$) .This was followed by $V_3$ (102.52 kg ha$^{-1}$)when the plant samples were analysed after completing the first experiment. But at the end of second year, the uptake of K was found significantly superior in $V_3$ (115.37 kg ha$^{-1}$) followed by $N_3$ (113.65 kg ha$^{-1}$) which was on par with $C_3$.

Table 51. Effect of organic manures on uptake of phosphorous (kg ha$^{-1}$) in *Curcuma aromatica* Salisb. during first and second year of study

| Treatments (t ha$^{-1}$) | I$^{st}$ Year | II$^{nd}$ Year | Pooled mean |
|---|---|---|---|
| $F_1$-20.0 | 13.37 | 15.62 | 14.50 |
| $F_2$-30.0 | 14.52 | 16.75 | 15.64 |
| $F_3$-40.0 | 15.72 | 17.25 | 16.49 |
| $V_1$-15.0 | 14.08 | 16.28 | 15.18 |
| $V_2$-20.0 | 15.32 | 16.92 | 16.12 |
| $V_3$-25.0 | 15.88 | 17.85 | 16.87 |
| $C_1$-20.0 | 12.83 | 15.19 | 14.01 |
| $C_2$-30.0 | 14.28 | 16.53 | 15.41 |
| $C_3$-40.0 | 15.53 | 17.07 | 16.30 |
| $N_1$-3.00 | 13.69 | 16.11 | 14.90 |
| $N_2$-4.50 | 14.68 | 17.25 | 15.97 |
| $N_3$-6.00 | 15.75 | 17.67 | 16.71 |
| Control | 10.25 | 11.27 | 10.76 |
| CD | 0.178 | 0.128 | 0.470 |
| SE | 0.054 | 0.044 | 0.047 |

CD Significant at 1% level

Table 52. Effect of organic manures on uptake of potassium (kg ha$^{-1}$) in *Curcuma aromatica* Salisb.during first and second year of study

| Treatments (t ha$^{-1}$) | I$^{st}$ Year | II$^{nd}$ Year | Pooled mean |
|---|---|---|---|
| $F_1$-20 .0 | 85.46 | 110.54 | 98.00 |
| $F_2$-30 .0 | 89.74 | 112.69 | 101.29 |
| $F_3$-40 .0 | 102.82 | 112.83 | 107.83 |
| $V_1$-15.0 | 72.30 | 111.77 | 92.04 |
| $V_2$-20.0 | 98.61 | 113.05 | 105.83 |
| $V_3$ -25.0 | 102.52 | 115.37 | 108.95 |
| $C_1$-20 .0 | 83.66 | 105.62 | 94.64 |
| $C_2$-30.0 | 94.20 | 113.01 | 103.61 |
| $C_3$-40.0 | 103.21 | 113.66 | 108.44 |
| $N_1$-3.00 | 95.65 | 110.81 | 103.23 |
| $N_2$-4.50 | 102.06 | 112.9 | 107.48 |
| $N_3$-6.00 | 103.13 | 113.65 | 108.39 |
| Control | 77.28 | 79.49 | 78.39 |
| CD | 0.570 | 0.243 | 2.350 |
| SE | 0.141 | 0.100 | 0.114 |

CD Significant at 1% level

The control plants recorded a least value when analysed after the first experiment (77.28 kg ha$^{-1}$) and second experiment (79.49 kg ha$^{-1}$).

The mean of pooled data with respect to uptake of K was found statistically significant for various organic manure treatment in both the years of experiment. The pooled mean of $V_3$ recorded the maximum uptake of K (108.95 kg ha$^{-1}$) during both the years. This was followed by $N_3$ (108.39 kg ha$^{-1}$) and $F_3$ (107.83 kg ha$^{-1}$) where uptake of K was on par. The control recorded least pooled mean for uptake of K during both the years.

### 4.2.8. Nutrient balance sheet

#### *4.2.8.1. Nutrient balance sheet for nitrogen*

The nutrient balance sheet for available nitrogen during first and second year of experimentation, is presented in Table 53 and 54, respectively. A considerable loss of nitrogen was observed during the first year in all the treatments (Table 53) whereas during the second year the loss was comparatively low (Table 54). In the first year of study, among different organic manures, tried, the loss was comparatively lower in $C_1$ treated plants followed by $N_1$ (44.27 kg ha$^{-1}$). The loss was highest in FYM treated plots (3.43 kg ha$^{-1}$).

But during second year, there was a gain of nitrogen in $C_1$ (41.15 kg ha$^{-1}$). The loss was least in $N_1$ (1.26 kg ha$^{-1}$), $C_2$ (4.19 kg ha$^{-1}$) and $V_1$ (5.32 kg ha$^{-1}$), whereas it was highest in FYM treated plots. In the first year the loss of nitrogen was highest in FYM treated plots.

#### *4.2.8.2. Nutrient Balance sheet for phosphorus*

Table 55 and 56 represents the nutrient balance sheet for available phosphorus for the first and second year of experimentation.

Table 53. Nutrient balance sheet of nitrogen during first year of study

| Treatments (t ha$^{-1}$) | Initial (Y) (Kg ha$^{-1}$ ) | N addition (A) (Kg ha$^{-1}$) | N uptake (B) (Kg ha$^{1}$ ) | Expected balance (C) (Kg ha$^{-1}$ ) | Available N (Kg ha$^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| F$_1$-20.0 | 111.90 | 200 | 86.07 | 225.83 | 124.63 | -101.20 |
| F$_2$-30.0 | 112.22 | 300 | 87.39 | 324.83 | 126.58 | -198.25 |
| F$_3$-40.0 | 112.55 | 400 | 90.07 | 422.48 | 136.54 | -285.94 |
| V$_1$-15.0 | 110.79 | 150 | 86.12 | 174.67 | 127.36 | -47.31 |
| V$_2$-20.0 | 112.94 | 200 | 87.35 | 225.59 | 131.24 | -94.35 |
| V$_3$-25.0 | 113.95 | 250 | 91.65 | 271.50 | 141.34 | -130.16 |
| C$_1$-20.0 | 111.00 | 100 | 86.01 | 124.99 | 121.56 | -3.43 |
| C$_2$-30.0 | 112.26 | 150 | 86.26 | 176.00 | 125.96 | -50.24 |
| C$_3$-40.0 | 112.95 | 200 | 88.64 | 224.31 | 131.42 | -92.89 |
| N$_1$-3.00 | 112.07 | 150 | 86.79 | 175.28 | 131.01 | -44.27 |
| N$_2$-4.50 | 112.34 | 225 | 88.16 | 249.18 | 150.07 | -99.11 |
| N$_3$-6.00 | 112.89 | 300 | 90.31 | 322.56 | 152.04 | -170.92 |

Table 54. Nutrient balance sheet for nitrogen during second year of study

| Treatments (t ha$^{-1}$) | Initial (Y) (Kg ha$^{-1}$ ) | N addition (A) (Kg ha$^{-1}$) | N uptake (B) (Kg ha$^{1}$ ) | Expected balance (C) (Kg ha$^{-1}$ ) | Available N (Kg ha$^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| $F_1$-20.0 | 111.90 | 200 | 90.27 | 221.63 | 164.44 | -57.19 |
| $F_2$-30.0 | 112.22 | 300 | 91.67 | 320.55 | 168.61 | -151.94 |
| $F_3$-40.0 | 112.55 | 400 | 93.12 | 419.43 | 179.03 | -240.4 |
| $V_1$-15.0 | 110.79 | 150 | 90.63 | 170.16 | 164.84 | -5.32 |
| $V_2$-20.0 | 112.94 | 200 | 92.65 | 220.29 | 171.27 | -49.02 |
| $V_3$-25.0 | 113.95 | 250 | 94.70 | 218.45 | 182.65 | -35.80 |
| $C_1$-20.0 | 111.00 | 100 | 90.31 | 120.69 | 161.84 | +41.15 |
| $C_2$-30.0 | 112.26 | 150 | 91.56 | 170.70 | 166.57 | -4.19 |
| $C_3$-40.0 | 112.95 | 200 | 91.97 | 220.98 | 176.39 | -44.59 |
| $N_1$-3.00 | 112.07 | 150 | 90.35 | 171.72 | 170.46 | -1.26 |
| $N_2$-4.50 | 112.34 | 225 | 92.47 | 113.67 | 183.00 | -60.33 |
| $N_3$-6.00 | 112.89 | 300 | 93.67 | 319.20 | 187.85 | -131.35 |

Table 55. Nutrient balance sheet for phosphorous during first year of study

| Treatments (t ha$^{-1}$) | Initial (Y) (Kg ha$^{-1}$ ) | P addition (A) (Kg ha$^{-1}$) | P uptake (B) (Kg ha$^{1}$ ) | Expected balance (C) (Kg ha$^{-1}$ ) | Available P (Kg ha$^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| $F_1$-20.0 | 41.20 | 100.00 | 13.37 | 127.83 | 49.82 | -78.01 |
| $F_2$-30.0 | 42.01 | 150.00 | 14.52 | 177.49 | 50.22 | -127.27 |
| $F_3$-40.0 | 43.32 | 200.00 | 15.72 | 227.60 | 59.69 | -167.91 |
| $V_1$-15.0 | 41.94 | 120.00 | 14.08 | 147.86 | 49.97 | -97.81 |
| $V_2$-20.0 | 42.43 | 160.00 | 15.32 | 187.11 | 50.60 | -136.51 |
| $V_3$-25.0 | 48.90 | 200.00 | 15.88 | 233.02 | 68.91 | -164.11 |
| $C_1$-20.0 | 40.89 | 80.00 | 12.83 | 108.06 | 49.75 | -58.31 |
| $C_2$-30.0 | 41.74 | 120.00 | 14.28 | 147.46 | 50.28 | -97.18 |
| $C_3$-40.0 | 42.31 | 160.00 | 15.53 | 186.78 | 59.52 | -127.26 |
| $N_1$-3.00 | 41.24 | 30.00 | 13.69 | 57.55 | 49.77 | -7.78 |
| $N_2$-4.50 | 41.62 | 45.00 | 14.68 | 71.94 | 50.27 | -21.67 |
| $N_3$-6.00 | 45.60 | 60.00 | 15.75 | 89.85 | 60.41 | -29.44 |

Table 56. Nutrient balance sheet for phosphorous during second year of study

| Treatments ($t\ ha^{-1}$) | Initial (Y) ($Kg\ ha^{-1}$) | P addition (A) ($Kg\ ha^{-1}$) | P uptake (B) ($Kg\ ha^{-1}$) | Expected balance (C) ($Kg\ ha^{-1}$) | Available P ($Kg\ ha^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| $F_1$-20.0 | 41.20 | 100.00 | 15.62 | 125.58 | 65.77 | -59.81 |
| $F_2$-30.0 | 42.01 | 150.00 | 16.75 | 175.26 | 79.47 | -95.79 |
| $F_3$-40.0 | 43.32 | 200.00 | 17.25 | 226.07 | 80.26 | -145.81 |
| $V_1$-15.0 | 41.94 | 120.00 | 16.28 | 145.66 | 68.79 | -76.87 |
| $V_2$-20.0 | 42.43 | 160.00 | 16.92 | 185.51 | 79.47 | -105.04 |
| $V_3$-25.0 | 48.90 | 200.00 | 17.85 | 231.05 | 80.62 | -150.43 |
| $C_1$-20.0 | 40.89 | 80.00 | 15.19 | 105.70 | 65.69 | -40.01 |
| $C_2$-30.0 | 41.74 | 120.00 | 16.53 | 145.21 | 79.07 | -66.14 |
| $C_3$-40.0 | 42.31 | 160.00 | 17.07 | 185.24 | 79.82 | -105.42 |
| $N_1$-3.00 | 41.24 | 30.00 | 16.11 | 55.13 | 65.93 | +10.80 |
| $N_2$-4.50 | 41.62 | 45.00 | 17.25 | 69.37 | 79.61 | +1.02 |
| $N_3$-6.00 | 45.60 | 60.00 | 17.67 | 87.93 | 80.63 | -7.30 |

During the first year, the net loss of available phosphorus was less in neem cake treated plots whereas it was more in FYM and vermicompost treated plots. On the other hand, during second year, there was a gain of 10.8 kg ha$^{-1}$ of available P in treatment $N_1$ and $N_2$ (1.02 kg ha$^{-1}$). A minimum loss of available phosphorus was noticed in $N_3$ (7.3 kg ha$^{-1}$). But the net loss was more in other treatments.

### *4.2.8.3. Nutrient Balance sheet for potassium*

The balance sheet of available potassium for the first and second year of experimentation is presented in Table 57 and 58.

During the first year, there was a loss in available potassium among the organic manure treatments. However, there was a minimum loss in neem cake treated plots. In $N_3$ treated plots the loss was 47.49 kg ha$^{-1}$. The loss was highest in coir pith compost treated plots compared to other treatments. In $C_3$ the loss was 422.84 kg ha$^{-1}$. During second year, the loss was comparatively low. But there was a net gain in available potassium in neem cake treated plots. The gain in $N_1$ was 116.11, $N_2$ 94.69 and $N_3$ 72.16 Kg ha$^{-1}$. But there was more loss in coir pith compost and vermicompost treated plots.

### 4.2.9. Incidence of pest and Diseases

No serious pests and diseases were noted during the crop growth. But in certain pockets a mild attack of top shoot borer (*Conogethes punctiferalis*) were noted during the early stages of growth in both the years of study. For controlling this pests, the affected the shoots were removed and a fortnightly spray of Nimbicidine two per cent was given. Apart from this, mild incidence of rhizome rot caused by *Pythium* sp. was also noticed in the field. Drenching the beds with per cent *Pseudomonas flourescens* was done to prevent the spread of this disease. But during second crop as a precautionary measure, 2 g *Trichoderma viride* per pit was applied along with the rhizome bits while planting.

Table 57. Nutrient balance sheet for potassium during first year of study

| Treatments (t ha$^{-1}$) | Initial (Y) (Kg ha$^{-1}$ ) | K addition (A) (Kg ha$^{-1}$) | K uptake (B) (Kg ha$^{-1}$ ) | Expected balance (C) (Kg ha$^{-1}$ ) | Available K (Kg ha$^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| $F_1$-20.0 | 208.62 | 200.00 | 85.46 | 323.16 | 240.26 | -82.9 |
| $F_2$-30.0 | 214.93 | 300.00 | 89.74 | 425.19 | 248.28 | -176.91 |
| $F_3$-40.0 | 217.58 | 400.00 | 102.82 | 514.76 | 248.71 | -266.05 |
| $V_1$-15.0 | 211.38 | 240.00 | 72.30 | 379.08 | 247.81 | -131.27 |
| $V_2$-20.0 | 214.98 | 320.00 | 98.61 | 436.37 | 248.27 | -188.10 |
| $V_3$-25.0 | 218.57 | 400.00 | 102.52 | 516.05 | 258.74 | -257.31 |
| $C_1$-20.0 | 208.47 | 280.00 | 83.66 | 404.81 | 241.27 | -163.54 |
| $C_2$-30.0 | 215.42 | 420.00 | 94.20 | 541.22 | 248.19 | -293.03 |
| $C_3$-40.0 | 215.61 | 560.00 | 103.21 | 672.40 | 249.56 | -422.84 |
| $N_1$-3.00 | 208.50 | 45.00 | 95.65 | 157.85 | 245.61 | -87.76 |
| $N_2$-4.50 | 214.73 | 67.50 | 102.06 | 180.17 | 246.39 | -66.22 |
| $N_3$-6.00 | 217.10 | 90.00 | 103.13 | 203.97 | 257.46 | -47.49 |

Table 58. Nutrient balance sheet for potassium during second year of study

| Treatments ($t\ ha^{-1}$) | Initial (Y) ($kg\ ha^{-1}$) | K addition (A) ($kg\ ha^{-1}$) | K uptake (B) ($kg\ ha^{-1}$) | Expected balance (C) ($kg\ ha^{-1}$) | Available K ($kg\ ha^{-1}$) | Net loss or gain |
|---|---|---|---|---|---|---|
| $F_1$-20.0 | 208.62 | 200.00 | 110.54 | 290.08 | 258.04 | -32.04 |
| $F_2$-30.0 | 214.93 | 300.00 | 112.69 | 402.24 | 260.19 | -142.05 |
| $F_3$-40.0 | 217.58 | 400.00 | 112.83 | 504.75 | 263.12 | -241.63 |
| $V_1$-15.0 | 211.38 | 240.00 | 111.77 | 339.61 | 260.0 | -79.54 |
| $V_2$-20.0 | 214.98 | 320.00 | 113.05 | 421.93 | 260.96 | -160.97 |
| $V_3$-25.0 | 218.57 | 400.00 | 115.37 | 503.20 | 267.80 | -235.40 |
| $C_1$-20.0 | 208.47 | 280.00 | 105.62 | 344.85 | 258.80 | -86.05 |
| $C_2$-30.0 | 215.42 | 420.00 | 113.01 | 522.41 | 263.98 | -258.43 |
| $C_3$-40.0 | 215.61 | 560.00 | 113.66 | 661.95 | 265.61 | -396.34 |
| $N_1$-3.00 | 208.50 | 45.00 | 110.81 | 142.69 | 258.80 | +116.11 |
| $N_2$-4.50 | 214.73 | 67.50 | 112.90 | 169.33 | 263.98 | +94.69 |
| $N_3$-6.00 | 217.10 | 90.00 | 113.65 | 193.45 | 265.61 | +72.16 |

### 4.2.10. Benefit : cost ratio

The economics of cultivation of kasthuri turmeric using organic manures are presented in Table 59 and 60 for the first and second year of experimentation. During first year, it is evident that application of $V_3$ (vermicompost 25t $ha^{-1}$) resulted in higher net return (Rs. 7,65,715 $ha^{-1}$) with a B:C ratio of 4.7 and the application of neemcake $N_3$ (6.0 t $ha^{-1}$) produced a net return of Rs. 7,27,575 $ha^{-1}$ with a B:C ratio of 4.4. The control produced a B:C ratio of 2.6, which resulted in a net return of Rs. 3,63,715 (Fig 13).

For the second year of experimentation, the net return was higher than the first year. The net return was highest for $V_3$ (Rs. 8,61,919 $ha^{-1}$) and the ratio was 5.7, this was followed by $N_3$ with a net return of Rs 8,01,525 $ha^{-1}$ and B:C ratio of 4.9. The least profit was from control which recorded B:C ratio of 1.2 which resulted in a net return of Rs 1.39,665 $ha^{-1}$ (Fig 13).

## 4.3. EXPERIMENT III

### Residual effect of different organic manures on succeeding vegetable crop (amaranthus)

The experiment on Residual effect of different organic manures on succeeding vegetable crop (Amaranthus) was conducted to evaluate the residual effect of previous experiment (Plate 8). The biomass yield of residual crop (amaranthus) was recorded. The data given in Table 61 clearly indicate that various organic manures applied to kasthuric turmeric showed significant influence on the yield of succeeding crop amaranthus. $N_3$ and $V_3$ were on par but significantly superior to all other treatments and recorded a biomass yield of 11.39 t $ha^{-1}$ and 10.41 t $ha^{-1}$, respectively. Treatments $F_3$ and $N_2$ were on par recording a biomass yield of 9.72 and 9.36 t $ha^{-1}$, respectively. The control recorded least biomass yield (5.40 t $ha^{-1}$) (Fig.14).

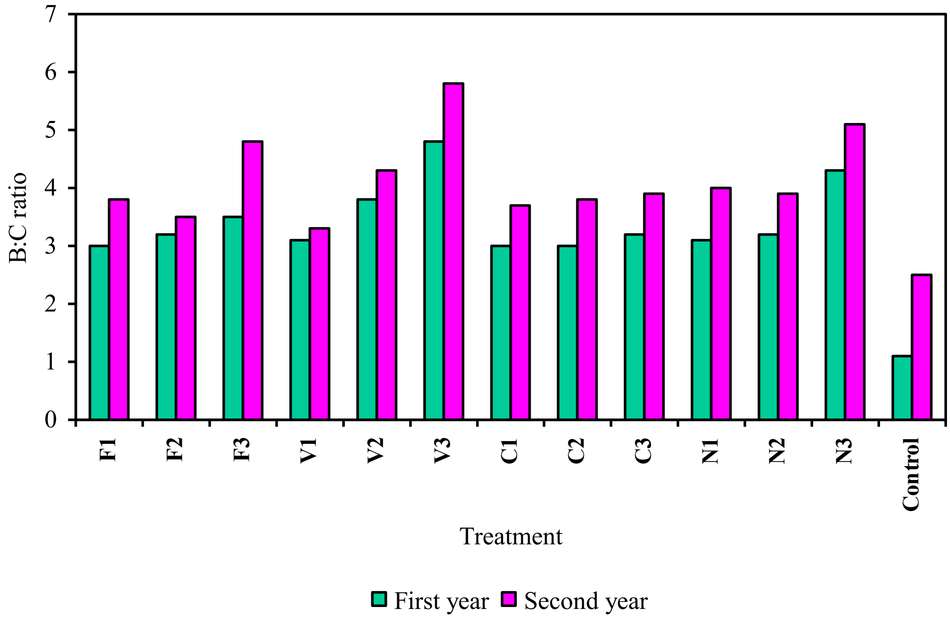


Fig. 13. Economics of cultivation in *Curcuma aromatica* Salisb. during first and second year of study

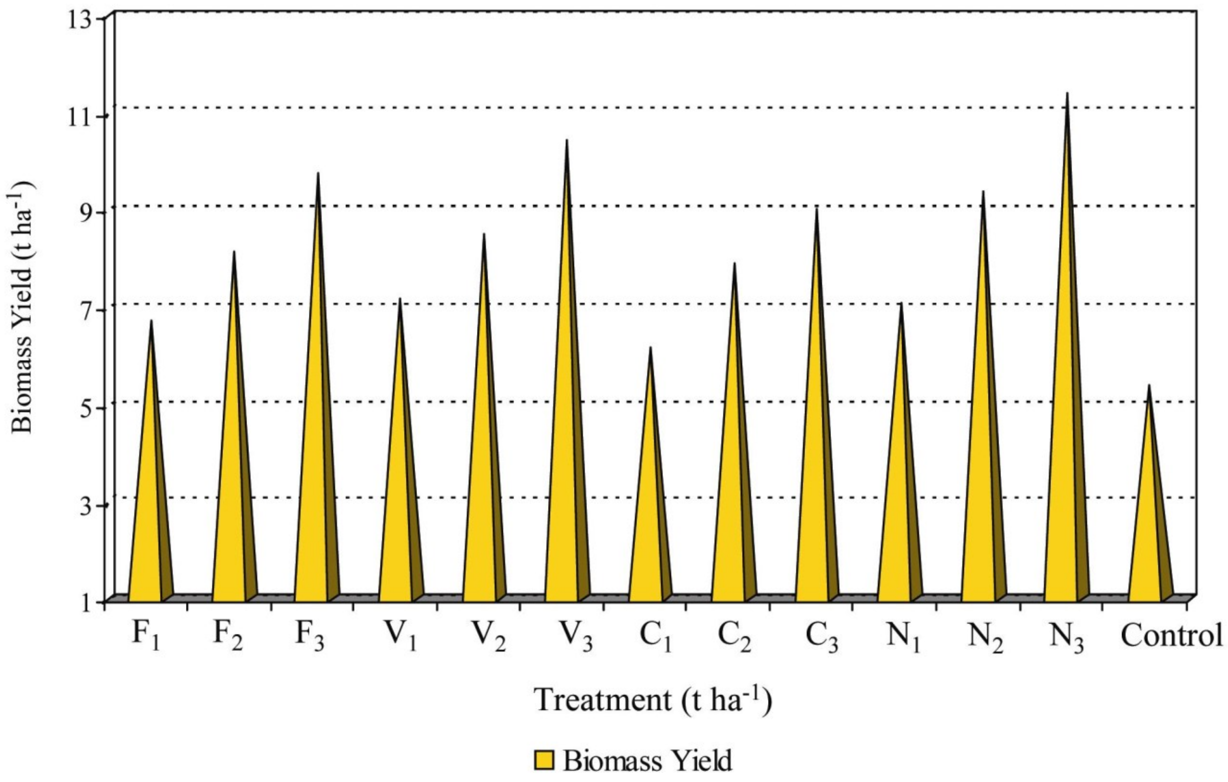


Fig. 14. Residual effect of organic manures on the yield of succeeding crop (amaranthus) (t ha $^{-1}$)

Plate 8. Field view of Experiment III (Residual crop)

Table 59. Economics of cultivation in *Curcuma aromatica* Salisb.during first year of study

| Treatment (t ha$^{-1}$) | Fresh Yield (t ha$^{-1}$) | Value of fresh rhizome (Rs.) | Cost | Profit | B:C |
|---|---|---|---|---|---|
| $F_1$-20.0 | 25.96 | 647500 | 157535 | 489965 | 3.1 |
| $F_2$-30.0 | 27.53 | 688250 | 160535 | 527715 | 3.3 |
| $F_3$-40.0 | 31.70 | 792500 | 177535 | 614965 | 3.5 |
| $V_1$-15.0 | 25.44 | 636600 | 152535 | 484065 | 3.2 |
| $V_2$-20.0 | 29.38 | 734500 | 157535 | 576965 | 3.7 |
| $V_3$-25.0 | 37.13 | 928250 | 162535 | 765715 | 4.7 |
| $C_1$-20.0 | 24.41 | 610250 | 157533 | 452717 | 2.9 |
| $C_2$-30.0 | 26.03 | 650750 | 167533 | 483217 | 2.9 |
| $C_3$-40.0 | 29.85 | 746250 | 177535 | 568715 | 3.2 |
| $N_1$-3.00 | 25.19 | 629750 | 158175 | 471575 | 3.0 |
| $N_2$-4.50 | 28.27 | 706750 | 170175 | 536575 | 3.2 |
| $N_3$-6.00 | 35.59 | 889750 | 162175 | 727575 | 4.4 |
| Control | 20.05 | 501250 | 137535 | 363715 | 2.6 |

Table 60. Economics of cultivation in *Curcuma aromatica* Salisb. during second year of study

| Treatment (t ha$^{-1}$) | Fresh Yield t ha$^{-1}$ | Value | Cost | Profit | B:C |
|---|---|---|---|---|---|
| $F_1$-20.0 | 26.15 | 653750 | 139585 | 514165 | 3.7 |
| $F_2$-30.0 | 26.68 | 667000 | 149585 | 517415 | 3.5 |
| $F_3$-40.0 | 35.56 | 889000 | 159585 | 729415 | 4.6 |
| $V_1$-15.0 | 23.25 | 581250 | 134585 | 446665 | 3.3 |
| $V_2$-20.0 | 29.78 | 744500 | 134585 | 604915 | 4.3 |
| $V_3$-25.0 | 40.54 | 1013500 | 151585 | 861919 | 5.7 |
| $C_1$-20.0 | 25.15 | 628750 | 139585 | 489165 | 3.5 |
| $C_2$-30.0 | 28.45 | 711250 | 149585 | 561665 | 3.8 |
| $C_3$-40.0 | 31.48 | 787000 | 159585 | 627415 | 3.9 |
| $N_1$-3.00 | 27.44 | 686000 | 140285 | 545715 | 3.9 |
| $N_2$-4.50 | 28.68 | 717000 | 152225 | 564775 | 3.7 |
| $N_3$-6.00 | 38.63 | 965750 | 164225 | 801525 | 4.9 |
| Control | 10.37 | 259250 | 119585 | 139665 | 1.2 |

Table 61. Residual effect of organic manures on the yield of succeeding crop (amaranthus) (t ha $^{-1}$)

| Treatments (t ha$^{-1}$) | Biomass yield |
|---|---|
| $F_1$-(20.0) | 6.70 |
| $F_2$-(30.0) | 8.12 |
| $F_3$-(40.0) | 9.72 |
| $V_1$-(15.0) | 7.15 |
| $V_2$-(20.0) | 8.49 |
| $V_3$-(25.0) | 10.41 |
| $C_1$-(20.0) | 6.15 |
| $C_2$-(30.0) | 7.87 |
| $C_3$-(40.0) | 9.01 |
| $N_1$-(3.00) | 7.08 |
| $N_2$-(4.50) | 9.36 |
| $N_3$-(6.00) | 11.39 |
| Control | 5.40 |
| CD | 0.474 |
| SE | 0.08 |

## 4.4. EXPERIMENT IV

### Effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)

### 4.4.1. Growth characters

#### *4.4.1.1. Plant height*

Plant height differed significantly under different treatments throughout the growth period (Table 62, Plate 9). Plants supplied with combination of *Azospirillum,* AMF, *Trichoderma* and *Pseudomonas* ($T_{15}$) showed significantly highest plant height of 58.67 cm at 60 DAP, 72.75 cm at 120 DAP, 77.62 cm at 180 DAP and 89.46 cm at 240 DAP (Fig.15). Among the various single application of bioinoculant *Pseudomonas* ($T_3$) recorded the highest plant height of of 39.37, 42.24, 54.69 and 56.36 cm at 60,120,180 and 240 DAP respectively. $T_{15}$ was followed by $T_{13}$ at all stages of growth. Among the lowest plant height was recorded by $T_1$. The control recorded the least plant height of 29.32 cm at 60 DAP, 31.59 cm at 120 DAP, 35.70 cm at 180 DAP and 40.77 cm at 240 DAP.

#### *4.4.1.2. Number of tillers*

At 60 DAP maximum tiller number (1.23) was obtained when a combination of *Azospirillum,* AMF, *Pseudomonas* and *Trichoderma* ($T_{15}$) was applied (Table 62). This was followed by $T_{14}$ recording the tiller number of 1.2. The control ($T_{16}$) did not produce any tillers. At 120 DAP maximum tiller number of 2.07 was produced in $T_{15}$. $T_{15}$ was on par with $T_{11}$ and $T_{13}$ with values of 1.75 and 1.70, respectively. Among the various single application of bioinoculants *Pseudomonas* ($T_3$) recorded the highest tiller number 1.28. At 180 DAP maximum number of tillers (2.10 ) was registered in $T_{15}$. This was on par with $T_{14}$ and $T_{13}$ recording a tiller number of 1.85 and 1.80, respectively. When *Trichoderma* ($T_4$) was applied alone the highest tiller number was 1.13.

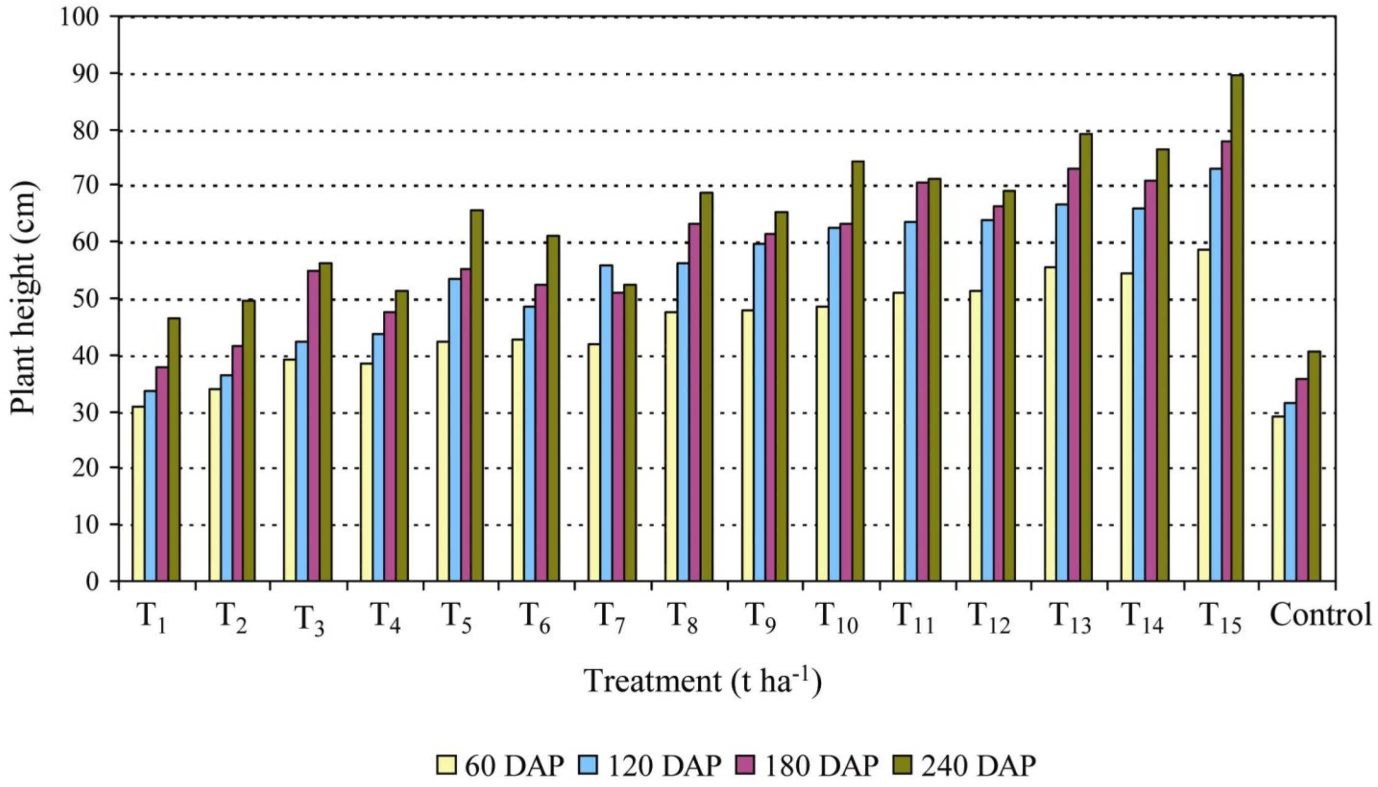
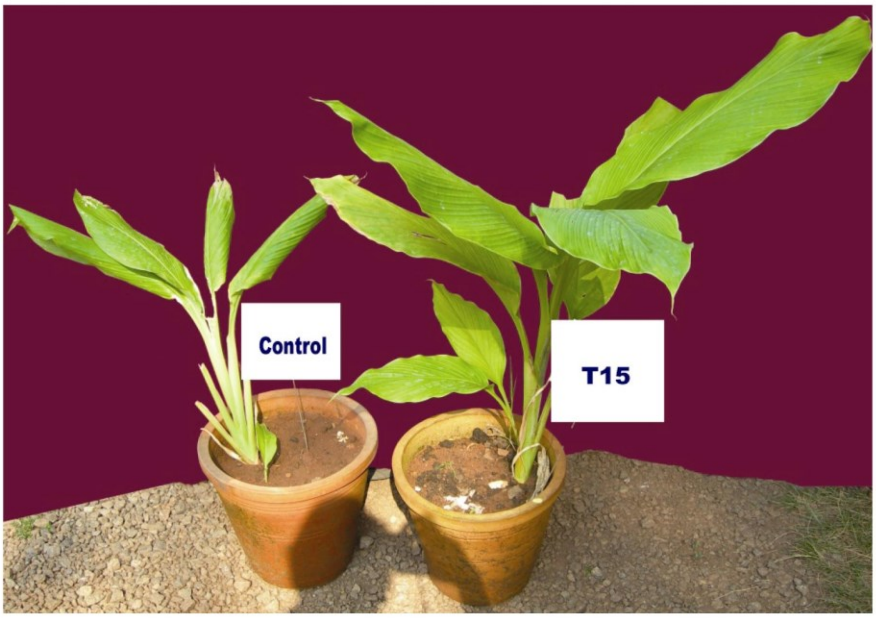


Fig. 15. Effect of microbial inoculants on height of the plant (cm) in *Curcuma aromatica* Salisb.



*Azospirillum* + AMF +*Pseudomonas* + *Trichoderma* ($T_{15}$)

Plate 9. Effect of organic manures on plant growth in *Curcuma aromatica* Salisb.

Table 62. Effect of microbial inoculants on height of plant (cm) and number of tillers in *Curcuma aromatica* Salisb.

| Treatments | Height of the plant | | | | Number of tillers | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 30.90 | 33.85 | 37.71 | 46.49 | 0.00 | 0.83 | 1.27 | 1.33 |
| $T_2$-(AMF) | 33.98 | 36.50 | 41.54 | 49.77 | 0.67 | 1.20 | 1.39 | 1.41 |
| $T_3$-(*Pseudomnas flourescens*) | 39.37 | 42.24 | 54.69 | 56.36 | 1.00 | 1.28 | 1.27 | 1.32 |
| $T_4$-(*Trichoderma harzianum*) | 38.44 | 43.76 | 47.67 | 51.46 | 0.33 | 1.10 | 1.13 | 1.16 |
| $T_5$-(A+AMF) | 42.51 | 53.63 | 55.16 | 65.55 | 0.73 | 1.01 | 1.26 | 1.31 |
| $T_6$-(A+P) | 42.59 | 48.54 | 52.55 | 61.24 | 0.33 | 0.97 | 1.08 | 1.30 |
| $T_7$-(A+T) | 41.99 | 55.83 | 51.19 | 52.37 | 0.33 | 1.03 | 1.38 | 1.52 |
| $T_8$-(AMF+P) | 47.46 | 56.35 | 63.31 | 68.66 | 1.07 | 1.46 | 1.56 | 1.58 |
| $T_9$-(AMF+T) | 47.85 | 59.8 | 61.34 | 65.16 | 0.73 | 1.21 | 1.26 | 1.29 |
| $T_{10}$-(P+T) | 48.57 | 62.38 | 63.16 | 74.18 | 1.13 | 1.49 | 1.58 | 1.61 |
| $T_{11}$-(A+AMF+P) | 50.89 | 63.39 | 70.58 | 71.06 | 1.20 | 1.75 | 1.85 | 1.86 |
| $T_{12}$-(A+AMF+T) | 51.43 | 63.75 | 66.31 | 69.17 | 0.70 | 1.36 | 1.44 | 1.48 |
| $T_{13}$-(AMF+P+T) | 55.63 | 66.79 | 72.79 | 79.25 | 0.82 | 1.70 | 1.74 | 1.79 |
| $T_{14}$-(P+A+T) | 54.61 | 65.89 | 70.83 | 76.27 | 1.20 | 1.63 | 1.80 | 1.85 |
| $T_{15}$-(A+AMF+P+T) | 58.67 | 72.75 | 77.62 | 89.46 | 1.23 | 2.07 | 2.10 | 2.14 |
| Control | 29.32 | 31.59 | 35.70 | 40.77 | 0.00 | 0.70 | 0.70 | 0.77 |
| CD | 1.43 | 2.01 | 3.17 | 1.42 | 0.73 | 0.58 | 0.48 | 0.49 |
| SE | 0.74 | 1.45 | 3.63 | 0.73 | 0.19 | 0.12 | 0.08 | 0.08 |

CD Significant at 1 % level

The control recorded the least tiller number 0.7. At harvest stage (240 DAP), $T_{15}$ recorded the highest number of tillers (2.14) and was on par with $T_{11}$ and $T_{14}$ recording a value of 1.86 and 1.85 respectively.

### *4.4.1.3. Number of Leaves*

All treatments differed significantly in the number of leaves at all stages of observation (Table 63). Among the treatments combined application of *Azospirillum,* AMF, *Pseudomonas* and *Trichoderma* ($T_{15}$) retained more number of leaves throughout the growth stages and was superior to all other treatments .The number of leaves observed at 60 DAP in $T_{13}$ and $T_{14}$ were 6.43 and 5.98 ,respectively. At 120 DAP $T_{13}$ and $T_{14}$ were on par recording 6.76 and 6.74 leaves, respectively. At 180 DAP treatment $T_{14}$ recorded 10.97. This was succeeded by $T_{12}$.. At 240 DAP $T_{15}$ was closely followed by $T_{14}$ where the number of leaves recorded was 12.97. Treatment $T_{13}$. was on par with $T_{11}$. Among the various single application of bioinoculant AMF ($T_2$) recorded the highest number of leaves throughout the growth period. The control recorded least number of leaves of 4.04 at 60 DAP, 4.54 at 120 DAP, 5.10 at 180 DAP and 6.36 at 240 DAP.

### *4.4.1.4. Leaf area (cm$^2$)*

There was significant difference among the various microbial inoculants and their combinations with respect to leaf area of the plants (Table 63). Plants supplied with combination of *Azospirillum,* AMF, *Trichoderma* and *Pseudomonas* showed significantly highest leaf area of 2156.67 cm$^2$ at 60 DAP, 2171.32 cm$^2$ at 120 DAP, 3199.44 cm$^2$ at 180 DAP and 4011.65 cm$^2$ at 240 DAP. This was closely followed by the treatment $T_{14}$, $T_{12}$ and $T_{13}$ throughout the growth stages. At harvest stage (240 DAP) leaf area $T_{15}$ was closely followed by $T_{14}$ recording a leaf area of 3198.32 cm$^2$.

Table 63. Effect of microbial inoculants on number of leaves and leaf area ($cm^2$) in *Curcuma aromatica* Salisb.

| Treatments | Number of leaves | | | | Leaf area | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 4.97 | 4.97 | 5.54 | 6.92 | 1006.9 | 1057.72 | 1118.02 | 1166.03 |
| $T_2$-(AMF) | 5.02 | 5.18 | 5.87 | 7.84 | 1017.56 | 1071.59 | 1132.05 | 1178.55 |
| $T_3$-(*Pseudomnas flourescens*) | 4.99 | 5.12 | 5.72 | 7.69 | 1013.35 | 1067.46 | 2017.31 | 2045.38 |
| $T_4$-(*Trichoderma harzianum*) | 4.97 | 5.06 | 5.70 | 7.64 | 1016.36 | 1069.69 | 2079.32 | 2145.93 |
| $T_5$-(A+AMF) | 5.40 | 6.36 | 7.00 | 8.17 | 1056.95 | 1089.49 | 2097.54 | 2126.60 |
| $T_6$-(A+P) | 5.30 | 6.03 | 6.78 | 8.06 | 1052.63 | 1073.57 | 2089.31 | 2121.67 |
| $T_7$-(A+T) | 5.06 | 5.91 | 6.66 | 7.99 | 1044.88 | 1071.38 | 2081.53 | 2178.27 |
| $T_8$-(AMF+P) | 5.53 | 6.45 | 7.36 | 8.83 | 1089.62 | 1101.29 | 2146.60 | 2186.54 |
| $T_9$-(AMF+T) | 5.26 | 6.16 | 7.27 | 8.41 | 1065.39 | 1088.60 | 2131.46 | 2172.49 |
| $T_{10}$-(P+T) | 5.73 | 6.59 | 8.53 | 9.67 | 1097.08 | 2085.62 | 3141.55 | 3171.54 |
| $T_{11}$-(A+AMF+P) | 5.77 | 6.87 | 9.09 | 10.42 | 2018.00 | 2101.01 | 3161.69 | 3165.00 |
| $T_{12}$-(A+AMF+T) | 5.75 | 6.99 | 9.99 | 10.23 | 2081.63 | 2118.33 | 3172.92 | 3190.59 |
| $T_{13}$-(AMF+P+T) | 6.43 | 6.76 | 9.78 | 11.73 | 2068.31 | 2110.36 | 3164.35 | 3184.23 |
| $T_{14}$-(P+A+T) | 5.98 | 6.74 | 10.97 | 12.97 | 2085.93 | 2131.59 | 3181.63 | 3198.32 |
| $T_{15}$-(A+AMF+P+T) | 6.96 | 7.41 | 12.25 | 13.67 | 2156.67 | 2171.32 | 3199.44 | 4011.65 |
| Control | 4.04 | 4.54 | 5.10 | 6.36 | 903.92 | 1006.82 | 1018.49 | 1033.77 |
| CD | 0.06 | 0.05 | 0.12 | 0.30 | 23.89 | 1.44 | 2.88 | 31.47 |
| SE | 0.002 | 0.008 | 0.005 | 0.030 | 205.750 | 0.750 | 3.000 | 357.000 |

CD Significant at 1 % level

This was succeeded by $T_{12}$, $T_{13}$ and $T_{10}$ .Among the various single application of bioinoculant *Trichoderma* ($T_4$) recorded highest leaf area of 1016.36, 1069.69, 2079.32 and 2145.38.0 cm$^2$ at 60,120,180 and 240 DAP respectively. The control recorded least leaf area of 903.92, 1006.82, 1018.49 and 1033.77 cm$^2$ at 60, 120, 180 and 240 DAP, respectively).

### 4.4.1.5. Rhizome spread

The effect of microbial inoculants on rhizome spread is given in Table 64. Rhizome spread was significantly influenced by different microbial inoculants at all stages of growth. At 60 DAP, the rhizome spread was highest in $T_{14}$ (5.84 cm). $T_{14}$ was on par with $T_{12}$ and $T_{13}$ where the rhizome spread was 5.75 and 5.65 cm, respectively. $T_{15}$ was significantly superior in rhizome spread of 6.66 cm at 120 DAP, 7.14 cm at 180 DAP and 13.83 cm at 240 DAP. At 120 DAP treatment $T_{14}$ recorded a rhizome spread of 6.46 cm which was on par with $T_{12}$ (6.35 cm). At 180 DAP $T_{15}$ was on par with $T_{14}$ and $T_{13}$ recording rhizome spread of 12.66 cm and 11.93 cm, respectively. At 240 DAP $T_{15}$ was closely followed by $T_{14}$ where the rhizome spread was 12.66 cm. Among the various single application of bio inoculants. *Trichoderma* ($T_4$) recorded the highest rhizome spread of 4.05, 4.67, 5.35 and 9.27 cm at 60,120,180 and 240 DAP respectively. The control recorded least rhizome spread of 2.91 cm at 60 DAP, 3.1 cm at 120 DAP, 3.55 cm at 180 DAP and 4.28 cm at 240 DAP.

### 4.4.1.6. Rhizome thickness

There was significant difference in the rhizome thickness under different microbial inoculants application (Table 64). Plants supplied with microbial inoculants produced more thickened rhizomes than the plants which did not receive. Combined application of microbial inoculants ($T_{15}$) was superior and recorded the maximum rhizome thickness in all the growth phases.

Table 64. Effect of microbial inoculants on rhizome spread and rhizome thickness (cm) in *Curcuma aromatica* Salisb.

| Treatments | Rhizome spread | | | | Rhizome thickness | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 3.21 | 3.56 | 4.01 | 5.43 | 1.16 | 1.19 | 1.36 | 1.39 |
| $T_2$-(AMF) | 3.50 | 3.78 | 5.21 | 7.33 | 1.19 | 1.26 | 1.41 | 1.50 |
| $T_3$-(*Pseudomnas flourescens*) | 3.75 | 4.34 | 4.95 | 7.27 | 1.17 | 1.2 | 1.34 | 1.37 |
| $T_4$-(*Trichoderma harzianum*) | 4.05 | 4.67 | 5.35 | 9.27 | 1.18 | 1.22 | 1.33 | 1.36 |
| $T_5$-(A+AMF) | 4.50 | 5.08 | 5.72 | 9.73 | 1.21 | 1.27 | 1.58 | 1.64 |
| $T_6$-(A+P) | 4.35 | 5.02 | 5.42 | 9.67 | 1.18 | 1.23 | 1.45 | 1.57 |
| $T_7$-(A+T) | 4.38 | 5.0 | 5.36 | 9.62 | 1.26 | 1.31 | 1.64 | 1.72 |
| $T_8$-(AMF+P) | 5.37 | 5.44 | 6.22 | 10.74 | 1.28 | 1.33 | 1.66 | 1.84 |
| $T_9$-(AMF+T) | 5.25 | 5.33 | 6.39 | 10.63 | 1.26 | 1.28 | 1.61 | 1.82 |
| $T_{10}$-(P+T) | 5.63 | 6.08 | 6.51 | 11.13 | 1.29 | 1.36 | 1.70 | 1.89 |
| $T_{11}$-(A+AMF+P) | 5.62 | 5.96 | 6.34 | 10.99 | 1.27 | 1.34 | 1.67 | 1.86 |
| $T_{12}$-(A+AMF+T) | 5.75 | 6.35 | 6.85 | 11.92 | 1.33 | 1.41 | 1.74 | 2.07 |
| $T_{13}$-(AMF+P+T) | 5.65 | 6.26 | 6.92 | 11.93 | 1.31 | 1.40 | 1.71 | 2.09 |
| $T_{14}$-(P+A+T) | 5.84 | 6.46 | 7.07 | 12.66 | 1.48 | 1.52 | 1.77 | 2.03 |
| $T_{15}$-(A+AMF+P+T) | 5.62 | 6.66 | 7.14 | 13.83 | 1.54 | 1.57 | 2.06 | 2.26 |
| Control | 2.91 | 3.10 | 3.55 | 4.28 | 0.95 | 1.06 | 1.10 | 1.13 |
| CD | 0.26 | 0.132 | 0.270 | 0.363 | 0.02 | 0.02 | 0.02 | 0.016 |
| SE | 0.020 | 0.006 | 0.030 | 0.047 | 0.009 | 0.001 | 0.001 | 0.001 |

CD Significant at 1 % level

$T_{15}$ recorded value of 1.54 cm at 60 DAP, 1.57 cm at 120 DAP, 2.06 cm at 180 DAP and 2.26 cm at 240 DAP. At 60 DAP $T_{14}$ and $T_{12}$ recorded rhizome thickness of 1.48 and 1. 33 cm, respectively. At 120 and 180 DAP, the rhizome thickness recorded in $T_{14}$ was 1.52 cm at 120 DAP and 1.77 cm at 180 DAP. At harvest stage (240 DAP) the rhizome thickness recorded by $T_{15}$ was 2.26 cm. This was followed by $T_{13}$ which recorded rhizome thickness of 2.09 cm. Among the various single application of microbial inoculant rhizome thickness was higher, when AMF ($T_2$) was applied. The value was 1.19, 1.26, 1.41 and 1.50 cm at 60,120,180 and 240 DAP respectively. At harvest stage rhizome thickness for control was least, recording a value of 0.95 cm at 60 DAP, 1.06 cm at 120 DAP,1.10 cm at 180 DAP, and 1.13 cm at 240 DAP.

### *4.4.1.7. Root length*

Table 65 shows the effect of microbial inoculation on root length. The effect of microbial inoculants on root length was significant at all stages of crop growth. Among the microbial inoculants ($T_{15}$) resulted in maximum root length and was found significantly superior and recorded a root length of 20.13 cm at 60 DAP, 19.32 cm at 120 DAP, 19.44 cm at 180 DAP and 21.91 cm at 240 DAP. This was closely followed by $T_{14}$ where the root length was 19.92, 18.86, 19.02 and 21.31 cm at 60, 120,180 and 240 DAP respectively. At harvest stage (240 DAP) $T_{15}$ was followed by $T_{13}$ (20.41 cm) which was on par with $T_{12}$ (19.97 cm). Among the various single application of bio inoculant AMF ($T_2$) recorded the longest root length of 15.23 cm at 60 DAP, 16.44 cm at 120 DAP, 16.88 cm at 180 DAP and 18.26 cm at 240 DAP. The control recorded the least value.

### *4.4.1.8. Root spread*

The effect of microbial inoculants on root spread is presented in Table 65.

Table 65. Effect of microbial inoculants on root length and root spread (cm) in *Curcuma aromatica* Salisb.

| Treatments | Root length | | | | Root spread | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 13.74 | 14.94 | 15.45 | 17.92 | 2.20 | 3.26 | 4.39 | 7.47 |
| $T_2$-(AMF) | 15.23 | 16.44 | 16.88 | 18.26 | 2.35 | 3.42 | 4.77 | 8.07 |
| $T_3$-(*Pseudomnas flourescens*) | 14.69 | 15.24 | 16.32 | 18.15 | 2.34 | 3.38 | 4.64 | 7.87 |
| $T_4$-(*Trichoderma harzianum*) | 14.46 | 15.22 | 16.27 | 18.23 | 2.36 | 3.39 | 4.56 | 7.88 |
| $T_5$-(A+AMF) | 15.85 | 16.92 | 17.21 | 18.85 | 3.30 | 3.67 | 4.94 | 11.47 |
| $T_6$-(A+P) | 15.09 | 16.63 | 16.87 | 18.73 | 3.70 | 3.43 | 4.85 | 11.22 |
| $T_7$-(A+T) | 15.34 | 16.99 | 17.35 | 19.25 | 3.88 | 4.35 | 4.85 | 11.36 |
| $T_8$-(AMF+P) | 16.75 | 17.13 | 17.25 | 18.45 | 3.74 | 4.24 | 4.82 | 11.34 |
| $T_9$-(AMF+T) | 16.24 | 16.99 | 17.13 | 18.22 | 3.66 | 4.26 | 4.82 | 11.33 |
| $T_{10}$-(P+T) | 15.95 | 17.66 | 17.99 | 19.11 | 3.93 | 4.70 | 5.24 | 12.37 |
| $T_{11}$-(A+AMF+P) | 17.84 | 17.96 | 18.44 | 19.46 | 4.23 | 4.87 | 5.47 | 12.86 |
| $T_{12}$-(A+AMF+T) | 18.88 | 18.21 | 18.66 | 19.97 | 4.36 | 5.07 | 5.98 | 13.07 |
| $T_{13}$-(AMF+P+T) | 19.45 | 18.43 | 18.85 | 20.41 | 4.23 | 5.16 | 6.25 | 13.60 |
| $T_{14}$-(P+A+T) | 19.92 | 18.86 | 19.02 | 21.31 | 4.57 | 5.27 | 6.37 | 13.74 |
| $T_{15}$-(A+AMF+P+T) | 20.13 | 19.32 | 19.44 | 21.91 | 4.83 | 6.18 | 6.64 | 14.85 |
| Control | 9.98 | 10.08 | 11.13 | 13.44 | 2.06 | 3.17 | 3.34 | 5.05 |
| CD | 0.150 | 0.168 | 0.150 | 0.711 | 0.286 | 0.166 | 0.179 | 0.275 |
| SE | 0.080 | 0.010 | 0.008 | 0.182 | 0.030 | 0.010 | 0.016 | 0.030 |

CD Significant at 1 % level

The effect of microbial inoculation on root spread showed significant difference at all stages of growth. At 60 DAP the root spread was highest in $T_{15}$ (4.83 cm) which was on par with $T_{14}$ (4.57 cm). Among the various single bioinoculant application, *Trichoderma* ($T_4$), increased the root spread (2.36 cm). Plants supplied with combined application of microbial inoculants like *Azospirillum,* AMF, *Pseudomonas and Trichoderma* ($T_{15}$) recorded highest root spread and was superior than other treatments throughout the crop growth. At 120 DAP $T_{14}$ recorded the root spread of 5.27 cm. $T_{13}$ and $T_{12}$ were on par. The values are 5.16 cm and 5.07 cm respectively. At 180 DAP $T_{14}$ recorded root spread of 6.37 cm. This was succeeded by $T_{13}$ (6.25 cm) and $T_{12}$ (5.98 cm). At 240 DAP $T_{15}$ recorded the highest root spread of 14.85 cm. This was closely followed by $T_{14}$ (13.74 cm). $T_{13}$ recorded root spread of 13.60 cm. Among the various single application of microbial inoculants, AMF ($T_2$) observed the highest root spread of 2.34, 3.38, 4.64 and 7.87 cm at 60,120,180 and 240 DAP, respectively. Contrary to that the control recorded the least root spread of 2.06 cm at 60 DAP, 3.17 cm at 120 DAP, 3.34 cm at 180 DAP, and 5.05 cm at 240 DAP.

#### *4.4.1.9. Root weight*

The effect of microbial inoculation on root weight is depicted on Table 66. At 60 DAP the root weight was maximum (1.27 g) in $T_{15}$ which was significantly superior. This was on par with $T_{13}$ and $T_{14}$ recording a value of 1.21 and 1.2 g, respectively. At 120 and 180 DAP also $T_{15}$ recorded the highest root weight (1.58 and 2.31 g), respectively. At 240 DAP treatment $T_{15}$ recorded the highest root weight of 2.61 g ,s followed by $T_{13}$ and $T_{14}$ which were on par. At 60 and 120 DAP, among the single application of bioinoculant AMF ($T_2$ ) recorded the highest root weight of 0.32 and 0.30 g, respectively. At 180 and 240 DAP, among the single application of bioinoculants *Trichoderma* ($T_4$) recorded the highest root weight of 1.12 g and 131 g, respectively. The control recorded least root weight.

Table 66. Effect of microbial inoculants on root weight (gm) and number of fingers in *Curcuma aromatica* Salisb.

| Treatments | Root weight | | | | Number of fingers | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 0.24 | 0.28 | 0.92 | 1.13 | 2.75 | 2.86 | 3.36 | 4.75 |
| $T_2$-(AMF) | 0.30 | 0.32 | 1.06 | 1.17 | 3.06 | 3.23 | 3.73 | 5.85 |
| $T_3$-(*Pseudomnas flourescens*) | 0.26 | 0.27 | 1.00 | 1.07 | 2.76 | 2.93 | 3.44 | 5.31 |
| $T_4$-(*Trichoderma harzianum*) | 0.25 | 0.31 | 1.12 | 1.31 | 3.08 | 3.44 | 4.73 | 5.98 |
| $T_5$-(A+AMF) | 0.39 | 0.66 | 1.11 | 1.26 | 3.12 | 3.25 | 3.44 | 5.04 |
| $T_6$-(A+P) | 0.26 | 0.39 | 1.11 | 1.21 | 3.10 | 3.25 | 3.51 | 5.03 |
| $T_7$-(A+T) | 0.50 | 0.90 | 2.09 | 2.31 | 3.31 | 3.56 | 4.96 | 6.42 |
| $T_8$-(AMF+P) | 0.51 | 0.78 | 2.03 | 2.26 | 3.26 | 3.51 | 4.84 | 6.31 |
| $T_9$-(AMF+T) | 0.49 | 0.63 | 2.01 | 2.23 | 3.21 | 3.44 | 4.81 | 6.25 |
| $T_{10}$-(P+T) | 0.76 | 1.12 | 2.13 | 2.46 | 3.36 | 3.67 | 5.07 | 6.83 |
| $T_{11}$-(A+AMF+P) | 0.99 | 1.11 | 2.17 | 2.37 | 3.49 | 3.74 | 5.74 | 7.26 |
| $T_{12}$-(A+AMF+T) | 1.12 | 1.26 | 2.20 | 2.34 | 4.42 | 4.74 | 6.79 | 7.44 |
| $T_{13}$-(AMF+P+T) | 1.20 | 1.37 | 2.21 | 2.57 | 4.56 | 4.85 | 6.96 | 7.75 |
| $T_{14}$-(P+A+T) | 1.21 | 1.46 | 2.26 | 2.56 | 4.66 | 4.97 | 7.05 | 7.84 |
| $T_{15}$-(A+AMF+P+T) | 1.27 | 1.58 | 2.31 | 2.61 | 4.81 | 5.26 | 7.41 | 8.06 |
| Control | 0.12 | 0.23 | 0.45 | 1.03 | 1.04 | 1.22 | 1.36 | 2.36 |
| CD | 0.06 | 0.03 | 0.04 | 0.03 | 0.09 | 0.18 | 0.16 | 0.16 |
| SE | 0.001 | 0.004 | 0.006 | 0.004 | 0.003 | 0.010 | 0.009 | 0.009 |

CD Significant at 1 % level.

### 4.4.1.10. Number of fingers

The effect of microbial inoculation on number of fingers is presented in Table 66. There were statistical variation among the treatments throughout the growth period. Combination of microbial inoculants like *Azospirillum,* AMF, *Pseudomonas and Trichoderma* ($T_{15}$) was found significantly superior and recorded the highest number of fingers of 4.81, 5.26, 7.41 and 8.06 at 60,120,180 and 240 DAP respectively. At 60 DAP $T_{14}$ recorded higher number of fingers (4.66). This was followed by $T_{13}$ (4.56) and $T_{12}$ (4.42). At 120 DAP $T_{14}$ recorded 4.97 fingers. This was followed by $T_{12}$ (4.74). At 180 DAP $T_{14}$ recorded 7.05 number of fingers. This was followed by $T_{13}$ (6.96) and $T_{12}$ (6.79). At 240 DAP $T_{14}$ recorded highest number of fingers (7.84). This was followed by $T_{13}$. Among the various single application of bioinoculants *Trichoderma* ($T_2$) recorded more number of fingers 3.08 at 60 DAP, 3.44 at 120 DAP, 4.73 at 180 DAP and 5.98 at 240 DAP. The control recorded least number of fingers of 1.04 at 60 DAP ,1.22 at 120 DAP,1.36 at 180 DAP, and 2.36 at 240 DAP.

## 4.4.2. Yield and Yield components

### *4.4.2.1. Rhizome yield (fresh)*

The effect of microbial inoculants on rhizome yield (fresh) is presented in Table 67. Rhizome yield fresh differed significantly under different treatments throughout the growth period. It is clearly evident from the Table that of combination of bioinoculants like *Azospirillum,* AMF, *Pseudomonas and Trichoderma* ($T_{15}$) resulted in significantly maximum fresh rhizome yield of 58.46 g plant$^{-1}$ at 60 DAP, 200.07 g plant$^{-1}$ at 120 DAP, 285.0 g plant$^{-1}$ at 180 DAP and 316.62 g plant$^{-1}$ at 240 DAP. At 60 DAP $T_{13}$ yielded (56.26 g plant$^{-1}$) fresh rhizome (Fig.16). This was followed by $T_{14}$ (51.43 g plant$^{-1}$) and $T_{12}$ (48.48 g plant$^{-1}$). At 120 DAP $T_{15}$ was followed by $T_{13}$ recording a fresh rhizome yield of 194.73 g plant$^{-1}$.

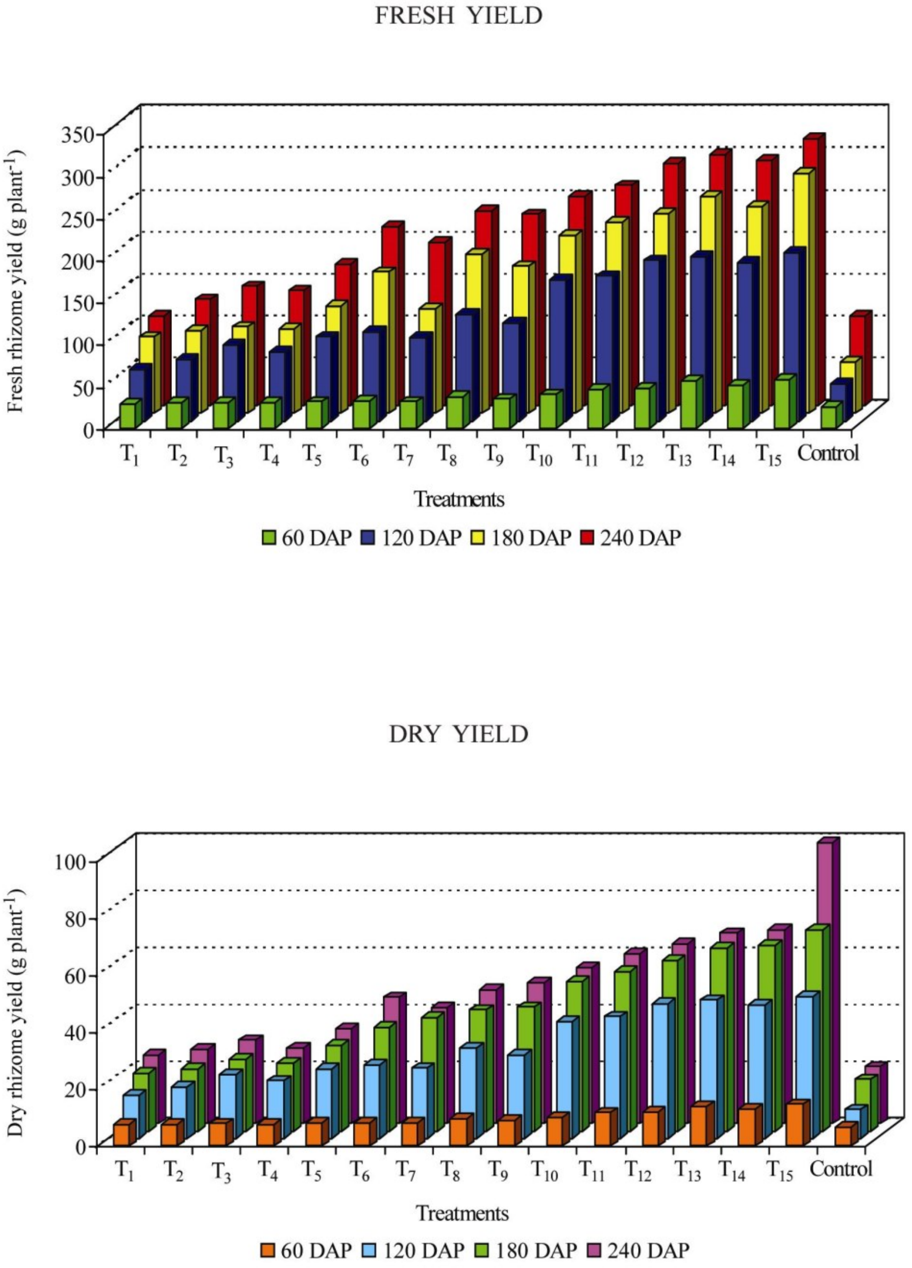


Fig. 16. Effect of microbial inoculants on rhizome yield (g plant$^{-1}$) in *Curcuma aromatica* Salisb.

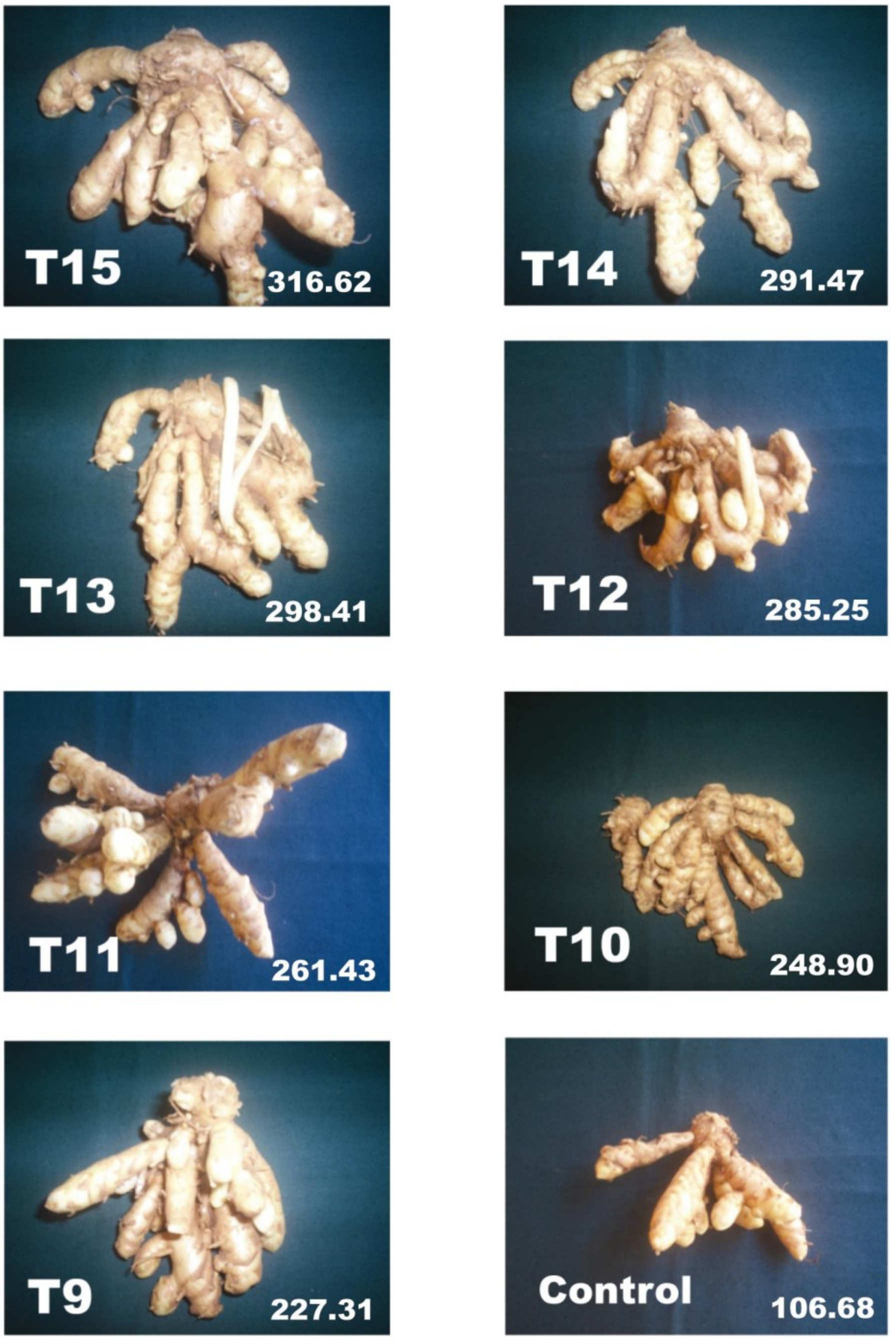


Plate 10. Effect of microbial inoculants on rhizome yield (g plant$^{-1}$) in *Curcuma aromatica* Salisb.

Table 67. Effect of microbial inoculants on rhizome yield fresh and dry (g plant$^{-1}$) in *Curcuma aromatica* Salisb.

| Treatments | Rhizome yield (fresh) | | | | Rhizome yield (dry) | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 29.63 | 61.45 | 90.74 | 106.43 | 7.51 | 15.36 | 20.52 | 24.30 |
| $T_2$-(AMF) | 30.67 | 72.75 | 98.68 | 126.43 | 7.67 | 18.18 | 21.87 | 26.24 |
| $T_3$-(*Pseudomnas flourescens*) | 31.16 | 90.81 | 102.64 | 141.73 | 7.79 | 22.64 | 25.43 | 29.25 |
| $T_4$-(*Trichoderma harzianum*) | 30.49 | 81.71 | 100.43 | 136.55 | 7.62 | 20.32 | 23.93 | 26.43 |
| $T_5$-(A+AMF) | 31.88 | 100.09 | 127.68 | 168.46 | 7.97 | 24.59 | 30.26 | 33.55 |
| $T_6$-(A+P) | 32.65 | 106.46 | 167.81 | 212.90 | 8.15 | 25.83 | 36.42 | 44.46 |
| $T_7$-(A+T) | 31.85 | 98.48 | 124.72 | 194.54 | 7.95 | 24.73 | 39.80 | 40.76 |
| $T_8$-(AMF+P) | 37.39 | 126.93 | 189.55 | 231.76 | 9.35 | 31.74 | 42.58 | 47.26 |
| $T_9$-(AMF+T) | 35.40 | 116.62 | 174.68 | 227.31 | 8.85 | 29.32 | 43.61 | 49.71 |
| $T_{10}$-(P+T) | 40.35 | 167.96 | 211.56 | 248.90 | 10.08 | 41.00 | 52.71 | 54.83 |
| $T_{11}$-(A+AMF+P) | 46.65 | 171.96 | 226.74 | 261.43 | 11.66 | 42.75 | 56.18 | 59.74 |
| $T_{12}$-(A+AMF+T) | 48.48 | 190.74 | 237.46 | 288.25 | 12.12 | 47.53 | 60.06 | 63.23 |
| $T_{13}$-(AMF+P+T) | 56.26 | 194.73 | 257.88 | 298.41 | 14.06 | 48.63 | 64.32 | 66.84 |
| $T_{14}$-(P+A+T) | 51.43 | 188.34 | 246.36 | 291.47 | 12.86 | 46.98 | 65.44 | 68.24 |
| $T_{15}$-(A+AMF+P+T) | 58.46 | 200.07 | 285.0 | 316.62 | 14.62 | 49.85 | 70.58 | 98.96 |
| Control | 26.46 | 43.73 | 61.48 | 106.68 | 6.53 | 10.09 | 18.24 | 20.01 |
| CD | 1.74 | 3.84 | 2.52 | 1.80 | 0.42 | 0.41 | 0.62 | 0.24 |
| SE | 1.09 | 5.31 | 2.28 | 1.17 | 0.06 | 0.06 | 0.14 | 0.02 |

CD Significant at 1 % level

At 180 DAP $T_{15}$ was followed by $T_{13}$, $T_{14}$ and $T_{12}$. At harvest (240 DAP) $T_{15}$ was followed by $T_{13}$ where rhizome yield of 298.41 g plant$^{-1}$ was obtained. This was succeeded by $T_{14}$ (291.47 g plant$^{-1}$. Among the single application of microbial inoculants *Pseudomonas* ($T_3$) recorded the highest fresh rhizome yield of 31.16 g plant$^{-1}$ at 60 DAP, 90.81 g plant$^{-1}$ at 120 DAP, 102.64 g plant$^{-1}$ at 180 DAP and 141.73 g plant$^{-1}$ at 240 DAP. The control recorded rhizome yield of 26.46, 43.73, 61.48 and 106.68 g plant$^{-1}$ at 60, 120, 180 and 240 DAP, respectively (Fig 16).

#### *4.4.2.2. Rhizome yield (Dry)*

The effect of microbial inoculants on dry rhizome yield is presented in Table 67. The influence of microbial inoculants on dry rhizome yield was found significant. When *Azospirillum,* AMF, *Pseudomonas and Trichoderma* ($T_{15}$) were applied together maximum dry rhizome yield was attained. Dry rhizome yield recorded was 14.62 g plant$^{-1}$ at 60 DAP, 49.85 g plant$^{-1}$ at 120 DAP, 70.58 g plant$^{-1}$ at 180 DAP and 70.58 g plant$^{-1}$ at 240 DAP. At 60 DAP $T_{13}$ recorded a dry rhizome yield of 14.06 g plant$^{-1}$. This was followed by $T_{14}$ (12.86 g plant$^{-1}$). At 120 DAP $T_{13}$ recorded dry rhizome yield of 48.63 g plant$^{-1.}$ This was followed by $T_{12}$ (190.74 g plant$^{-1}$) and $T_{14}$ (188.34 g plant$^{-1}$). At 180 DAP T14 was followed by $T_{13.}$ At 240 DAP $T_{14}$ recorded dry rhizome yield of 68.24 g plant$^{-1}$, which was followed by $T_{13}$ recording a value of 66.84 g plant$^{-1}$. Among the single application of microbial inoculants, *Pseudomonas* ($T_3$) recorded a dry rhizome yield of 7.79, 22.64, 25.43 and 29.25 g plant$^{-1}$ at 60, 120, 180 and 240 DAP respectively. The control recorded the least dry rhizome yield.

#### *4.4.2.3. Top yield*

There was significant difference in Top yield in different treatments (Table 68). The top yield was recorded at 120 and 180 DAP. It was found that at 120 and 180 DAP $T_{15}$ recorded the maximum top yield (30.1 and 29.07 g plant$^{-1}$).

Table 68. Effect of microbial inoculants on top yield (g plant$^{-1}$) and crop duration in *Curcuma aromatica* Salisb.

| Treatments | 120 DAP | 180 DAP | 240 DAP |
|---|---|---|---|
| | Top yield (g plant$^{-1}$) | | Crop duration |
| $T_1$-(*Azospirillum brasilense*) | 15.65 | 14.56 | 232.13 |
| $T_2$-(AMF) | 16.73 | 15.71 | 232.00 |
| $T_3$-(*Pseudomnas flourescens*) | 19.97 | 17.07 | 232.09 |
| $T_4$-(*Trichoderma harzianum*) | 17.77 | 16.04 | 231.63 |
| $T_5$-(A+AMF) | 18.88 | 18.18 | 230.16 |
| $T_6$-(A+P) | 20.16 | 19.03 | 230.07 |
| $T_7$-(A+T) | 23.61 | 21.44 | 229.46 |
| $T_8$-(AMF+P) | 27.24 | 25.11 | 229.68 |
| $T_9$-(AMF+T) | 25.45 | 23.61 | 229.10 |
| $T_{10}$-(P+T) | 28.48 | 25.72 | 227.31 |
| $T_{11}$-(A+AMF+P) | 28.74 | 26.81 | 226.01 |
| $T_{12}$-(A+AMF+T) | 29.62 | 26.94 | 223.01 |
| $T_{13}$-(AMF+P+T) | 29.88 | 27.62 | 222.01 |
| $T_{14}$-(P+A+T) | 29.95 | 27.76 | 221.03 |
| $T_{15}$-(A+AMF+P+T) | 30.01 | 29.07 | 219.01 |
| Control | 10.05 | 12.51 | 235.16 |
| CD | 0.050 | 0.083 | 0.751 |
| SE | 0.04 | 0.03 | 0.26 |

CD Significant at 1 % level

This was followed by $T_{14}$ (29.95 g plant$^{-1}$), $T_{13}$ (29.88 g plant$^{-1}$) and $T_{12}$ (29.62 g plant$^{-1}$). At 120 DAP Treatments $T_{11}$ and $T_{10}$ recorded higher top yield (28.74 and 28.48 g plant$^{-1}$) respectively. At 180 DAP $T_{15}$ recorded maximum top yield of 29.07 g plant$^{-1}$. $T_{14}$ recorded top yield of 27.76 g plant$^{-1}$ and $T_{13}$ recorded 27.62 g plant$^{-1}$. Among single application of microbial inoculan *Pseudomonas* ($T_3$) recorded highest top yield throughout the crop growth. Control recorded least top yield during both the stages.

### *4.4.2.4. Crop duration*

There was significant difference among various treatments in crop duration (Table 68). At 240 DAP the crop duration was observed. The control plants took more days to harvest (235.16 days). This was followed by $T_1$ where the crop duration was 232.13 which was on par with $T_3$ (232.09) and $T_2$ (232 days). In $T_{12}$ the crop duration was 223.01 days. The crop took minimum number of days for attaining maturity when the treatments $T_{14}$ and $T_{15}$ were given and gave values of 221.03 days and 219.01, respectively.

## 4.4.3. Physiological characters

### *4.4.3.1. Dry matter production (DMP)*

The effect of microbial inoculation on dry matter production is presented in Table 69. The microbial inoculants had significant difference among different treatments for dry matter production (Fig. 17). Plants supplied with combination of *Azospirillum,* AMF, *Trichoderma* and *Pseudomonas* ($T_{15}$) was significantly superior in recording highest DMP. The DMP content. at 60 DAP was 19.07 g plant$^{-1}$, at 120 DAP was 29.90 g plant$^{-1}$ and at 180 DAP it was 51.47 g plant$^{-1}$ . At 60 DAP $T_{15}$ was followed by $T_{14}$ and $T_{12}$ where the DMP recorded was 18.93 and 18.71 g plant$^{-1}$ respectively. At 120 DAP the DMP recorded by $T_{14}$ was 27.36 g plant$^{-1}$.

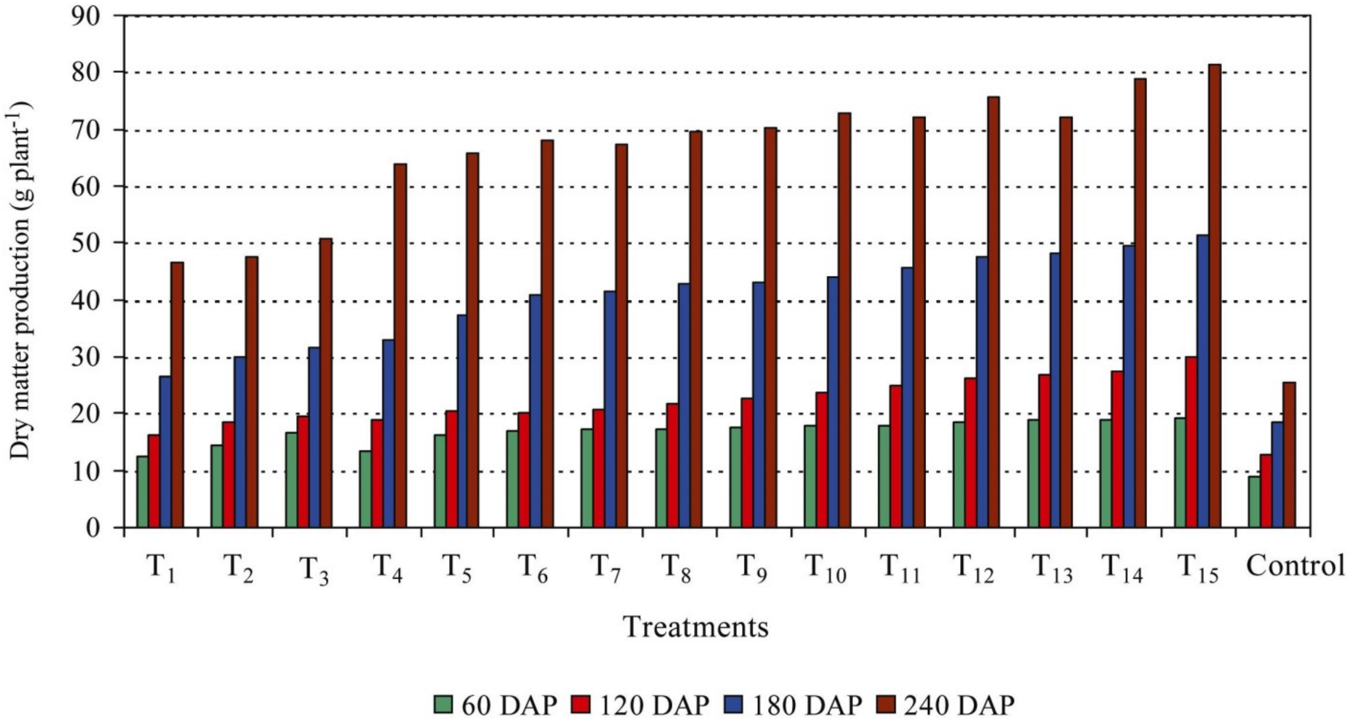


Fig. 17. Effect of microbial inoculants on dry matter production (g plant$^{-1}$) in *Curcuma aromatica* Salisb.

Table 69. Effect of microbial inoculants on dry matter production (g plant $^{-1}$) and leaf area index in *Curcuma aromatica* Salisb.

| Treatments | Dry matter production | | | | Leaf area index | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAP | 120 DAP | 180 DAP | 240 DAP | 60 DAP | 120 DAP | 180 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 12.45 | 16.42 | 26.43 | 46.45 | 1.119 | 1.175 | 1.242 | 1.295 |
| $T_2$-(AMF) | 14.40 | 18.63 | 29.98 | 47.48 | 1.133 | 1.191 | 1.258 | 1.309 |
| $T_3$-(*Pseudomnas flourescens*) | 16.70 | 19.55 | 31.75 | 50.72 | 1.133 | 1.187 | 2.241 | 2.272 |
| $T_4$-(*Trichoderma harzianum*) | 13.45 | 18.88 | 32.80 | 63.84 | 1.129 | 1.188 | 2.310 | 2.384 |
| $T_5$-(A+AMF) | 16.19 | 20.33 | 37.47 | 65.86 | 1.173 | 1.213 | 2.330 | 2.363 |
| $T_6$-(A+P) | 16.83 | 20.21 | 40.96 | 67.98 | 1.167 | 1.123 | 2.322 | 2.358 |
| $T_7$-(A+T) | 17.12 | 20.86 | 41.48 | 67.45 | 1.160 | 1.191 | 2.313 | 2.420 |
| $T_8$-(AMF+P) | 17.30 | 21.75 | 42.64 | 69.54 | 1.210 | 1.223 | 2.385 | 2.429 |
| $T_9$-(AMF+T) | 17.58 | 22.66 | 43.00 | 70.25 | 1.184 | 1.210 | 2.368 | 2.414 |
| $T_{10}$-(P+T) | 17.86 | 23.74 | 43.94 | 72.72 | 1.220 | 2.317 | 3.490 | 3.524 |
| $T_{11}$-(A+AMF+P) | 18.03 | 24.77 | 45.60 | 72.03 | 2.420 | 2.342 | 3.513 | 3.535 |
| $T_{12}$-(A+AMF+T) | 18.57 | 26.29 | 47.43 | 75.68 | 2.310 | 2.353 | 3.525 | 3.545 |
| $T_{13}$-(AMF+P+T) | 18.71 | 26.79 | 48.24 | 72.26 | 2.290 | 2.345 | 3.516 | 3.538 |
| $T_{14}$-(P+A+T) | 18.93 | 27.36 | 49.33 | 78.93 | 2.320 | 2.368 | 3.535 | 3.553 |
| $T_{15}$-(A+AMF+P+T) | 19.07 | 29.90 | 51.47 | 81.46 | 2.380 | 2.425 | 3.555 | 4.457 |
| Control | 9.08 | 12.68 | 18.37 | 25.47 | 1.000 | 1.118 | 1.131 | 1.295 |
| CD | 0.181 | 0.158 | 0.142 | 1.030 | 0.030 | 0.006 | 0.003 | 0.111 |
| SE | 0.054 | 0.054 | 0.044 | 0.359 | 0.032 | 0.005 | 0.003 | 0.031 |

CD Significant at 1 %leve

At 180 DAP the DMP recorded in $T_{14}$ was 49.33 g plant$^{-1}$. Among the single application of microbial inoculants in *Pseudomonas* ($T_3$) the DMP was16.70, 19.55 and 31.75 g plant$^{-1}$ at 60, 120 and 180 DAP, respectively. At harvest stage (240 DAP) also $T_{15}$ recorded highest DMP (81.46 g plant$^{-1}$). It was found that as growth advances the DMP also increased from initial to final stage. This was followed by $T_{14}$ where the DMP recorded was 78.93 g plant$^{-1}$. This was followed by $T_{12}$ and $T_{11}$. Among the single application of microbial inoculant *Trichoderma* ($T_4$) recorded highest DMP of 63.84 g plant$^{-1}$. The control recorded the least DMP of 25.47 g plant$^{-1}$.

### *4.4.3.2. Leaf Area Index (LAI)*

Leaf Area Index varied significantly throughout the growth period (Table 69) due to microbial inoculation. At 60 DAP $T_{11}$ recorded the maximum LAI and was superior (2.42). At 60 DAP $T_{15}$ recorded LAI of 2.38. $T_{14}$ and $T_{12}$ were on par. When AMF ($T_2$) was applied alone recorded higher LAI (1.13). At 120 DAP treatment $T_{15}$ recorded highest LAI of 2.43.This was followed by $T_{14}$ where the LAI was 2.37. At 60 and 120 DAP among single application of bio inoculants AMF recorded higher LAI (1.13 and 1.19) respectively. At 180 DAP $T_{15}$ recorded the highest LAI of 3.55. At harvest stage $T_{15}$ recorded highest LAI of 4.46. This was followed by $T_{14}$ which was on par with $T_{12}$ and $T_{13}$. Among single application of bio inoculants *Trichoderma* ($T_4$) recorded the higher LAI at 180 (2.310) and 240 (2.38) DAP. The control recorded least LAI.

### *4.4.3.3. Crop growth rate (CGR)*

The effect of microbial inoculation on crop growth rate is depicted in Table 70. The treatment showed significant variation for crop growth rate due to application of microbial inoculants. The CGR showed increasing trend as the period of growth advanced and then decreased.

Table 70. Effect of microbial inoculants on crop growth rate and relative growth rate (gm$^{-2}$ day$^{-1}$) in *Curcuma aromatica* Salisb.

| Treatments | Crop growth rate | | | Relative growth rate | | |
|---|---|---|---|---|---|---|
| | 60-120 DAP | 120 -180 DAP | 180-240 DAP | 60-120 DAP | 120-180 DAP | 180-240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 2.003 | 2.414 | 1.020 | 0.004 | 0.012 | 0.002 |
| $T_2$-(AMF) | 2.251 | 2.436 | 1.046 | 0.005 | 0.013 | 0.002 |
| $T_3$-(*Pseudomnas flourescens*) | 2.264 | 2.559 | 1.057 | 0.007 | 0.012 | 0.002 |
| $T_4$-(*Trichoderma harzianum*) | 2.378 | 2.585 | 1.071 | 0.004 | 0.013 | 0.003 |
| $T_5$-(A+AMF) | 2.553 | 2.639 | 1.127 | 0.005 | 0.013 | 0.002 |
| $T_6$-(A+P) | 2.613 | 2.736 | 1.156 | 0.004 | 0.013 | 0.003 |
| $T_7$-(A+T) | 2.667 | 2.986 | 1.176 | 0.004 | 0.012 | 0.002 |
| $T_8$-(AMF+P) | 2.714 | 3.005 | 1.164 | 0.005 | 0.013 | 0.002 |
| $T_9$-(AMF+T) | 2.734 | 3.016 | 1.194 | 0.005 | 0.012 | 0.003 |
| $T_{10}$-(P+T) | 3.005 | 3.046 | 2.016 | 0.007 | 0.016 | 0.004 |
| $T_{11}$-(A+AMF+P) | 3.293 | 3.742 | 2.001 | 0.009 | 0.017 | 0.003 |
| $T_{12}$-(A+AMF+T) | 3.486 | 3.967 | 2.051 | 0.008 | 0.016 | 0.003 |
| $T_{13}$-(AMF+P+T) | 4.000 | 4.012 | 2.116 | 0.009 | 0.017 | 0.004 |
| $T_{14}$-(P+A+T) | 4.001 | 4.053 | 2.234 | 0.011 | 0.017 | 0.010 |
| $T_{15}$-(A+AMF+P+T) | 4.084 | 4.133 | 2.634 | 0.011 | 0.017 | 0.004 |
| Control | 1.048 | 1.148 | 0.904 | 0.004 | 0.002 | 0.002 |
| CD | 0.18 | 0.10 | 0.10 | NS | NS | NS |
| SE | 0.152 | 0.114 | 0.114 | - | - | - |

CD Significant at 1 % level NS- Non significant

At 60-120 DAP, CGR was maximum in treatment $T_{15}$ (4.084 g $m^{-2}$ $day^{-1}$) which was on par with $T_{14}$ (4.001 $gm^{-2}$ $day^{-1}$ and $T_{13}$ (4.0 $gm^{-2}$ $day^{-1}$). Between 120-180 DAP $T_{15}$ recorded the highest CGR (4.133 $gm^{-2}$ $day^{-1}$) which was followed by $T_{14}$. $T_{14}$ was on par with $T_{13}$. At final stage $T_{15}$ recorded highest CGR (2.634 $gm^{-2}$ $day^{-1}$). This was closely followed by $T_{14}$ (2.234 $gm^{-2}$ $day^{-1}$) and $T_{13}$ (2.116 $gm^{-2}$ $day^{-1}$). Among single application of bioinoculants, *Trichoderma* ($T_4$) recorded higher CGR (2.378,2.585 and 1.071 $gm^{-2}$ $day^{-1}$) between 60 -120 DAP, 120-180 DAP and 180-240 DAP, respectively. The control was significantly inferior and recorded least CGR of 1.048 $gm^{-2}$ $day^{-1}$ between 60-120 DAP, 1.148 $gm^{-2}$ $day^{-1}$ between 120-180 DAP and 0.904 $gm^{-2}$ $day^{-1}$ between 180-240 DAP, respectively.

### *4.4.3.4. Relative growth rate (RGR)*

The effect of microbial inoculants on RGR are presented in Table 70. It was found that RGR was non significant.

### *4.4.3.5. Net assimilation rate (NAR)*

The effects of microbial inoculants on NAR are presented in Table 71. Microbial inoculant application showed variations among the treatments throughout the crop growth stages. A general decreasing trend in NAR was noticed as the growth advances .Between 60-120 DAP, value of NAR increased and between 120-180 DAP also a slight increase in NAR was observed. However at final phase a slight decrease in NAR value was noticed. Between 60-120 DAP $T_{15}$ recorded the maximum NAR (1.368 $gm^{-2}$ $day^{-1}$) and was superior among all other treatments. This was followed by $T_{14}$ (1.326 $gm^{-2}$ $day^{-1}$) and $T_{13}$. Among various single application of bio inoculant *Pseudomonas* ($T_3$) showed higher NAR values (0.616 $gm^{-2}$ $day^{-1}$). At 120-180 DAP $T_{11}$ recorded maximum NAR value (2.801 $gm^{-2}$ $day^{-1}$). This was followed by $T_{10}$ recording NAR value of 2.593 $gm^{-2}$ $day^{-1}$. At 180-240 DAP, $T_5$ showed maximum NAR (0.678 $gm^{-2}$ $day^{-1}$) which was followed by $T_{13}$ (0.496 $gm^{-2}$ $day^{-1}$).

Table 71. Effect of microbial inoculants on net assimilation rate (gm$^{-2}$ day$^{-1}$) and leaf area duration in *Curcuma aromatica* Salisb.

| Treatments | Net assimilation rate | | | Leaf area duration | | |
|---|---|---|---|---|---|---|
| | 60-120 DAP | 120 -180 DAP | 180-240 DAP | 60-120 DAP | 120-180 DAP | 180-240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 0.542 | 2.001 | 0.315 | 87.37 | 115.63 | 203.63 |
| $T_2$-(AMF) | 0.564 | 2.017 | 0.381 | 90.18 | 118.14 | 205.16 |
| $T_3$-(*Pseudomnas flourescens*) | 0.616 | 2.136 | 0.451 | 93.33 | 120.17 | 209.36 |
| $T_4$-(*Trichoderma harzianum*) | 0.578 | 2.246 | 0.459 | 95.64 | 122.37 | 210.05 |
| $T_5$-(A+AMF) | 0.663 | 2.145 | 0.678 | 98.17 | 127.64 | 211.33 |
| $T_6$-(A+P) | 0.554 | 2.016 | 0.264 | 100.07 | 130.33 | 215.67 |
| $T_7$-(A+T) | 0.576 | 2.098 | 0.296 | 105.64 | 131.63 | 218.45 |
| $T_8$-(AMF+P) | 0.614 | 2.136 | 0.345 | 115.36 | 148.18 | 236.89 |
| $T_9$-(AMF+T) | 0.664 | 2.263 | 0.398 | 121.64 | 163.14 | 243.66 |
| $T_{10}$-(P+T) | 0.716 | 2.593 | 0.401 | 129.13 | 170.63 | 251.16 |
| $T_{11}$-(A+AMF+P) | 0.798 | 2.801 | 0.415 | 131.00 | 175.64 | 259.66 |
| $T_{12}$-(A+AMF+T) | 0.810 | 2.031 | 0.430 | 136.34 | 205.33 | 298.64 |
| $T_{13}$-(AMF+P+T) | 0.856 | 2.046 | 0.496 | 145.01 | 219.18 | 320.18 |
| $T_{14}$-(P+A+T) | 1.326 | 2.145 | 0.266 | 150.01 | 224.63 | 324.63 |
| $T_{15}$-(A+AMF+P+T) | 1.368 | 2.190 | 0.281 | 151.01 | 229.06 | 330.13 |
| Control | 0.423 | 2.132 | 0.33 | 65.81 | 129.00 | 220.01 |
| CD | 0.05 | 0.02 | 0.03 | 3.98 | 7.08 | 7.90 |
| SE | 0.026 | 0.031 | 0.031 | 0.152 | 0.084 | 0.114 |

CD Significant at 1 % level

Among various single application of microbial inoculants, *Trichoderma* ($T_4$) recorded higher NAR. The control recorded least NAR of 0.33 $gm^{-2}$ $day^{-1}$.

### *4.4.3.6. Leaf area duration (LAD)*

The effect of microbial inoculation on LAD is presented in Table 71. Different microbial inoculants significantly influenced the LAD throughout the growth stages. Between 60-120 DAP $T_{15}$ registered highest LAD (151.01) which was on par with $T_{14}$ (150.01). This was succeeded in $T_{13}$ (145.01) and $T_{11}$ (131.0). Between 120-180 DAP maximum LAD was obtained in treatment $T_{15}$ (229.06), and was superior. This was followed by $T_{14}$ (224.63) and $T_{13}$ (219.18) which were on par. At 180-240 DAP also $T_{15}$ recorded highest LAD (330.14). However $T_{15}$ was on par with $T_{14}$ (324.6). Among various single application of microbial inoculants, *Trichoderma* ($T_4$) recorded higher LAD of 95.64 between 60-120 DAP, 122.37 between 120-180 DAP and 210.05 between 180-240 DAP. The control recorded least LAD of 65.81 between 60-120 DAP, 129.00 between 120-180 DAP and 220.01 between 180-240 DAP

### *4.4.3.7. Rhizome shoot ratio*

Data in Table 72 indicate the effect of microbial inoculants on rhizome shoot ratio. There was significant difference among treatments for rhizome shoot ratio throughout the crop growth. The rhizome shoot ratio was superior in combined application of bioinoculants like *Azospirillum,* AMF, *Trichoderma* and *Pseudomonas* ($T_{15}$) recording the maximum rhizome shoot ratio of 1.66 and 2.42 at 120 and 180 DAP respectively. At 120 DAP $T_{13}$ (1.63) and $T_{12}$ (1.60) recorded higher rhizome shoot ratio. Among the various single application of microbial inoculants *Trichoderma* ($T_4$) recorded higher rhizome shoot ratio (1.14). At 180 DAP $T_{15}$ was followed by $T_{14}$ which recorded a rhizome shoot ratio of 2.36.

Table 72. Effect of microbial inoculants on rhizome:shoot ratio and harvest index in *Curcuma aromatica* Salisb.

| Treatments | 120 DAP | 180 DAP | 240 DAP |
|---|---|---|---|
| | Rhizome shoot ratio | | Harvest index |
| $T_1$-(*Azospirillum brasilense*) | 1.01 | 1.66 | 0.54 |
| $T_2$-(AMF) | 1.09 | 1.67 | 0.56 |
| $T_3$-(*Pseudomnas flourescens*) | 1.13 | 1.71 | 0.56 |
| $T_4$-(*Trichoderma harzianum*) | 1.14 | 1.66 | 0.43 |
| $T_5$-(A+AMF) | 1.30 | 1.66 | 0.51 |
| $T_6$-(A+P) | 1.28 | 1.91 | 0.65 |
| $T_7$-(A+T) | 1.05 | 1.86 | 0.60 |
| $T_8$-(AMF+P) | 1.16 | 1.70 | 0.69 |
| $T_9$-(AMF+T) | 1.15 | 1.85 | 0.71 |
| $T_{10}$-(P+T) | 1.44 | 2.05 | 0.75 |
| $T_{11}$-(A+AMF+P) | 1.49 | 2.09 | 0.83 |
| $T_{12}$-(A+AMF+T) | 1.60 | 2.23 | 0.84 |
| $T_{13}$-(AMF+P+T) | 1.63 | 2.30 | 0.88 |
| $T_{14}$-(P+A+T) | 1.57 | 2.36 | 0.86 |
| $T_{15}$-(A+AMF+P+T) | 1.66 | 2.42 | 0.93 |
| Control | 1.00 | 1.59 | 0.43 |
| CD | 0.002 | 0.030 | 0.020 |
| SE | 0.017 | 0.032 | 0.026 |

CD Significant at 1 % level

Among the various single application of microbial inoculants at 180 DAP *Pseudomonas* ($T_3$) recorded rhizome shoot ratio of 1.71. The control recorded least rhizome shoot ratio of 0.997 at 120 DAP and 1.59 at 180 DAP.

#### *4.4.3.8. Harvest Index*

Table 72 shows the effect of microbial inoculation on harvest index of crop. Data from table revealed that there was significant difference between treatments, throughout the crop growth. $T_{15}$ recorded maximum harvest index of 0.93. This was followed by $T_{13}$ (0.88) which was on par with $T_{14}$ (0.86). The control plants $T_{16}$ recorded low harvest index (0.43).

### 4.4.4. Anatomical characters

#### *4.4.4.1. Leaf cuticle thickness*

Results of microbial inoculation on leaf cuticle thickness is presented in Table 73. The leaf cuticle thickness in plant was found significant due to the application of microbial inoculation. At 120 DAP $T_{15}$ recorded highest value (0.347µm). However $T_{15}$ was on par with $T_{14}$ and $T_{13}$ recording a value of 0.309 and 0.304 µm, respectively. It was observed that leaf cuticle thickness was maximum in $T_{15}$ at 180 DAP and it was significantly superior, the value being 0.363 µm. This was followed by $T_{14}$ (0.342 µm) and $T_{13}$ (0.324 µm). At 180 DAP among various single application of bioinoculants *Trichoderma* application increased leaf cuticle thickness (0.251µm). The control recorded least leaf cuticle thickness of 0.149 and 0.125 µm at 120 and 180 DAP respectively.

#### *4.4.4.2. Number of vascular bundles in rhizome*

Data presented on the effect of microbial inoculation on number of vascular bundles in rhizome is presented in Table 73.

Table 73. Effect of microbial inoculants on leaf cuticle thickness (µm) and number of vascular bundles in rhizome and root in *Curcuma aromatica* Salisb.

| Treatments | Leaf cuticle thickness | | Number of vascular bundles | | | |
|---|---|---|---|---|---|---|
| | | | Rhizome | | Root | |
| | 120 DAP | 180 DAP | 120 DAP | 180 DAP | 120 DAP | 180 DAP |
| $T_1$-(*Azospirillum brasilense*) | 0.208 | 0.226 | 7.56 | 7.79 | 7.43 | 7.57 |
| $T_2$-(AMF) | 0.213 | 0.217 | 7.82 | 7.90 | 7.46 | 7.63 |
| $T_3$-(*Pseudomnas flourescen*s) | 0.223 | 0.220 | 7.74 | 7.86 | 7.49 | 7.68 |
| $T_4$-(*Trichoderma harzianum*) | 0.234 | 0.251 | 7.73 | 7.85 | 7.51 | 7.70 |
| $T_5$-(A+AMF) | 0.241 | 0.271 | 7.78 | 7.97 | 7.51 | 7.81 |
| $T_6$-(A+P) | 0.249 | 0.278 | 7.90 | 8.10 | 7.63 | 7.88 |
| $T_7$-(A+T) | 0.257 | 0.290 | 7.96 | 8.17 | 7.70 | 7.98 |
| $T_8$-(AMF+P) | 0.270 | 0.294 | 8.05 | 8.26 | 7.81 | 8.08 |
| $T_9$-(AMF+T) | 0.276 | 0.302 | 8.16 | 8.32 | 7.88 | 8.21 |
| $T_{10}$-(P+T) | 0.286 | 0.306 | 7.97 | 8.46 | 7.95 | 8 .32 |
| $T_{11}$-(A+AMF+P) | 0.292 | 0.309 | 8.36 | 8.65 | 7.97 | 8.44 |
| $T_{12}$-(A+AMF+T) | 0.297 | 0.314 | 8.51 | 8.92 | 8.01 | 8.65 |
| $T_{13}$-(AMF+P+T) | 0.304 | 0.324 | 8.64 | 9.01 | 8.08 | 8.84 |
| $T_{14}$-(P+A+T) | 0.309 | 0.342 | 8.39 | 9.12 | 8.11 | 8.97 |
| $T_{15}$-(A+AMF+P+T) | 0.347 | 0.363 | 9.08 | 9.21 | 8.16 | 9.05 |
| Control | 0.149 | 0.125 | 6.55 | 6.62 | 6.92 | 6.94 |
| CD | 0.050 | 0.080 | 0.342 | 0.030 | 0.030 | 0.010 |
| SE | 0.017 | 0.089 | 0.114 | 0.036 | 0.036 | 0.017 |

CD Significant at 1 % level

At 120 DAP, $T_{15}$ obtained the maximum number of vascular bundles in rhizome (9.08) which was superior to all other treatments. $T_{13}$ (8.64) was on par with $T_{12}$ (8.51) and $T_{14}$ (8.39). At 180 DAP also $T_{15}$ recorded maximum number of vascular bundles in rhizome (9.21) and was superior than other treatments. This was followed by $T_{14}$ (9.12) and $T_{13}$ (9.01). Among the various single application of bioinoculants AMF ($T_2$) recorded the highest number of vascular bundles at 120 and 180 DAP whereas control recorded lower number of vascular bundles in rhizome.

#### *4.4.4.3. Number of vascular bundles in roots*

The results on the effect of microbial inoculation on number of vascular bundles in root is presented in Table 73. The application of microbial inoculants produced a significant effect on treatments in the number of vascular bundles in root throughout the crop growth period. At 120 DAP $T_{15}$ recorded maximum number of vascular bundles in roots (8.16) and was found superior. $T_{14}$ was on par with $T_{13}$ recording 8.11 and 8.08 vascular bundles in roots respectively. This was followed by $T_{12}$, $T_{11}$ and $T_{10}$. At 180 DAP $T_{15}$ recorded highest number of vascular bundles in roots (9.05). This was followed by $T_{14}$ (8.97), $T_{13}$ (8.84) and $T_{12}$ (8.65). When *Trichoderma* ($T_4$) was applied alone increased the number of vascular bundles increased in roots 7.51 and 7.70 at 120 and 180 DAP, respectively. The control recorded least number of vascular bundles in roots (6.92 and 6.94) at 120 and 180 DAP respectively.

#### *4.4.4.4. Stomatal frequency (abaxial)*

The data on the effect of microbial inoculation on stomatal frequency on abaxial side is presented in Table 74. The observations were recorded at 120 and 180 DAP. There was significant difference between the treatments due to application of microbial inoculants. At 120 DAP $T_{15}$ recorded the highest stomatal frequency (518.69). This was followed by $T_{14}$.

Table 74. Effect of microbial inoculants on stomatal frequency (abaxial) and (adaxial) in *Curcuma aromatica* Salisb.

| Treatments | Abaxial | | Adaxial | |
|---|---|---|---|---|
| | 120 DAP | 180 DAP | 120 DAP | 180 DAP |
| $T_1$-(*Azospirillum brasilense*) | 484.48 | 488.39 | 2068.91 | 2145.13 |
| $T_2$-(AMF) | 486.42 | 491.50 | 2077.77 | 2081.84 |
| $T_3$-(*Pseudomnas flourescen*s) | 488.73 | 494.60 | 2079.48 | 2084.66 |
| $T_4$-(*Trichoderma harzianum*) | 490.75 | 498.72 | 2081.73 | 2086.37 |
| $T_5$-(A+AMF) | 492.73 | 501.63 | 2086.50 | 2096.40 |
| $T_6$-(A+P) | 496.09 | 503.82 | 2089.50 | 2099.68 |
| $T_7$-(A+T) | 496.36 | 506.81 | 2089.50 | 2105.52 |
| $T_8$-(AMF+P) | 498.49 | 509.76 | 2092.6 | 2106.43 |
| $T_9$-(AMF+T) | 501.6 | 512.51 | 2090.7 | 2107.37 |
| $T_{10}$-(P+T) | 506.48 | 515.64 | 2096.4 | 2111.67 |
| $T_{11}$-(A+AMF+P) | 508.66 | 518.44 | 2104.2 | 2119.81 |
| $T_{12}$-(A+AMF+T) | 511.47 | 520.40 | 2108.5 | 2221.77 |
| $T_{13}$-(AMF+P+T) | 513.70 | 530.48 | 2115.7 | 2227.47 |
| $T_{14}$-(P+A+T) | 515.79 | 545.60 | 2118.9 | 2231.38 |
| $T_{15}$-(A+AMF+P+T) | 518.69 | 574.34 | 2221.4 | 2240.75 |
| Control | 456.52 | 462.53 | 2230.70 | 1498.68 |
| CD | 0.883 | 0.721 | 1.660 | 48.070 |
| SE | 0.306 | 0.249 | 0.577 | 5.270 |

CD Significant at 1 % level

At 180 DAP $T_{15}$ recorded the highest stomatal frequency (574.34). $T_{14}$ recorded a value of 545.0 and $T_{13}$ recorded 530.48. Among the various single applications of bio inoculants *Trichoderma* recorded higher stomatal frequency during both the stages. The control recorded the least stomatal frequency (abaxial) 456.52 and 462.53 at 120 and 180 DAP, respectively.

#### *4.4.4.5. Number of stomatal frequency (adaxial)*

The effect of microbial inoculants on stomatal frequency (adaxial) is presented on Table 74. There was significant variation among the treatments in stomatal frequency (adaxial) due to microbial inoculant application. At 120 DAP $T_{15}$ recorded the highest stomatal frequency (adaxial) value of 2221.4 and was superior. This was followed by $T_{14}$ (2118.9) and $T_{13}$ (2115.7). Among the single application of bio inoculants *Trichoderma* ($T_4$) application recorded higher stomatal frequency. At 180 DAP $T_{15}$ recorded highest stomatal frequency (2240.75). The control recorded least value of 2230.70 and 1498.68 at 120 and 180 DAP, respectively.

### 4.4.5. Biochemical characters

#### *4.4.5.1. Curcumin content*

The results on the effect of microbial inoculation on curcumin content is presented in Table 75. There was significant difference among the treatments on curcumin content due to application of microbial inoculants throughout the crop growth (Fig 18). At 120 and 240 DAP $T_{15}$ recorded the highest curcumin content and was significantly superior than other treatments. At 120 DAP $T_{14}$ (0.067 %) were on par with $T_{13}$ (0.066 %). At 240 DAP the highest curcumin content (0.082 %) was obtained in $T_{15}$. This was followed by $T_{14}$ (0.079 %) and $T_{13}$ (0.077 %).

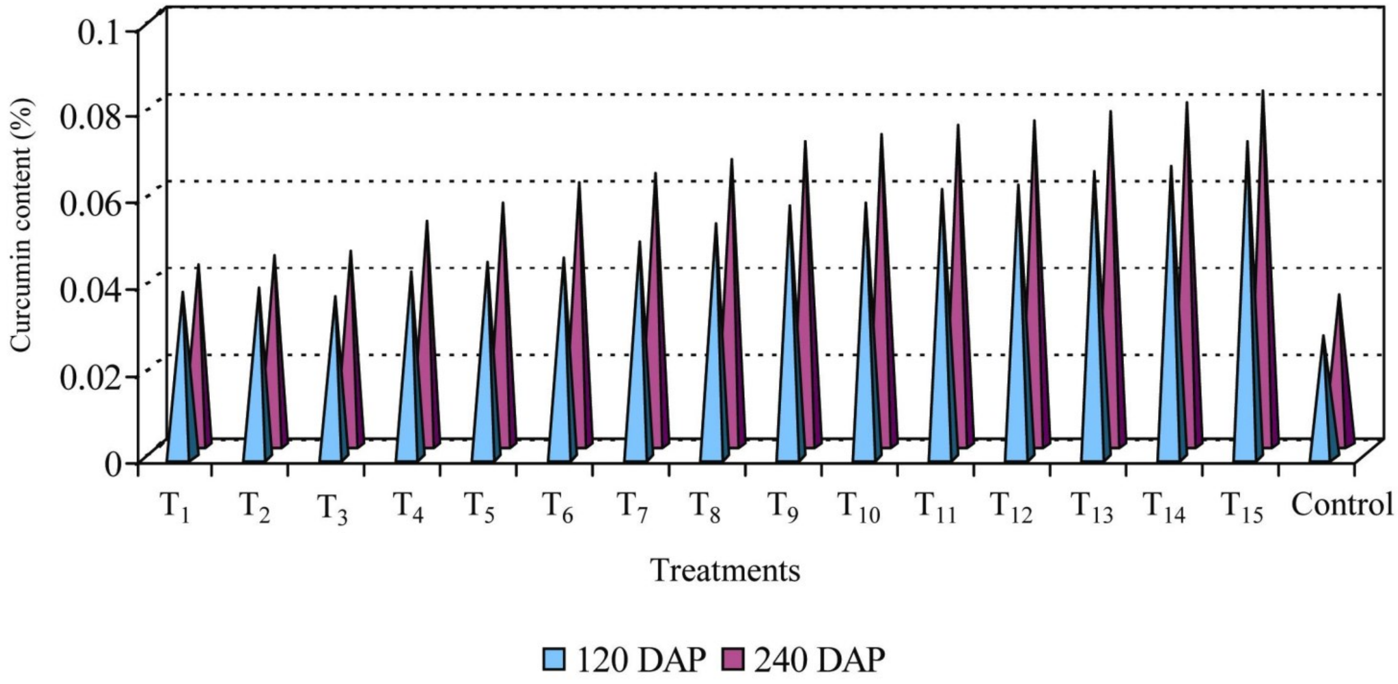


Fig. 18. Effect of microbial inoculants on curcumin content (%) in *Curcuma aromatica* Salisb.

Table 75. Effect of microbial inoculants on curcumin and volatile content (v/w) in *Curcuma aromatica* Salisb.

| Treatments | Curcumin content | | Volatile oil | |
|---|---|---|---|---|
| | 120 DAP | 240 DAP | 120 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 0.038 | 0.042 | 4.06 | 4.14 |
| $T_2$-(AMF) | 0.039 | 0.044 | 4.09 | 4.16 |
| $T_3$-(*Pseudomnas flourescens*) | 0.037 | 0.045 | 4.14 | 4.18 |
| $T_4$-(*Trichoderma harzianum*) | 0.043 | 0.052 | 4.14 | 4.26 |
| $T_5$-(A+AMF) | 0.045 | 0.056 | 4.15 | 4.34 |
| $T_6$-(A+P) | 0.046 | 0.061 | 4.16 | 4.42 |
| $T_7$-(A+T) | 0.050 | 0.063 | 4.19 | 4.52 |
| $T_8$-(AMF+P) | 0.054 | 0.066 | 4.21 | 4.54 |
| $T_9$-(AMF+T) | 0.058 | 0.070 | 4.24 | 4.58 |
| $T_{10}$-(P+T) | 0.059 | 0.072 | 4.31 | 4.63 |
| $T_{11}$-(A+AMF+P) | 0.062 | 0.074 | 4.34 | 4.67 |
| $T_{12}$-(A+AMF+T) | 0.063 | 0.075 | 4.37 | 4.69 |
| $T_{13}$-(AMF+P+T) | 0.066 | 0.077 | 4.46 | 4.74 |
| $T_{14}$-(P+A+T) | 0.067 | 0.079 | 4.54 | 4.74 |
| $T_{15}$-(A+AMF+P+T) | 0.073 | 0.082 | 4.57 | 4.87 |
| Control | 0.028 | 0.035 | 3.93 | 4.08 |
| CD | 0.002 | 0.001 | 0.050 | 0.115 |
| SE | 0.005 | 0.005 | 0.170 | 0.036 |

CD Significant at 1 % level

Among single application of bio inoculants *Trichoderma* ($T_4$) recorded higher curcumin content of 0.04 per cent 120 DAP and 0.05 per cent at 240 DAP. The curcumin content was least in control which recorded a value of 0.028 and 0.035 per cent at 120 and 240 DAP, respectively.

### *4.4.5.2. Volatile oil*

The results on the effect of microbial inoculation on volatile oil content is presented in Table 75. At 120 DAP the volatile oil content was 4.57 per cent in $T_{15}$. $T_{15}$ was on par with $T_{14}$ recording a value 4.54 per cent. This was succeeded by $T_{13}$ (4.46 %). At 240 DAP $T_{15}$ recorded the highest volatile oil content of 4.87 per cent and was superior among other treatments. $T_{12}$ and $T_{11}$ were on par. The volatile oil content observed was 4.69 and 4.67 per cent respectively. Compared to single application of bio inoculants *Trichoderma* ($T_4$) recorded highest volatile content (4.14 and 4.26 %) at 120 and 240 DAP respectively. The control recorded least volatile oil content of 3.93 and 4.08 per cent at 120 and 240 DAP respectively (Fig 19).

### *4.4.5.3. Non volatile ether extract (NVEE)*

The effect of microbial inoculants on NVEE was studied and the results are presented in Table 76. NVEE differed significantly due to the application of microbial inoculants. At 120 DAP $T_{15}$ recorded highest NVEE (5.96 %) and was significantly superior. $T_{14}$ recorded NVEE content of 5.93 per cent. $T_{13}$ (5.90 %) and $T_{12}$ (5.89 %) gave higher NVEE content. At 240 DAP also $T_{15}$ recorded maximum NVEE content (6.24 %). This was followed by $T_{14}$ (6.18 %). $T_{13}$ (6.15 %) and $T_{12}$ (6.12 %) recorded better NVEE content. Among various single application of microbial inoculants *Trichoderma* ($T_4$) when applied produced highest NVEE content of 5.36 and 5.35 per cent at 120 and 240 DAP respectively. The control recorded least NVEE during both the stages.

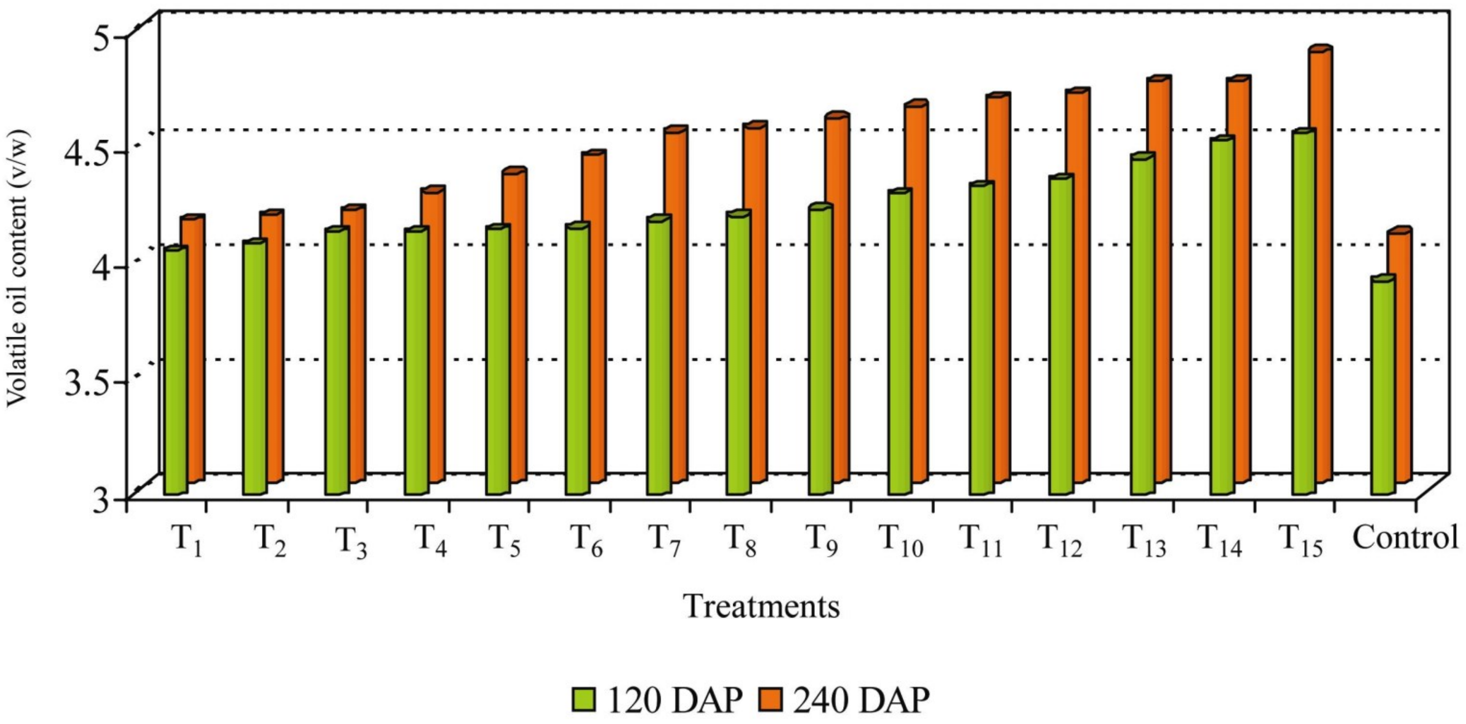


Fig. 19. Effect of microbial inoculants on volatile oil content (v/w) in *Curcuma aromatica* Salisb.

Table 76. Effect of microbial inoculants on NVEE, and crude fibre (%) in *Curcuma aromatica* Salisb.

| Treatments | NVEE | | Crude fibre | |
|---|---|---|---|---|
| | 120 DAP | 240 DAP | 120 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 5.17 | 5.25 | 2.41 | 2.80 |
| $T_2$-(AMF) | 5.21 | 5.28 | 2.35 | 2.78 |
| $T_3$-(*Pseudomnas flourescens*) | 5.25 | 5.31 | 2.40 | 2.74 |
| $T_4$-(*Trichoderma harzianum*) | 5.36 | 5.35 | 2.30 | 2.70 |
| $T_5$-(A+AMF) | 5.39 | 5.39 | 2.20 | 2.83 |
| $T_6$-(A+P) | 5.40 | 5.53 | 2.24 | 2.58 |
| $T_7$-(A+T) | 5.55 | 5.63 | 2.26 | 2.62 |
| $T_8$-(AMF+P) | 5.67 | 5.75 | 2.32 | 2.65 |
| $T_9$-(AMF+T) | 5.72 | 5.87 | 2.27 | 2.49 |
| $T_{10}$-(P+T) | 5.79 | 5.94 | 2.20 | 2.72 |
| $T_{11}$-(A+AMF+P) | 5.84 | 6.08 | 2.21 | 2.32 |
| $T_{12}$-(A+AMF+T) | 5.89 | 6.12 | 2.19 | 2.31 |
| $T_{13}$-(AMF+P+T) | 5.90 | 6.15 | 2.18 | 2.26 |
| $T_{14}$-(P+A+T) | 5.93 | 6.18 | 2.16 | 2.06 |
| $T_{15}$-(A+AMF+P+T) | 5.96 | 6.24 | 1.94 | 1.79 |
| Control | 4.84 | 4.86 | 2.48 | 3.06 |
| CD | 0.02 | 0.02 | 0.02 | 0.55 |
| SE | 0.017 | 0.017 | 0.017 | 0.192 |

CD Significant at 1 % level

#### *4.4.5.4. Crude fibre*

The data on the effect of microbial inoculants on crude fibre content is presented in Table 76. There was significant variation in crude fibre content, among different treatments. At 120 DAP $T_{15}$ recorded least crude fibre (1.94 %). This was followed by $T_{14}$ (2.16 %). At 240 DAP $T_{15}$ recorded the least crude fibre content of 1.79 percent. Among various single application of bio inoculants application of *Trichoderma* ($T_4$) recorded lower crude fibre (2.30 and 2.70 %) at 120 and 240 DAP respectively. The control recorded the highest crude fibre content.

#### *4.4.5.5. Starch*

The data on the effect of microbial inoculants on starch is presented in Table 77. There was significant variation among different treatments by application of microbial inoculants. At 120 DAP $T_{15}$ recorded the maximum starch content (22.14 %) and was significantly superior. This was succeeded by $T_{14}$ (22.10 %) and $T_{13}$ (21.98 %). The low starch content (20.82 %) was observed in treatment $T_1$. At 240 DAP $T_{14}$ recorded the highest starch content (22.58 %) which was on par with $T_{15}$ (22.38 %). When *Trichoderma* (T4) was applied alone recorded higher starch content (21.08 %) at 120 DAP and (21.55 %) at 240 DAP. The control recorded least starch content.

#### *4.4.5.6. Total Carbohydrates*

The data on the effect of microbial inoculation on total carbohydrate content is presented in Table 77. Application of microbial inoculants showed significant influence among the treatments. At 120 DAP treatment $T_{15}$ was found significantly superior (1.74 %). This was followed by $T_{14}$ recording 1.68 percent. At 240 DAP the treatment $T_{15}$ recorded highest carbohydrate content (1.90%) which was on par with $T_{14}$ (1.87 %).

Table 77. Effect of microbial inoculants on starch, total carbohydrate and protein content (%) in *Curcuma aromatica* Salisb.

| Treatments | Starch | | Total carbohydrate | | Protein | |
|---|---|---|---|---|---|---|
| | 120 DAP | 240 DAP | 120 DAP | 240 DAP | 120 DAP | 240 DAP |
| $T_1$-(*Azospirillum brasilense*) | 20.82 | 21.23 | 1.22 | 1.38 | 5.12 | 5.78 |
| $T_2$-(AMF) | 20.96 | 21.32 | 1.23 | 1.46 | 5.17 | 5.80 |
| $T_3$-(*Pseudomnas flourescen*s) | 20.98 | 21.35 | 1.26 | 1.59 | 5.20 | 5.81 |
| $T_4$-(*Trichoderma harzianum*) | 21.08 | 21.55 | 1.27 | 1.60 | 5.26 | 5.86 |
| $T_5$-(A+AMF) | 21.16 | 21.61 | 1.30 | 1.62 | 5.28 | 5.91 |
| $T_6$-(A+P) | 21.36 | 21.72 | 1.32 | 1.64 | 5.38 | 5.95 |
| $T_7$-(A+T) | 21.47 | 21.80 | 1.36 | 1.68 | 5.47 | 5.98 |
| $T_8$-(AMF+P) | 21.55 | 21.80 | 1.38 | 1.70 | 5.53 | 6.00 |
| $T_9$-(AMF+T) | 21.60 | 21.82 | 1.40 | 1.74 | 5.58 | 6.05 |
| $T_{10}$-(P+T) | 21.74 | 21.94 | 1.45 | 1.79 | 5.63 | 6.10 |
| $T_{11}$-(A+AMF+P) | 21.83 | 21.96 | 1.48 | 1.81 | 5.75 | 6.22 |
| $T_{12}$-(A+AMF+T) | 21.87 | 22.27 | 1.52 | 1.82 | 5.77 | 6.31 |
| $T_{13}$-(AMF+P+T) | 21.98 | 22.36 | 1.64 | 1.86 | 5.81 | 6.45 |
| $T_{14}$-(P+A+T) | 22.10 | 22.58 | 1.68 | 1.87 | 5.86 | 6.51 |
| $T_{15}$-(A+AMF+P+T) | 22.14 | 22.53 | 1.74 | 1.90 | 5.92 | 6.75 |
| Control | 19.88 | 20.11 | 1.06 | 1.19 | 4.82 | 5.02 |
| CD | 0.030 | 0.150 | 0.020 | 0.030 | 0.020 | 0.040 |
| SE | 0.026 | 0.044 | 0.005 | 0.032 | 0.026 | 0.032 |

CD Significant at 1 % level

Among various single application of microbial inoculants application *Trichoderma* ($T_4$) recorded 1.27 and 1.60 percent at 120 and 240 DAP respectively. The control recorded least total carbohydrate content at 120 DAP (1.06 %) and at 240 DAP (1.19 %).

### *4.4.5.7. Protein*

The data on the effect of microbial inoculation on protein content is presented in Table 77. The microbial inoculants application has produced significant difference among the treatments in protein content. At 120 DAP, $T_{15}$ recorded highest protein content (5.92 %). This was followed by treatment $T_{14}$, where the protein content was 5.86 percent. $T_{13}$, $T_{12}$ and $T_{11}$ were on par which gave a value of 5.81, 5.77 and 5.75 percent. At 240 DAP protein content was highest in $T_{15}$ treatment (6.75 %). This was followed in $T_{14}$ (6.51 %). $T_{13}$ recorded a protein content of 6.45 percent, which was followed by $T_{12}$. *Trichoderma* ($T_4$) applied alone recorded higher protein content at 120 and 240 DAP. The control recorded low protein content during both the stages.

### *4.4.5.8. Leaf chlorophyll content (a)*

The data on the effect of microbial inoculants on leaf chlorophyll (a)content is presented in the Table 78. When microbial inoculants were applied there were significant difference among the treatments in chlorophyll 'a' content. At 120 DAP $T_{15}$ treatment was found superior in increasing the chlorophyll ‘a’ content (0.490 mg $g^{-1}$). This was found on par with $T_{14}$ (0.482 mg $g^{-1}$). This was succeeded by $T_{13}$ (0.479 mg $g^{-1}$) and $T_{12}$ (0.464 mg $g^{-1}$). At 180 DAP $T_{15}$ recorded highest chlorophyll 'a' content (0.490 mg $g^{-1}$) and was superior. $T_{14}$ observed leaf chlorophyll ‘a’ content of 0.487 mg $g^{-1}$. $T_{13}$ recorded leaf chlorophyll ‘a’ content of 0.481 mg $g^{-1}$ and $T_{12}$ recorded a value of 0.469 mg $g^{-1}$. Among various single application of bio inoculants *Trichoderma* ($T_4$) recorded higher chlorophyll 'a' content of 0.390 and 0.392 mg $g^{-1}$ at 120 and 180 DAP respectively. The control recorded least value of 0.310 and 0.317 mg $g^{-1}$ at 120 and 180 DAP respectively.

### *4.4.5.9. Chlorophyll 'b'*

The data on the effect of microbial inoculants on leaf chlorophyll (b) content is presented in Table 78. The microbial inoculants significantly influenced the chlorophyll 'b' content. At 120 DAP and 180 DAP $T_{15}$ recorded the highest chlorophyll 'b' content of 0.234 and 0.278 mg $g^{-1}$ respectively. At 120 DAP $T_{15}$ was followed by $T_{14}$ where the chlorophyll 'b' content was 0.232 mg $g^{-1}$. This was succeeded by $T_{13}$ (0.227 mg $g^{-1}$) and $T_{12}$ (0.227 mg $g^{-1}$). At 180 DAP treatment $T_{15}$ recorded the highest chlorophyll 'b' content (0.278 mg $g^{-1}$). This was followed by $T_{14}$ (0.265 mg $g^{-1}$). $T_{13}$ and $T_{12}$ recorded chlorophyll 'b' content of 0.258 mg $g^{-1}$ and 0.237 mg $g^{-1}$ respectively. At 120 and 180 DAP treatment $T_4$ (*Trichoderma*) recorded highest chlorophyll 'b' content (0.168 and 0.185 mg $g^{-1}$) when single application of bio inoculants was given. The control recorded least value.

### *4.4.5.10. Total chlorophyll*

The data on the effect of microbial inoculants on total chlorophyll is presented in Table 78. There is significant variation in total chlorophyll due to application of microbial inoculants. At 120 DAP $T_{14}$ recorded the maximum total chlorophyll content of 0.622 mg $g^{-1}$). This was followed by $T_{13}$ and $T_{12}$. At 180 DAP $T_{15}$ recorded highest chlorophyll content (0.768 mg $g^{-1}$). This was followed by $T_{14}$ (0.752 mg $g^{-1}$). $T_{13}$ (0.739 mg $g^{-1}$), $T_{12}$ (0.706 mg $g^{1}$) and $T_{11}$ (0.687 mg $g^{-1}$) recorded higher total chlorophyll. Among various single application of bio inoculants application of *Trichoderma* ($T_4$) recorded the higher total chlorophyll content (0.558 and 0.577 mg $g^{-1}$) at 120 DAP and 180 DAP respectively. The control recorded least total chlorophyll content of 0.424 and 0.441mg $g^{-1}$ during both the stages.

Table 78. Effect of microbial inoculants on chlorophyll 'a', 'b' and total chlorophyll (mg $g^{-1}$) in *Curcuma aromatica* Salisb.

| Treatments | Chlorophyll 'a' | | Chlorophyll 'b' | | Total chlorophyll | |
|---|---|---|---|---|---|---|
| | 120 DAP | 180 DAP | 120 DAP | 180 DAP | 120 DAP | 180 DAP |
| $T_1$-(*Azospirillum brasilense*) | 0.347 | 0.351 | 0.154 | 0.158 | 0.501 | 0.509 |
| $T_2$-(AMF) | 0.350 | 0.325 | 0.158 | 0.164 | 0.508 | 0.489 |
| $T_3$-(*Pseudomnas flourescens*) | 0.364 | 0.375 | 0.164 | 0.179 | 0.528 | 0.554 |
| $T_4$-(*Trichoderma harzianum*) | 0.390 | 0.392 | 0.168 | 0.185 | 0.558 | 0.577 |
| $T_5$-(A+AMF) | 0.395 | 0.398 | 0.172 | 0.189 | 0.567 | 0.587 |
| $T_6$-(A+P) | 0.412 | 0.416 | 0.183 | 0.193 | 0.590 | 0.609 |
| $T_7$-(A+T) | 0.422 | 0.426 | 0.194 | 0.194 | 0.617 | 0.620 |
| $T_8$-(AMF+P) | 0.424 | 0.429 | 0.198 | 0.212 | 0.623 | 0.641 |
| $T_9$-(AMF+T) | 0.435 | 0.433 | 0.204 | 0.220 | 0.639 | 0.645 |
| $T_{10}$-(P+T) | 0.443 | 0.447 | 0.218 | 0.223 | 0.662 | 0.670 |
| $T_{11}$-(A+AMF+P) | 0.458 | 0.461 | 0.225 | 0.226 | 0.683 | 0.687 |
| $T_{12}$-(A+AMF+T) | 0.464 | 0.469 | 0.227 | 0.237 | 0.696 | 0.706 |
| $T_{13}$-(AMF+P+T) | 0.479 | 0.481 | 0.229 | 0.258 | 0.712 | 0.739 |
| $T_{14}$-(P+A+T) | 0.486 | 0.487 | 0.232 | 0.265 | 0.721 | 0.752 |
| $T_{15}$-(A+AMF+P+T) | 0.490 | 0.490 | 0.234 | 0.278 | 0.622 | 0.768 |
| Control | 0.310 | 0.317 | 0.114 | 0.124 | 0.424 | 0.441 |
| CD | 0.004 | 0.004 | 0.003 | 0.002 | 0.020 | 0.020 |
| SE | 0.316 | 0.017 | 0.005 | 0.005 | 0.026 | 0.026 |

CD Significant at 1 % level

### 4.4.6. Soil biological properties

#### *4.4.6.1. AMF colonization percentage*

AMF colonization percentage is presented in Table 79. At 15 DAP after planting $T_8$ recorded highest AMF colonization (38 %) followed by $T_{14}$ (37.38 %) and $T_9$ (37.5 %). The control recorded 15.14 percent. The AMF colonization increased on second sampling (30 days after planting) $T_9$ recorded the highest AMF colonization percentage (55.86 %) followed by $T_2$ (54.75 %). The control recorded the least AMF colonization (18.74 %). At 45 DAP, AMF colonization further increased. $T_2$ recorded the highest AMF colonization percentage (67.10 %) followed by $T_{15}$ (66.01 %) and $T_{13}$ (65.32 %). The control recorded lowest AMF colonization percentage (19.73 %). After 60 DAP the AMF colonization was found highest in $T_2$ treatment (74.36 %), where $T_{15}$ and $T_9$ (73.64 %) recorded the same value. The control recorded lowest AMF colonization (21.66%).

Table 79. Effect of microbial inoculants in AMF colonization percentage in *Curcuma aromatica* Salisb.

| Treatments | 15 DAP | 30 DAP | 45 DAP | 60 DAP |
|---|---|---|---|---|
| $T_2$-(AMF) | 37.00 | 54.75 | 67.10 | 74.36 |
| $T_5$-(A+AMF) | 36.00 | 53.70 | 60.66 | 72.14 |
| $T_8$-(AMF+P) | 38.00 | 53.90 | 62.30 | 72.64 |
| $T_9$-(AMF+T) | 37.50 | 55.86 | 65.13 | 73.64 |
| $T_{11}$-(A+AMF+P) | 34.96 | 54.60 | 60.16 | 70.86 |
| $T_{12}$-(A+AMF+T) | 36.37 | 52.81 | 64.10 | 70.88 |
| $T_{13}$-(AMF+P+T) | 36.14 | 53.10 | 65.32 | 71.36 |
| $T_{15}$-(A+AMF+P+T) | 37.38 | 54.01 | 66.01 | 73.64 |
| Control | 15.14 | 18.74 | 19.73 | 21.66 |

Table 80. Effect of microbial inoculants on microbial load

| Treatments | Fungi | | Bacterial | | Actinomycetes | |
|---|---|---|---|---|---|---|
| | Initial | Final ($10^5$) | Initial | Final ($10^7$) | Initial | Final($10^5$ ) |
| $T_1$-(*Azospirillum brasilense*) | 4 x $10^5$ | 120.00 | 10 x $10^7$ | 81.33 | 5 x $10^5$ | 91.00 |
| $T_2$-(AMF) | 4 x $10^5$ | 113.00 | 10 x $10^7$ | 121.33 | 5 x $10^5$ | 118.00 |
| $T_3$-(*Pseudomnas flourescen*s) | 4 x $10^5$ | 121.00 | 10 x $10^7$ | 127.66 | 5 x $10^5$ | 120.00 |
| $T_4$-(*Trichoderma harzianum*) | 4 x $10^5$ | 130.00 | 10 x $10^7$ | 131.00 | 5 x $10^5$ | 122.00 |
| $T_5$-(A+AMF) | 4 x $10^5$ | 129.00 | 10 x $10^7$ | 137.00 | 5 x $10^5$ | 122.66 |
| $T_6$-(A+P) | 4 x $10^5$ | 130.33 | 10 x $10^7$ | 141.00 | 5 x $10^5$ | 126.00 |
| $T_7$-(A+T) | 4 x $10^5$ | 141.00 | 10 x $10^7$ | 143.00 | 5 x $10^5$ | 129.00 |
| $T_8$-(AMF+P) | 4 x $10^5$ | 143.66 | 10 x $10^7$ | 146.00 | 5 x $10^5$ | 131.00 |
| $T_9$-(AMF+T) | 4 x $10^5$ | 148.00 | 10 x $10^7$ | 148.00 | 5 x $10^5$ | 148.00 |
| $T_{10}$-(P+T) | 4 x $10^5$ | 151.00 | 10 x $10^7$ | 156.00 | 5 x $10^5$ | 152.00 |
| $T_{11}$-(A+AMF+P) | 4 x $10^5$ | 155.00 | 10 x $10^7$ | 176.00 | 5 x $10^5$ | 154.00 |
| $T_{12}$-(A+AMF+T) | 4 x $10^5$ | 158.00 | 10 x $10^7$ | 195.00 | 5 x $10^5$ | 162.67 |
| $T_{13}$-(AMF+P+T) | 4 x $10^5$ | 171.00 | 10 x $10^7$ | 211.67 | 5 x $10^5$ | 171.00 |
| $T_{14}$-(P+A+T) | 4 x $10^5$ | 169.00 | 10 x $10^7$ | 245.67 | 5 x $10^5$ | 196.00 |
| $T_{15}$-(A+AMF+P+T) | 4 x $10^5$ | 179.00 | 10 x $10^7$ | 243.33 | 5 x $10^5$ | 252.67 |
| Control | - | 31.00 | - | 42.33 | - | 32.33 |
| CD | - | 7.07 | - | 24.49 | - | 2.83 |
| SE | - | 2.451 | - | 8.491 | - | 0.981 |

CD significant at 1 % level.

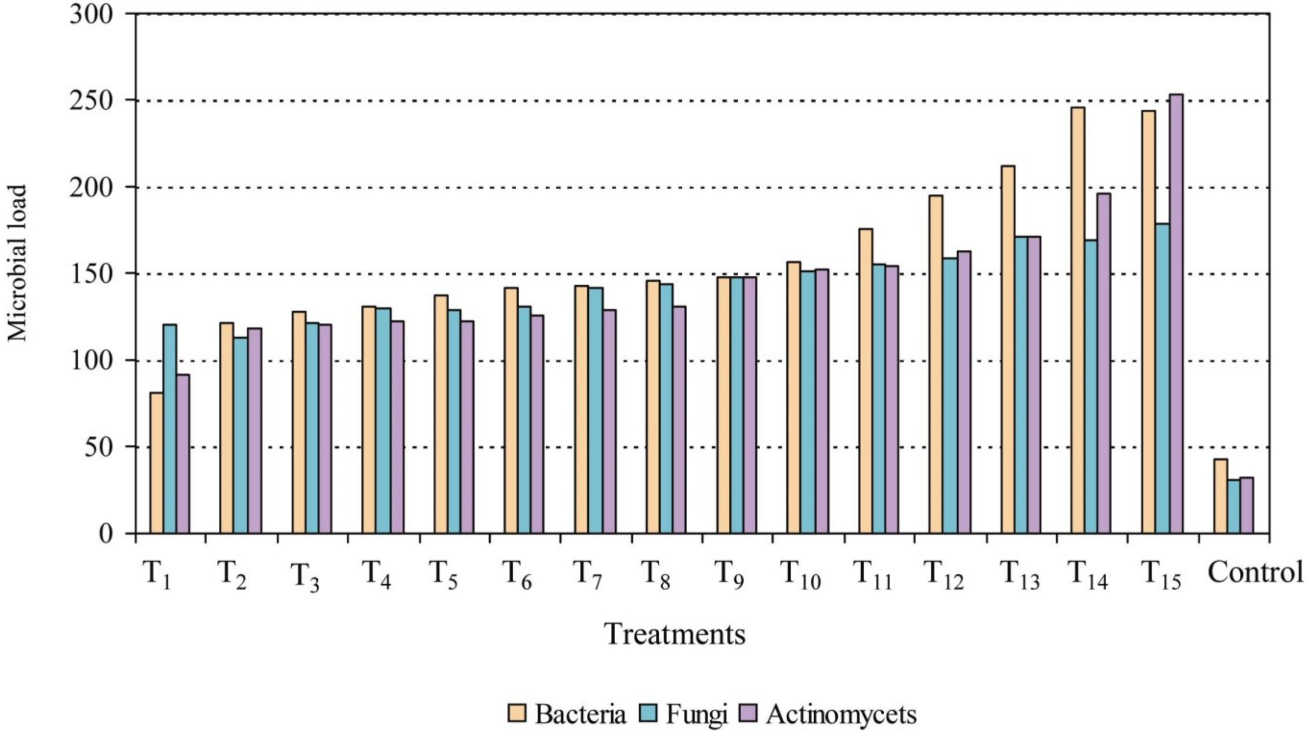


Fig. 20. Effect of microbial inoculants on microbial load

### *4.4.6.2. Microbial load*

Effect of microbial inoculants on (bacterial, fungal and actinomycetes load) are presented in Table 80. The soil microbes increased from the initial load due to the application of microbial inoculants. The bacterial load was found highest in treatment $T_{14}$ (245.67 x $10^7$). This was followed by $T_{15}$ (243.33 x $10^7$). The bacterial load increased in $T_{13}$ and $T_{12}$. When *Trichoderma* ($T_4$) was applied alone the bacterial load increased to 131.0 x $10^7$. The control recorded least bacterial load of 42.33 x $10^7$ (Fig 20).

Application of microbial inoculants was found significant in increasing fungal load. Combined application of *Azospirillum* along with *AMF, Trichoderma* and *Pseudomonas* ($T_{15}$) increased the fungal load (179 x $10^5$) and was found significantly superior. This was followed by $T_{13}$ (171 x $10^5$) which was on par with $T_{14}$ (169.0 x $10^5$). Among the various single application of bio inoculants *Trichoderma* ($T_4$) recorded fungal load of 130.0 x $10^5$. The control recorded lower (31 x $10^5$) fungal load.

The effect of microbial inoculant was found significant and increased actinomycetes load. The highest actinomycetes load was observed in $T_{15}$ treatment (249.84 x $10^5$). This was followed by $T_{14}$ (196.$10^5$). $T_{13}$ recorded actinomycetes load of 171.0 x $10^5$ and $T_{12}$ which recorded 162.67 x $10^5$. Among the various single application of microbial inoculants application *Trichoderma* ($T_4$) recorded highest actinomycetes load (122 x $10^5$). Control recorded 32.33 x $10^5$ in the case of actinomycetes load.

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# DISCUSSION

# 5. DISCUSSION

Kasthuri turmeric (*Curcuma aromatica* Salisb.) is a medicinal and aromatic plant with multiple uses. Skin care is the major domain of application of this aromatic plant. It is also used in medicines as a stomachic, carminative and emmenogogue and recently as a health food in Japan (Kojima et al., 1998).

As far as the medicinal and cosmetic plants are concerned, the active principles of the plants are generally secondary metabolites and their biosynthesis, though controlled genetically is strongly affected by environmental and cultural factors. It is therefore advised not to use chemical fertilizers, insecticides and pesticides in the cultivation of these crops. Hence organic cultivation is more reliable in this crop. At present there is no package of practices recommendation for true kasthuri turmeric. Hence a study entitled "Standardization of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)" was undertaken to standardize agro techniques for the cultivation of true kasthuri turmeric. The results of the investigation are discussed below.

Organic farming is the fastest growing agricultural production system in the world addressing ecological conservation, self reliance in food production, rural development, biodiversity conservation and health protection. In this farming system there is a dynamic interaction among soil, plant, ecosystem and environment.

The use of organic sources as nutrients are known from the beginning of agriculture (Gowda and Babu, 1999). India has a potential of manurial resources like FYM, green manures, compost, crop residues etc. The on-farm recycling of organic wastes and the application of bulky organic manures such as FYM and compost are adopted to sustain good soil health. Apart from these manures, other organic sources like vermicompost, neemcake, coirpith compost and bio inoculants and biofertilizers are also used.

Vermicompost is a potential organic source due to the presence of readily available plant nutrients, growth enhancing substances, beneficial microbes like nitrogen fixing, P solubilising and cellulose decomposing organisms. These organisms are known to induce many biochemical transformations like mineralization of organically bound form of materials, exchange reactions, fixation of atmospheric nitrogen, solubilisation of insoluble P and various other changes leading to better availability of nutrients (Sheeba, 2004). Vermicompost is rich in macro and micro nutrients. It has immobilized enzymes like proteases, lipase, amylase, cellulase and chitinase. It is rich in vitamins, antibiotics and growth hormones. Application of vermicompost enhance the soil pH and thus improves the availability of nutrients. It changes the C/N ratio in the soil by increasing the level of carbon, thus improving microbial activity (Usha Kumari, 2004). Beneficial influence of worm cast due to the biological factors like giberellins, cytokinins, auxins are released by the metabolic activities of microbes harboured in the cast (Tomati et al., 1988). Vermicompost accelerates the humification of organic matter and influences microbial populations, enhances production of plant hormones as well as humic acids (Casenave de Sanfilippo et al., 1990). The humic acids involve in cell respiration, photosynthesis, oxidative phosphorylation, protein synthesis and various enzymatic reactions (Vaughan et al., 1985).

Neemcake is rich in plant nutrients, alkaloids like nimbin and nimbidin and certain sulphur compounds inhibit nitrification process (Reddy and Prasad 1975, Rajkumar and Sekhon, 1981). As a result it acts like a slow releasing nitrogen fertilizer by inhibiting nitrification process. Neemcake increases the agronomic use efficiency and nutrient use efficiency and insect repellent action (Nihad, 2005). It is also rich in nutrients, supress nematode population and increase insect repellent action. It is a rich source of N, P, K, Ca and Mg which favours growth of plants (Som et al., 1992).

FYM provides nutrients and enhances the aeration and microbial activities of soil. It serves as a good source of almost all plant nutrients.

Coirpith compost increases the water holding capacity of soil and it is rich in potassium which is made available for plants over years.

The study was conducted as four separate experiments, the first being laboratory incubation studies of the organic manures, to asses the nutrient release pattern of various organic manures *viz.* FYM, vermicompost, coirpith compost and neem cake in soil. The results of various soil parameters like N, $P_2O_5$, $K_2O$ and organic carbon status influenced by different organic sources incubated for a period of 60 days at an interval of 15 days are discussed here under.

The data given in Table 1 revealed that the soil treated with different organic manures registered higher content of available N as compared to control (soil alone). The reason could be attributed to the fact that the addition of organic matter primarily provides nitrogen to the soil. The organically bound form of nitrogen becomes available in soil after decomposition of organic sources followed by mineralization into inorganic forms (Tusneem and Patrick, 1971), which in turn improves the available N content in soil. The nitrogen release pattern of various manures was found to have pronounced variation with the advancement of time. In the case of all the treatments, the amount of mineralized N increased from initial value at 15th day after incubation (DAI) and thereafter there was a gradual increase. The increase in available nitrogen is due to the enhanced mineralization of organic matter consequence of high microbial activity. The process of aminisation, ammonification and oxidative deamination all brought about by microbially mediated systems are believed to be active in organic sources treated medium, thus contributing more soluble nitrogen to the soil. The available nitrogen content declined after 45 DAI in control alone, it may be due to stabilized nature of organic matter (Dinesh and Dubey, 1999).

After the 15th day of incubation the available N content of soil gradually increased. In the case of treatment $N_3$ the value progressively increased after 15th DAI and reached the peak at 60th DAI (240.54 and 289.58 kg $ha^{-1}$) during 15th DAI and 60th DAI respectively. For vermicompost and FYM the release of available N increased steadily up to 60 days of incubation, whereas for soil alone the values increased gradually up to 45th DAI and then declined. Nitrogen from coir pith compost must first be released from its organic substrates and this process takes from several days to several weeks. Hence N availability from compost is extended for a longer period (Hue and Silva, 2000). Comparing $F_3$ and $C_3$ available N content was significantly higher in $N_3$ and $V_3$ through out the period of incubation. The inferior performance of $C_3$ might be due to its lower nitrogen content and wider C: N ratio coupled with its nitrification inhibition property due to the presence of soluble tannins (Nagarajan et al., 1990). Slower release of N from neem cake might be due to its nitrification inhibition property. In addition to nutrients, neem cake contains the alkaloids, nimbin and nimbidin, which effectively inhibit the nitrification process in soil (Reddy and Prasad, 1975). Thus neem cake act as an immobilizer, thus conserving the applied and soil nitrogen and mineralizing steadily over a longer period. In the case of vermicompost higher nitrogen content contributed by the earth worm activity and biological nitrogen fixation effected by the large population of microbes and enhanced urease activity might have improved the available N content (Asha Raj, 2006). Similar results were reported by Bijulal (1997) and Sheeba (2004).

Table 2 represents the effect of various treatments and periods of incubation on available $P_2O_5$ content of soil. There was significant variation among treatments and all organic manures registered higher content of available $P_2O_5$ as compared to control (soil alone). This might be due to the significant addition of phosphorus through organic matter incorporation coupled with the improved solubility of P due to intense microbial activity as reported by Bijulal (1997). More over phosphorus from organic sources is more readily available to plants. Organic matter from manure interacts with clay minerals and reduced P absorption by the soil there by enhancing P availability to plants (Hue, 1990). In the case of $V_3$ there was progressive increase in the availability from $0^{th}$ to $60^{th}$ day with peak values of 124.10 kg $ha^{-1}$. For neem cake also the availability reached the peak at $60^{th}$ DAI (116.98 kg $ha^{-1}$). $F_3$ recorded a gradual increase from the initial value of 45.59 kg $ha^{-1}$ to peak value of 119.97 kg $ha^{-1}$ at 60 DAI. Though the available $P_2O_5$ was less in treatment $C_3$ there was a gradual increase and recorded a value of 101.54 kg $ha^{-1}$at $60^{th}$ DAI. The mean values indicated that available $P_2O_5$ was highest (124.10 kg $ha^{-1}$) in treatment $V_3$ followed by $N_3$ (116.98 kg $ha^{-1}$), which could be attributed to their higher phosphorus content. Also studies on the effect of vermicompost on soil fertility status carried out by Sharply and Syers (1987) revealed an increased availability of P due to the indirect microbial population and phosphatase activity. The increase in available $P_2O_5$ content due to vermicompost application was reported by Gaur (1990). This may be due to the greater mineralization of organic matter with the aid of micro organisms associated with earthworms and increased phosphatase activity.

The data given in Table 3 revealed the significant influence of various treatments and periods of incubation on available potassium content. In general, available $K_2O$ increased progressively at all stages of incubation up to 60 DAI for all the treatments. Similar results were reported by Bijulal (1997) and Nair et al. (2003). All organic manures recorded higher $K_2O$ content than soil alone. This might be due to the addition of potassium through organic manures. More over organic amendments usually have a large cation exchange capacity enabling them to retain K ions effectively. Also decomposition of organic manures produces organic acids, which cause the dissolution of insoluble K minerals and increase the available $K_2O$ content (Hue and Silva, 2000). In the case of neem cake there was a progressive increase of K up to 60th day (313.62 kg $ha^{-1}$). This might be due to the rapid mineralization of potassium from neem cake. But in treatments $V_3$, $C_3$ and $F_3$ also availability of K extended for a period, reaching the peak at 60th DAI recording the value of 310.10, 305.53 and 305.92 kg $ha^{-1}$, respectively. The treatments $F_3$ and $C_3$ were on par. This might be due to the better retention of potassium ions in the humic complexes and their slow release.

The highest value for available $K_2O$ was registered by vermicompost application. Reason for higher potassium may be due to accelerated mineralization due to high microbial activity and release of K from exchange site due to interaction of organic matter with clay (Tan, 1982). Increased availability of K by earthworm activity was reported by Rao et al., (1996). As the major portion of $K_2O$ is obtained from mineralization of organic matter the peak concentration of available $K_2O$ also synchronized with the peak time of mineralization (Dhanokar et al., 1994). Bhasker et al., (1994) inferred from the incubation experiment that the exchangeable potassium content increased significantly due to earthworm activity. The higher concentration of potassium of the soil with worms compared with that of the soil without worms at the same moisture level confirms the positive role of earthworms in influencing this fraction of potassium.

Different treatments showed significant variation with respect to organic carbon content of soil (Table 4). Organic carbon content of soil increased upto 15th day of incubation and thereafter declined. The organic carbon content observed at 60th DAI was more in treatment $N_3$ (0.40 %) followed by $V_3$ (0.31 %). The observed decrease in organic carbon content with time after a peak is due to intensive mineralization and loss of carbon as $CO_2$. By introducing earthworms and applying organic matter in the red arid soil, the organic carbon content of soil increases from 0.5 to 0.6 per cent. (Shuxin et al., 1991). More (1994) reported that addition of farm waste and organic manures increased the status of organic carbon.

The second experiment was to study the effect of organic manures on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.). The experiment was repeated during the second year also. From the study it was observed that growth characters like plant height, number of tillers, number of leaves, leaf area, rhizome spread, rhizome thickness, root length, root spread, root weight and number of fingers were found to be influenced by the application of different doses of various organic manures like neemcake, vermicompost, coirpith compost and FYM during two years of crop study. As a general trend , it was observed that $V_3$ (Vermicompost 25.0 t $ha^{-1}$) and $N_3$ (Neemcake 6.0 t $ha^{-1}$) treated plants were taller when compared to other treatment plants and they were vigorously growing and produced more number of tillers and leaves, maximum leaf area, rhizome spread and thickness, root length, spread and weight and also more number of fingers during first year and second year of experimentation. In certain characters $V_3$ and $N_3$ were on par whereas in some others, $V_3$ was followed by $N_3$.The presence of plant growth promoting hormones and easy availability of nutrients in vermicompost, (Ushakumari, 2004) and the nutrient use efficiency and increased insect repellant action of neem cake.

(Rakhee, 2002) might have contributed to the better growth characters observed in these plants. These results are also in conformity with the findings of Rakhee (2002) in turmeric, Sreekala (2004) in ginger, Sheeba (2004) in amaranthus and Santhosh Kumar (2004) in *Plumbago rosea.*

The fresh and dry yield of rhizomes were found to be influenced by the application of various organic manures. At the harvest stage, $V_3$ was significantly superior to all other treatments and recorded the highest fresh rhizome yield of 362.95 and 396.33 g plant$^{-1}$ during first and second crop, respectively. The pooled analysis also showed that $V_3$ was significantly superior and recorded a fresh rhizome yield of 379.64 g plant$^{-1}$. The dry rhizome yield recorded by $V_3$ treated plants was also significantly superior but at final stage $V_3$ and $N_3$ were on par (Table 16). The pooled mean revealed that $V_3$ and $N_3$ were on par but significantly superior. The higher yield from $V_3$ and $N_3$ treated plots might be due to readily available nutrients from soil, and the enhanced enzyme activity especially in vermicompost (Ushakumari, 2004). Neemcake reduces leaching loss and extends the period of availability of N to the crop from the applied N (Sathianathan, 1982). The higher yield is obtained due to higher uptake of N, P and K (Table 50,51 and52) leading to production of more leaves, more tillers resulting in the accumulation of more photosynthates and their further efficient translocation to the rhizome contributing to yield. However, neemcake is rich in N, P, K, Ca and Mg which helps in plant growth and development and ultimately to increased yield. This can also be attributed to the greater uptake of N,P and K (Table 50,51and52) mobilized from vermicompost and neemcake, during the current as well as previous season and thus resulted highest biomass accumulation and further diversion to rhizomes. This is in conformity with findings of Rakhee (2002) in turmeric Sadanandan and Hamza (1998) in ginger, Sharu (2000) in chilli and Sreekala (2004) in ginger. The top yield was maximum in treatment $V_3$ at 120 and 180 DAP during both the years (Table 17). This might be due to the effect of vermicompost which is a potential source of readily available nutrients and growth hormones, which will help to produce more number of leaves, leaf area and number of tillers. The above result is in accordance with the findings of Rakhee (2002) in turmeric.

The crop took minimum number of days of 221.43 (first crop) and 222.58 days (second crop) for attaining maturity when the treatment $V_3$ was given. Vermicompost which is rich in plant nutrients and hormones might have helped in vigorous growth, development and early maturation. The above result is in conformity with the studies of Athani et al., (1999) in banana.

Physiological characters like DMP, LAI, CGR, NAR, LAD, rhizome shoot ratio and harvest index were found to be positively influenced by the various organic manures. Initially at 60 DAP $V_3$ treatment produced the highest DMP of 22.84 g plant$^{-1}$ during first year. But during second year $V_3$ was on par with $N_3$. At final phase, $V_3$ was on par with $N_3$ during both the years. The pooled mean also showed that $V_3$ was significantly superior and recorded highest DMP. $V_3$ and $N_3$ treated plants also recorded maximum root weight and rhizome spread which in turn might have contributed to a high DMP compared to other treatment plants. Similar findings were reported by Pushpa (1996) in tomato, Niranjana (1998) in amaranthus, Sharu (2000) in chilli and Rakhee (2002) in turmeric.

Initially LAI was influenced by $N_3$ and $V_3$ treatments which were significantly superior. But at the harvest stage the plants given $V_3$ treatment produced maximum LAI during both the years of experimentation. The enhanced leaf production coupled with more number of functional leaves retained per plant and higher photosynthetic area might have resulted in the higher LAI in $V_3$ and $N_3$ treatments. The above result is in conformity with the findings of Arunkumar (2000) in amaranthus and Nihad (2005) in Chettikoduveli.

Generally an increased CGR was noticed in the initial phase in all the treatments (Table). However, at final stage the various treatments recorded a lower CGR. At initial phase, $N_3$ and $V_3$ were on par during both the years of experimentation. During final phase $V_3$ was found superior. The higher LAI and DMP might have contributed to these effects. This result is also in coincidence with the findings of Sharu (2000) in chilli, Rakhee (2002) in turmeric and Sreekala (2004) in ginger .

The treatment $V_3$ and $N_3$ were found to influence the RGR significantly throughout the growth period. The increased DMP in the above treatments might have increased the RGR. The above result is supported by Sharu (2000) in chilli and Rakhee (2002) in turmeric.

During initial stages $N_3$ and $V_3$ were on par and recorded higher NAR in both the years. During final phase of growth , plants given $N_3$ treatment was superior. A decrease in NAR towards the final phase of growth was noted in all treatment plants. This trend is in accordance with the postulation of Watson (1958) that as leaf area ratio falls with advancing age, the rate of respiration per unit leaf area tends to increase and hence NAR decreases, independently of any change in the rate of photosynthesis or respiration per unit dry weight. The above result was in accordance with the findings of Sharu (2000) in chilli and Rakhee (2002) in turmeric.

LAD was found significantly superior in $V_3$ treatment between180-240 DAP during both the years. Higher LAD might be due the higher LAI as well as the longer retention of the leaves throughout the crop growth. The positive effect of vermicompost contributing to LAD is in conformity with the findings of Rakhee (2002) in turmeric.

The rhizome : shoot ratio was significant at various growth stages during both years. At 120 DAP, $C_3$ and $V_3$ treated plants were superior and recorded the highest rhizhome : shoot ratio during first and second year, respectively. On the contrary at 180 DAP $N_3$ treatment was found superior and recorded maximum rhizome : shoot ratio during both the years of crop. The rhizome shoot ratio was more in $C_3$, $V_3$ and $N_3$ treated plants, and this might be because of less allocation of photosynthates to shoot at later stages of growth, where most of the assimilates might have been translocated to add to economic part. The above result was supported by Rakhee (2002) in turmeric and Sailaja Kumari and Usha Kumari (2002) in cowpea.

The harvest index (HI) recorded at 240 DAP was found to be significant. The treatment $V_3$ was significantly superior and recorded highest HI during both the years of study. A better translocation of dry matter into rhizomes as reflected by high dry weight of rhizome might have contributed to maximum HI. This result is in corroborance with the findings of Maheswarappa et al., (2000) in galangal and Sajitha (2005) in garden bean.

Anatomical characters like leaf cuticle thickness, number of vascular bundles in rhizome and roots, and stomatal frequency were increased by $V_3$ and $N_3$ treatments. The application of vermicompost and neemcake with their fast release of growth hormones, nutrient availability and rich nutrient use efficiency produced healthy plants, with healthy leaves and root biomass, which might have contributed to better anatomical characters..

The biochemical characters like curcumin, volatile oil, NVEE, starch, total carbohydrates and protein were found to be significantly influenced by application of organic manures. The quality characters were studied and estimated at 120 and 240 DAP. It was observed that $V_3$ plants recorded highest curcumin and volatile content at both the stages during first and second year of study. At 120 DAP $N_3$ and $V_3$ recorded the same NVEE content during first year. During second year $V_3$ was significantly superior. But at 240 DAP $V_3$ and $N_3$ recorded the same value for NVEE during both the years of experimentation. Vermicompost, which is rich in vitamins and growth hormones and also neemcake with high agronomic use effeciency when applied alone or in combination increases better quality of diverse crops (Gavirilov, 1962; Tomati et al., 1983; Bano et al., 1987). Rakhee (2002) opined that curcumin content in turmeric was increased by the application of neemcake. According to Arumugham Shakila and Prabu (2007) the volatile oil content was increased by the application of vermicompost in mint.

The starch, crude fibre, total carbohydrate content and protein content showed maximum values for $V_3$ treated plants at 240 DAP during both the years. The increase in DMP due to application of vermicompost and neemcake might have increased the starch and total carbohydrate content. Application of vermicompost exerted significant influence on protein content. This might be due to the favourble effect of nitrogen involved in protein synthesis. The positive influence of vermicompost in increasing starch content were reported by Suresh Kumar (1998) in sweet potato and Sreekala (2004) in ginger. The total carbohydrates content in crops was also found to be increased by the application of vermicompost which was supported by Pushpa (1996) in tomato and Athani et al., (2006) in guava and Sheeba (2004) in amaranthus, where the crude fibre content was influenced by the application of vermicompost.

Chlorophyll 'a', 'b' and total chlorophyll content in leaves was significantly influenced and $V_3$ treated plants gave maximum chlorophyll content at 120 and 180 DAP during both the years. The application of vermicompost produced healthy plants, with healthy green leaves which might have increased the chlorophyll content in these plants. This is in accordance with the findings of Nihad (2005) in *Plumbago rosea* and Arumugham Shakila and Prabu (2007) in mint.

Application of organic manures like vermicompost, neemcake, FYM and coirpith compost decreased the bulk density of soil. At the end of first experiment , the bulk density recorded by $V_3$ and $N_3$ was same (1.51 gm $cc^{-1}$). After the second experiment also the bulk density was superior in $V_3$ and $N_3$ which recorded same value (1.45 gm $cc^{-1}$). But at the end of residual crop the bulk density decreased further and the lowest bulk density was recorded by $V_3$ (1.47 gm $cc^{-1)}$. The ability of earthworms to influence the soil physical environment has reported by Shipitalo and Protz (1988). Maheswarappa et al., (1999) studied the effect of organic manures on soil physical properties and reported that vermicompost application decreased the bulk density of the soil to a greater extent. Similar findings were reported by Kala and Krishnamoorthy (1981) and Sadanandan and Hamza (1998) in ginger.

After the first crop , water holding capacity increased from initial value and $V_3$ recorded the highest value. At the end of second year, water holding capacity increased further and $V_3$ was superior (Table 43). It increased further after the residual crop, too. Kala and Krishnamoorthy (1981) described the role of earthworms in the degradation of organic wastes and in improving the physico-chemical properties of soil. According to Lee, 1985, vermicompost enhances the soil structure and improves the water holding capacity and porosity and facilitates the root penetration and growth This finding is also in conformity with the findings of Sheeba (2004), in amaranthus.

At the end of first, second, and residual crop, pH of soil decreased. The decrease in pH might be due to the organic matter decomposition as a result of which carbondioxide will be produced and get dissolved in water to produce carbonic acid. This weak acid might have reduced the $P^H$ of soil.

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The soil EC increased from initial stage to harvest stage. After the harvest of first crop , the soil EC was highest in $V_3$ treatment (0.380 $dsm^{-1}$). After the end of second crop also $V_3$ was significantly superior and recorded an EC of 0.547 $dsm^{-1}$. EC further increased (0.747$dsm^{-1}$) at the end of residual crop. This might be due to the faster release of bases and soluble organic fractions to the soil by mineralization. Vermicompost are fully humified and contained large concentration of bases which may lead to enhanced EC compared to other manure. This is in agreement with the findings of Thompson et al. (1989).

The organic carbon content in soil showed a decreasing trend due to application of organic manures. At the end of first experiment $C_1$ (0.583%) and $C_2$ (0.570%) recorded the highest organic carbon content. But at the end of second year $C_1$ and $F_1$ recorded the same organic carbon content (0.41%). After the residual crop, the organic carbon content further decreased. By adding organic manure in soil microbial population will be increased which will result in the increased production of $Co_2$, and reduced the carbon content in soil.

The available nitrogen content was found to be significantly influenced by the application of various organic manures. After the harvest of first crop $N_3$ recorded highest available nitrogen (152.04 kg $ha^{-1}$). After second crop there was an increasing trend and $N_3$ recorded highest available nitrogen (187.85 kg $ha^{-1}$). After the residual crop also $N_3$ recorded the highest available nitrogen. The pooled mean of $N_3$ also showed the same trend with available nitrogen (162.85 kg $ha^{-1}$) (Table 47). Among the various manures neem cake registered higher available nitrogen values. This might be due to the higher nitrogen content in neem cake coupled with its gradual release there by conserving more nitrogen, resulting in the minimization of losses of nitrogen through leaching, denitrification and run off. There was also an increase in available nitrogen in $N_3$ treatment in incubation study where the mineralization pattern showed an increasing trend (Table 1). Available N content was substantially higher after second crop when compared to the previous one, which can be attributed to the cumulative build up of soil nitrogen due to recurrent application of organic manures.

Application of various organic manures significantly improved the available phosphorus content in soil (Table 48). After the first year of experiment , the P content increased from initial status and $V_3$ recorded the highest available $P_2O_5$ (68.91 kg $ha^{-1}$). At the end of second year $N_3$ and $V_3$ were on par recording $N_3$ (80.63 kg $ha^{-1}$) and $V_3$ (80.62 kg $ha^{-1}$) of available $P_2O_5$. After the end of residual crop the available $P_2O_5$ was maximum for $V_3$ (83.70 kg $ha^{-1}$). The pooled mean of $V_3$ also showed the maximum available $P_2O_5$ of 70.53 kg $ha^{-1}$. The presence of P solubilizing organisms in vermicompost might have increased the available $P_2O_5$ status of the soil. This is in conformity with the finding of Gaur (1990).

The available potassium content increased from initial stage to the end of first and second crop and $V_3$ was significantly found superior. At the end of residual crop $V_3$ (280.75 kg $ha^{-1}$) and $C_3$ (280.53 kg $ha^{-1}$) were on par in available $K_2O$ content. The pooled mean of $V_3$ was also significantly superior and recorded maximum available potassium of 256.45 kg $ha^{-1}$. Increased availability of potassium due to the application of vermicomposts may be due to the increased concentration of available and exchangeable potassium content in worm casts compared to surrounding soils. Baskar et al., (1994) inferred that earthworm increases the availability of potassium by shifting the equilibrium among the forms of K from relatively unavailable forms to more available forms.

The results of the plant analysis after the end of first experiment showed that the uptake of N was significantly superior in $V_3$ (91.65 kg $ha^{-1}$) and at the end of second year the uptake of N increased to 94.70 kg $ha^{-1}$. The increase in N uptake may be due to the fact that vast portion of non oxidisable N present in organic matter can be made available to plants through vermicomposting and microbial activity. The higher rate of metabolic activity with rapid cell division brought about by vermicompost applications resulted in high uptake of nutrients and this might have resulted in increased utilization of N and this was in accordance with the findings of Zacharia (1995).

The uptake of P was significant due to application of organic manures. At the end of first crop, $V_3$ and $N_3$ were on par in the uptake of P. But at the end of second crop, $V_3$ was found superior. The pooled analysis also showed that $V_3$ was superior with a maximum uptake of P (16.87 kg $ha^{-1}$). The increased P availability by the increase in solubility of phosphorus by higher phosphatase activity in vermicompost application was noticed by Syres and Springett (1984). The increased mineralization of soil P as a result of production of organic matter may also be one of the reasons for increased P uptake by the plants. This was supported by Shuxin et al., (1991).

At the end of first harvest , the uptake of K, was significant where $C_3$ (103 kg $ha^{-1}$) was on par with $N_3$ (103.13 kg $ha^{-1}$). At the end of second year of experiment, the uptake of K was superior in treatment $V_3$ (115.37 kg $ha^{-1}$). The pooled mean was maximum where $V_3$, $C_3$ and $N_3$ which were on par. The increased concentration of potassium in the vermicompost treated soil under field condition could have resulted from the transport of potassium from the potassium rich horizon of subsoil by earthworm activity or may be due to a change in one or more of the factors affecting fixation and release of potassium in the soil (Baskar et al., 1994). This reflects the earlier works of Zacharia (1995) and Nihad (2005) in *Plumbago rosea*.

Nutrient Balance sheet for available N showed a net negative balance in both the years. However lower net losses were observed in the second year except for $C_1$ (Table 53 and 54). The results support the findings of Sadanandan and Mahapatra (1973). The net loss or gain of N was arrived in the soil from the actual N balance or available N content of the soil. The lower value of initial N status of first year as compared to the second year resulted in higher expected nutrient balance at the first year compared to the second year. The net loss of N may be due to high mobility of N as well as rapid loss of N due to leaching and volatilization. However, at the commencement of second year the available N content was slightly higher than that of initial status in the first year. This might be due to the residual effect of organic manures. This factor coupled with comparatively greater addition of nutrients through various organic treatments, slightly higher crop removal on account of higher yield and low nutrient loss during the second year might have resulted in comparatively lower net losses of available N in the organic treatments of second year. Net gains of N in crop sequences involving legumes/green manures ground nut jute rice (Sadanandan and Mahapatra, 1973), Soyabean - wheat (Raghuywanshi et al., 1991) and daincha - wheat (Binod Kumar et al., 2000) were reported earlier.

Among the organic manure treatments apparently lower net loss of N in the experiment was observed in the treatment $N_1$ (1.26 kg $ha^{-1}$) and $C_2$ (4.19 kg $ha^{-1}$) whereas $C_1$ gave a gain of 41.15 kg $ha^{-1}$ during second year.

The balance sheet for available phosphorus reveal a deficit at both the years except for $N_1$ and $N_2$ in the second year (Table 55 and 56). Deficit balance sheet for available P for various treatments have been reported by Suja (2001). Apart from this, temporary conversion of mineralized inorganic form to organically bound ligands might have reduced the available P status to the present crop though the same is available in the long run (Russell, 1973). Hence the actual P balance could never come upto the expected P balance which is computed theoretically on the assumption that 100 per cent mineralization of organic P takes place. Considerable decrements in net losses was observed in the second year since there was slight increase in the content of available P at the end of the second year when compared to the initial stagesof the experiment. A minimum loss was recorded in $N_1$ (7.78 kg $ha^{-1}$) during first year. But in second year there was gain in treatments $N_1$ (10.80 kg $ha^{-1}$) and $N_2$ (1.02 kg $ha^{-1}$), whereas a minimum loss of 7.30 kg $ha^{-1}$ was seen in $N_3$.

The balance sheet of potassium for both the years of study (Table 57 & 58) revealed a deficit at both years, except for neemcake treated plots during second year. The actucal K balance could never reach upto the expected K balance which is computed theoretically on the assumption that 100 per cent mineralization of organic K takes place. Considerable loss was observed in the second year since there was slight increase in available K content at the end of second year compared to the start of the experiment. A minimum loss of K was seen in treatment $N_3$ (47.49 kg $ha^{-1}$) during first year. During second year there was a gain of available K in $N_1$ (116.11 kg $ha^{-1}$), $N_2$ (94 kg $ha^{-1}$) and $N_3$ (72.16 kg $ha^{-1}$). The minimum loss was seen in $F_1$ (32.04 kg $ha^{-1}$).

Economic analysis is important to ascertain whether a system is sustainable or not. Benefit : Cost relationship using different levels of various organic manures such as FYM, coirpith compost, vermicompost and neemcake were analysed inorder to identify the prospects of cultivation of kasthuri turmeric using organic manures and thereby enable the farmers to undertake this enterprise on a commercial basis. The B:C ratio was highest in $V_3$ treatment with 4.7 and 5.7 during first and second year, respectively. $N_3$ recorded a B: C ratio of 4.4 and 4.9 during first and second year of experiment, respectively. Thus the benefit cost analysis indicates that the crop can be cultivated as a profitable enterprise using vermicompost 25.0 t $ha^{-1}$ or neemcake 6.0 t $ha^{-1}$. Vermicompost is environmentally safe, technologically sound and economically viable. Though the cost of neemcake is high the agronomic value and the insecticidal property along with a gain in nutrient balance sheet are highly advantageous.

The residual study clearly indicate that various organic manures applied to kasthuri turmeric significantly increased the yield of succeeding amaranthus crop. In contrast to chemical fertilizers the availability of nutrients present in organic manures is quite slow, to the immediate crop leaving a certain portion to the residual crop which might have contributed to a higher yield of succeeding amaranthus crop. Gaur (1982) reported that less than 30 per cent of nitrogen and small fraction of phosphorus and potash in organic manure may become available to immediate crop and rest to subsequent crops. Hence the high residual effect of organic manures might have resulted in increasing the green yield of succeeding amaranthus crop as against chemical fertilizers, which release all its nutrients to the immediate crop leaving no residual effect on the succeeding crop.

Among various organic manures tried the highest yield of amaranthus (11.39 t $ha^{-1}$) was obtained from plots treated with neem cake ($N_3$) which was on par with $V_3$ (10.41 t $ha^{-1}$) and were significantly superior to all other treatments. Neem cake is a concentrated organic manure rich in nutrients especially nitrogen. In addition to nutrients it contains certain alkaloids, which inhibit the nitrification process in soil (Reddy and Prasad, 1975). As a result neem cake acts like a slow releasing nitrogenous fertilizer and nutrients are available very slowly and are protected from various losses. The nitrogen release pattern of neem cake ($N_3$) as given in Table 1 also revealed the slow nitrogen release characterization of neem cake. Higher nutrient content in vermicompost ($V_3$) coupled with gradual release of nutrients and reduced nutrient losses might have resulted in yield of succeeding amaranthus crop. Higher residual effect of vermicompost on Davana crop was reported by Chalapathi et al. (2003). According to Asha Raj (2006), the highest green yield of 15.07 t $ha^{-1}$ was recorded in neem cake applied plots and was followed by enriched vermicompost (14.30 t $ha^{-1}$). FYM and coir compost treated plants recorded comparatively lower yield .This might be due to the low nutrient content in these manures and their very slow release due to their wider C:N ratio (Gaur ,1982).

The last experiment was to evaluate the effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* salisb), which was taken up as a pot culture study. The efficiency of microbial biocontrol agents proved to be an effective alternative to obviate the deficiencies realized through the exclusive reliance on chemicals. Microbial biocontrol agents are harmless to human beings and animals, cheaper than pesticides, highly effective throughout the crop growth period with high rhizosphere competence, improve plant growth, increase yield, bestowed with high cost benefit ratio, environmentally safe, performs in a sustainable way and contributes for sustainable crop production. There is no risk of the pathogen developing resistance and residues in food and ground water. They are compatible with biofertilizers. (Sivaprasad et al., 2005).

*Pseudomonas* are plant growth promoting rhizobacteria (PGPR). They have been used as biological control agents for the suppression of soil borne diseases competing with pathogens for resources such as nutrients, produces antibiotics or host defence mechanisms. These organisms often bring about the growth effects synergistically. They produce antibiotics like bacterocins, 2,4 diacetyl phloroglucinol, phenazine, pyrrolnutrin and pyoleutcerin etc. which help in suppression of growth of pathogen (Sivaprasad and Meena Kumari, 2005). The mode of action of pseudomonads involve both direct and indirect mechanisms. The direct mechanisms are growth stimulation, by their metabolites that serve as growth hormones and by improving nutrient availability. The indirect methods are through competition by increasing the activities of pathogens through action of antibiotics, siderophores and Hydrogen cyanide (Elad and Chet 1987, Kloepper and Schroth 1978, Thomasshow and Weller 1988, Weller 1988). *Pseudomonads* secretes siderophore like pyoverdine, Pyochelin and pseudobactins. Solubilization of iron may involve in the reduction of $Fe^{3+}$ to $Fe^{2+}$ as well as chelation of $Fe^{3+}$ by siderophores (Dori et al., 1990). Phosphorus is commonly deficient in most natural soils, since it is fixed as insoluble iron and aluminium phosphates. However, insoluble forms of phosphates can be made available to plants by soil and rhizosphere microorganisms, by release of organic acids. (Cunningham and Kuiack, 1992;Goldstein, 1995). Similarly iron and manganese are made into solubilised form to plants. Some antagonistic root-colonizing pseudomonads react to limiting iron conditions by using a high-affinity iron uptake system based on the release of $Fe^{3+}$ chelating siderophores. This chelated iron is not available to plant pathogens, whose activity is thereby reduced (Baker et al., 1988), while plant roots can take up chelated iron. The positive effects of PGPR are mainly due to morphological and physiological changes of the roots of inoculated plants, which lead to an enhancement of water and mineral uptake. These effects are linked with the secretion of plant growth hormones such as auxins, gibberellins and cytokinins by the bacterium. Plant growth is also due to biological nitrogen fixation, production of phytohormones and physiological changes of the roots of the inoculated plants, which lead to increase in length of roots, elongation of lateral roots, thus increasing the root surface area. These effects are linked to the secretion of plant growth hormones. Growth parameters such as height, number of nodes in black pepper was observed when *Pseudomonas* was applied. *Pseudomonas* spp. treated plants showed a maximum increase in biomass (Diby et al., 2001).

*Trichoderma* increases plant growth either in the presence or absence of other micro organisms and they induce disease suppression in soil by different mechanisms. The mode of action of *Trichoderma* are competition, hyphal coiling antibiosis, hyper parasitism, induced resistance and plant growth promotion. In case of competition most of the soil borne pathogensare controlled by the competition for space or court of infection on roots and seeds. Competition for carbon and nitrogen by *T. harzianum* suppressed the infection of *Fusarium* (Sivan and Chet,1989). *Trichoderma* *viride* produces antibiotics like trichodermin, dermadin and trichoviridin which suppressed the growth of pathogens. The cells exposed to antibiotics of *Trichoderma* spp. lead to ultrastrutural changes like retraction of plasmalemma breakdown of organelles, cytoplasmic disintegration and loss of turgor and finally the death of host cells. Mutants of *T. viride* namely M3 and M5 produced maximum volatile substances under invitro condition and reduced the growth of *Macrophomina phaseolina* (Dinakaran, 1997). Cell wall degrading enzymes like ß-1, 3 glucanases, chitinases, proteinase and lipases are produced during interaction of both pathogen and leads to lysis. *T. harzianum* produced mixture of lytic enzymes comprising of chitinolytic and gluconolytic enzymes which involved in mycoparasitism (Sivan and Chet 1989). *T. hamatum* grow towards host hyphae and after contact, formed coils and appressoria like structure from which penetration occurs and kills the pathogen (Chet et al., 1981). *Trichoderma* offers induced resistance that triggers the expression of a set of genes which encode for pathogenesis related proteins such as chitinases, thymidine etc. with antifungal activity and induce systemic protection against fungal pathogen was reported in rice against *Rhizoctonia solani* (Nandakumar, 1998).

Mycorrhizal fungi (AMF) perform many extremely valuable functions from their host plants like seeking out nutrients particularly P from far greater soil area than the plant can access by itself. Fungus may make up 5-20 per cent root weight. This will increase surface area of root mass. AMF increases uptake of P due to increased root volume and surface area thus decreasing the diffusion path for P movement, penetration of small hyphae into sites too small for plant root to reach and also fungal phosphates. AMF increases the uptake of N, P, K, Cu and Zn. It survives in drought condition and protects against heavy metals. It increases the overall absorption capacity of roots and mobilize the transfer of nutrients P, N, S and micro nutrients. AMF application improves nutrition of mycorrhizal plants.Anatomical and morphological changes in root system such as increased lignification, root branching, meristematic and nuclear activities of root cells and the microbial changes in the mycorrhizosphere, due to AMF colonization affect the infection and development of pathogens. (Sivaprasad and Meena Kumari, 2005). Accumulation of amino acids arginine and citrulline, higher activity of chitinase, glucanase, phytoalexins, glycoproteins phenolics are some of the factors involved in plant defence in relation to AMF formulation (Joseph and Sivaprasad, 2000).

*Azospirillum* application help to fix nitrogen in soil and also produce growth promoting substances like GA and cytokinins and antifungal substances (Subramanian et al., 2003). Among the free living nitrogen fixers *Azospirillum* spp is considered to be more efficient with nitrogenase properties. *Azospirillum* inoculated plants are able to absorb nutrients from soil solutions at faster rate than uninoculated plants (Okon, 1985). *Azospirillum* promote yield of agriculturally important crop (Okon and Labandera, 1994)

Application of these microbial inoculants significantly influenced the growth characters of kasthuri turmeric. $T_{15}$ (combined application of *Azospirillum*, AMf, *Pseudomonas* and *Trichoderma*) recorded highest plant height, tiller number, number of leaves, leaf area, rhizome spread, root length, root spread, root weight and number of fingers. All these beneficial factors of *Pseudomonas*, *Trichoderma*, AMF and *Azospirillum* together enhanced the growth of plants which in turn resulted in increased growth characters like plant height, number of leaves, leaf area, rhizome spread, root length, root spread, root weight and number of fingers. The results obtained in this study is in agreement with the reports of Sreekala (2004) in ginger and Nihad (2005) in *Plumbago rosea* and Raja (2006) in Rice.

The treatment $T_{15}$ was significantly superior in increasing rhizome yield, top yield and crop duration. The higher vegetative growth as indicated by higher number of tillers, leaves and leaf area under $T_{15}$ resulted in higher rhizome yield, top yield also. Crop duration was minimum in $T_{15}$

and produced more number of tillers and leaves. The phytohormones secreted by these bioinoculants might have enhanced crop maturation soon. This is in accordance with the findings of Sreekala (2004) in ginger and Asad Rokhzadi et al. (2008) in chick pea.

The combined inoculation of microbial inoculants was found significant in physiological characters. $T_{15}$ increased DMP, CGR, LAD, rhizome shoot ratio and harvest index. RGR was found non significant. However, LAI and NAR recorded highest value by combined application of *Azospirillum*, AMF and *Pseudomonas* ($T_{11}$). The higher DMP due to microbial inoculants increase the higher leaf number, root mass as well as rhizome production at these stages. The increase in CGR might be due to the more uptake of nutrients due to microbial inoculants for crop nutrition which resulted in more LAI and DMP. However a decrease in NAR towards final phase was noted. This trend is in accordance with the postulation of Watson (1958) that with advancing age , and the rate of respiration per unit leaf area tends to increase and hence NAR decreases. The combined application of microbial inoculants produced higher LAI as well as longer retention of leaves over a longer period and increased LAD. The translocation of assimilate to the rhizomes was higher in $T_{15}$ than other treatments and there by increased the harvest index and rhizome shoot ratio. Similar findings were also made by Sreekala (2004) in ginger and Nihad (2005) in *Plumbago rosea*.

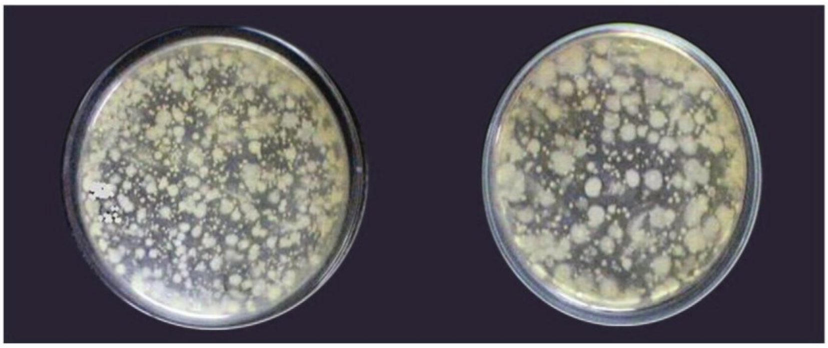
Combined application of *Azospirillum*, AMF, *Pseudomonas* and *Trichoderma* ($T_{15}$) recorded the highest leaf cuticle thickness, number of vascular bundles in rhizome and root and stomatal frequency. The application of bioinoculants produced healthy plants with healthy disease free leaves This might have increased the anatomical characters.

The combined effect of *Azospirillum*, AMF, *Pseudomonas* and *Trichoderma* ($T_{15}$) recorded maximum curcumin content, NVEE, total carbohydrates and protein content. But in volatile oil $T_{15}$ and $T_{14}$ were on par and recorded higher volatile content. At 120 and 240 DAP $T_{14}$ (*Pseudomonas, Azospirillum* and *Trichoderma*) recorded least crude fibre and maximum starch content. Combined application of microbial inoculants, enhanced the production of volatile oil, NVEE, curcumin content, total carbohydrates, protein and crude fibre content due to production of plant growth hormones antibiotics and enzymes from microbial inoculants. In curcumin content similar results was reported by Nihad (2005) in *Plumbago rosea*. Volatile oil and NVEE was in accordance with the findings of Sreekala (2004) in ginger. In crude fibre content the results of Meena Mary Mathew and Shahul Hameed (1989) was in agreement with the above findings. Starch, total carbohydrates and protein content was in accordance with the findings of Asad Rokhzadi et al. (2008) in Chick pea.

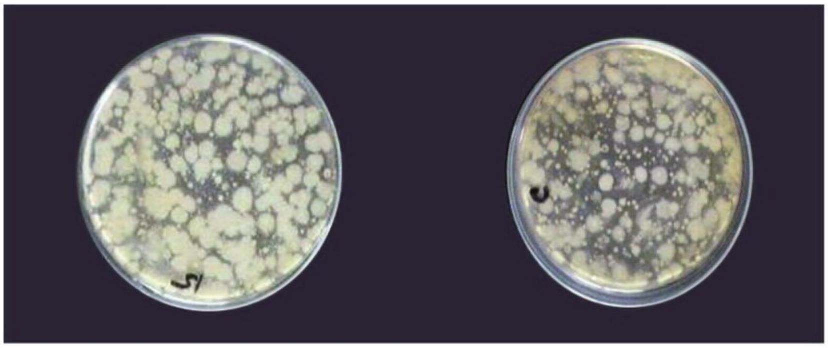
$T_{15}$ recorded the highest chlorophyll content at 120 and 180 DAP. The application of microbial inoculants produced healthy plants with healthy green leaves which might have increased the chlorophyll content in plants. This is supported by Nihad (2005) in *Plumbago rosea*

The microbial load increased from the initial level (uninoculated). After microbial inoculation, the bacterial, fungal and actinomycetes load in soil increased. $T_{14}$ and $T_{15}$ were on par and significantly superior and recorded high bacterial load (Plate 11). $T_{15}$ (combined application *Azospirillum*, AMF, *Pseudomonas* and *Trichoderma*) was significantly superior in increasing fungal and actinomycetes load in soil. The application of microbial inoculants might have increased the microbial load.

Among the various organic manures tried, the overall performace of kasthuri turmeric (*Curcuma aromatica* Salisb.) was found better when vermicompost 25.0 t ha$^{-1}$ or neemcake 6.0t ha-$^{1}$ were applied as basal dose. Hence further studies on the higher levels of these organic manures and



*Pseudomonas* + *Trichoderma* + *Azospirillum*



*Pseudomonas* + *Trichoderma* + *Azospirillum* + AMF

Plate 11. Effect of microbial inoculants on bacterial load

their split application are necessary for standardizing an optimum dose of organic manure for getting good quality produce with maximum returns. The results of the pot culture studies on the effect of various microbial inoculants should be tried in the field along with organic manures so that an organic Package of Practices Recommendations could be developed. Further studies on other organic cultural practices and plant protection measures are essential. Moreover, value addition should be taken up in kasthuri turmeric. However, popularization of the crop and development of appropriate marketing strategy are necessary to make the crop more remunerative.

# SUMMARY

# 6. SUMMARY

An experiment entitled "Standardization of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram, during 2006-2007 and 2007-2008. The main objective of the study was to standardize an optimum dose of organic manure and to evaluate the effect of microbial inoculants on growth, yield and quality of kasthuri turmeric of high cosmetic value, which is a medicinal and aromatic plant with multiple uses.

The investigation was taken up as four experiments. A laboratory incubation study was conducted as the first experiment to asses the relative efficiencies of various organic manures, like FYM, vermicompost, neemcake and and coirpith compost in their nutrient release pattern.

The second experiment was to study the effect of organic manures on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.). The experiment was laid out in RBD with 3 replications and 13 treatments. Three levels of 4 organic manures *viz.* FYM, vermicompost, coirpith compost and neemcake were tried. The treatments were FYM (20.0 t $ha^{-1}$, 30.0 t $ha^{-1}$ and 40.0 t $ha^{-1}$), vermicompost (15.0 t $ha^{-1}$, 20.0 t $ha^{-1}$ and 25.0 t $ha^{-1}$), coirpith compost (20.5 t $ha^{-1}$, 30.0 t $ha^{-1}$ and 40.0 t $ha^{-1}$) and neemcake (3.0 t $ha^{-1}$, 4.5 t $ha^{-1}$ and 6.0 t $ha^{-1}$) with one absolute control. The experiment was repeated during second year also.

The third experiment was to study the residual effect of different organic manures on succeeding vegetable crop (Amaranthus).

The fourth experiment was to evaluate the effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatic* Salisb.). This was carried out as a pot culture study in CRD with 16 treatments and 3 replications. The microbial inoculants tried were *Azospirillum brasilense*, Arbuscular Mycorrhizal fungi (AMF), *Pseudomonas flourescens* and *Trichoderma harzianum* and their combinations.

Various parameters like growth characters, yield and yield components, physiological characters, anatomical characters and biochemical characters as influenced by the application of organic manures and microbial inoculants were studied. Biological properties of the potting mixture before and after the application of microbial inoculants were attempted

Soil analysis before and after the experiment were done to study its physical and chemical properties when organic manures were applied. Plant analysis were also undertaken and the uptake of N,P and K were studied. Nutrient balance sheet was prepared.

Incidence of pests and diseases were noted during the crop period and B:C ratio was worked out.

The salient findings of the above studies are summarized in this chapter.

1. The soil incubation study revealed the mineralization pattern of N, P K and organic carbon content upto 60 days. The treatment $N_3$ (neemcake 6.0 t $ha^{-1}$) recorded the maximum available nitrogen content and was significantly superior throughout the incubation period. In control there was declining trend from 45 days of incubation. The $P_2O_5$ content showed an increasing trend throughout the incubation period. The treatment $V_3$ (vermicompost 25t $ha^{-1}$) was significantly superior

and recorded maximum $P_2O_5$ throughout the incubation period. In control, the $P_2O_5$ decreased from 45 days after incubation. The available K also showed an increasing trend and $V_3$ and $N_3$ were significantly superior followed by $C_3$. Generally the organic carbon content of incubated soil increased upto 15 days of incubation and then showed a declining trend in all treatments.

2. In the second experiment which was laid out in the field, when different levels of various organic manures were applied, the plant growth characters were found to be influenced during both the years of experimentation. $V_3$ and $N_3$ treatments were significantly and produced plants with increased height, more number of tillers, maximum number of leaves, leaf area, rhizome spread, rhizome thickness, root length, root spread, root weight and number of fingers during both years of study.

3. Yield was found to be influenced by the application of organic manures. At 240 DAP, $V_3$ was significantly superior and recorded a maximum fresh rhizome yield of 364.95 and 396.33 g plant$^{-1}$ during first and second year of experiment, respectively. The dry rhizome yield of $V_3$ treated plants were the highest which was significantly superior to all other treatments during both the years. But at 240 DAP,$V_3$ and $N_3$ were on par ($V_3$ recorded 69.66 and 72.60 g plant$^{-1}$ during first and second year, respectively and $N_3$ recorded 70.43 and 71.06 g plant$^{-1}$ during first and second year, respectively). The control recorded least fresh and dry rhizome yield.

4. Top yield also was highly influenced by organic manure application. At 120 DAP and 180 DAP, $V_3$ and $N_3$ were significantly superior than other treatments and recorded highest top yield during both years of study.

5. $V_3$ treated plants took minimum days to mature (221.43 days) and was found to be superior during first year. During second year of study, $V_3$ and $N_3$ were on par and significantly superior (222.58 and 223.13, respectively). The control took more days to complete its vegetative and maturity phase (234.13 days.)

6. Physiological characters when analysed, treatments $V_3$ and $N_3$ were found to be significantly superior and recorded highest DMP throughout the crop growth. At 240 DAP, $V_3$ was on par with $N_3$ but significantly superior than all other treatments during both years where $V_3$ recorded a DMP of 97.49 and 99.48 g plant$^{-1}$ during first and second crop, respectively and $N_3$ recorded 95.45 and 97.44 g plant$^{-1}$ during first and second year of study, respectively.

7. Organic manures had significant effect on LAI at all stages of growth. At 60, 180 and at 240 DAP, $V_3$ was significantly superior and produced maximum LAI during both years. But at 120 DAP,$V_3$ and $N_3$ were found to be on par and significantly superior in the first and second year of experimentation.

8. CGR was found to be significantly influenced by the application of various organic manures. Between 60-120 DAP, $V_3$ and $N_3$ were significantly superior during first year and recorded highest CGR (3.619 and 3.484 gm$^{-2}$ day$^{-1}$, respectively). In the first year between 120-180 DAP, $C_3$ and $V_3$ were on par and superior to other treatments and recorded the highest CGR. Between 180-240 DAP, in the first year and between 120-180 DAP in the second year $V_3$ was significantly superior (4.013 and 6.619 gm$^{-2}$ day$^{-1}$, respectively)

9. RGR was significant and $V_3$ and $N_3$ recorded same value of 0.011 g day$^{-1.}$ which were on par during first year. During second year also, at the same stage $V_3$ and $N_3$ recorded same RGR value of 0.010 g day$^{-1}$. But between

180 and 240 DAP, $N_3$ was significantly superior and recorded a value of 0.010 and 0.009 g day$^{-1}$ during first and second year, respectively.

10. NAR was found to be significant at all growth stages due to the application of various organic manures. $V_3$ and $N_3$ were significantly superior and recorded the highest NAR values during both the years, throughout the growth stages.

11. Organic manures had positive influence on LAD at various stages. Between 60-120 DAP during both the years $V_3$ and $N_3$ were significantly superior recording highest LAD. Between 120-180 and 180-240 DAP, compared to other treatments, $V_3$ was significantly superior and at final phase between 180-240 DAP also $V_3$ was superior and recorded a maximum LAD of 368.70 and 376.70 during first and second crop, respectively.

12. The rhizome : shoot ratio was significantly superior in $C_3$ and recorded a value of 1.86 during first year at 120 DAP. But during second year, $V_3$ was significantly superior with a value of 1.73. At 180 DAP, $N_3$ was significantly superior recorded maximum rhizome : shoot ratio of 3.17 and 3.18 in the first and second crop, respectively.

13. Harvest index was maximum in $V_3$ treatment which was significantly superior to all other treatments and recorded a value of 0.83 and 0.85, during first and second year, respectively.

14. The anatomical characters like leaf cuticle thickness, number of vascular bundles, stomatal frequency were found to vary significantly by the application of organic manures. Among the various treatments tried, $V_3$ and $N_3$ were found to be significantly superior (Table 27-31).

15. The leaf chlorophyll content (a, b and total chlorophyll) were highest in $V_3$ which was significantly superior compared to other treatments. This was succeeded by $N_3$

16. The organic manure application showed a positive influence on the biochemical characters of kasthuri turmeric. At 240 DAP, $V_3$ was found significantly superior and recorded a maximum curcumin content of 0.083 and 0.092 per cent during first and second year, respectively (Table 32). $V_3$ treated plant also gave significantly superior values of volatile oil content (6.58 and 6.73 %) during first and second crop, respectively. $V_3$ and $N_3$ were significantly superior and recorded highest NVEE content (Table 34).

17. The soil characters were found to be significantly influenced by application of organic manures. In general, the bulk density showed a decreasing trend even after residual crop. After the residual crop $V_3$ recorded a bulk density of 1.37 $gcc^{-1}$and $N_3$ obtained a bulk density of 1.38 $gcc^{-1}$ which were significantly superior par $V_3$ was found significantly superior recording maximum water holding capacity, after each crop. The water holding capacity was 29.76 per cent after first crop and 32.65 per cent after the second crop and showed an increasing trend after the residual crop.

18. The soil pH and soil organic carbon content showed an decreasing trend, after each stage of experiment. Electrical conductivity was highest in $V_3$ treated plants which was superior to all other treatments and followed by $N_3$. NPK status of the soil was much influenced by organic manures. $N_3$ was superior and recorded the highest available nitrogen whereas $V_3$ was superior with highest available $P_2O_5$ after each crop. The available $K_2O$ status was significantly superior in $V_3$ treatment.

19. The effect of various organic manures on the uptake of nitrogen, phosphorus and potassium was significant in both the years of experimentation. Plants given $V_3$ treatment was significantly superior and recorded maximum uptake of nitrogen (91.65 and 94.70 kg $ha^{-1}$ during first and second year of study, respectively). $V_3$ and $N_3$ were superior and recorded a higher uptake of phosphorus during both the years. But $C_3$ was significantly superior in the uptake of potassium which was on par with $N_3$ in first year, whereas in the second year $V_3$ was superior to all other treatments with a value of 115.3 kg $ha^{-1}$.

20. There was a net loss of N during first and second year. A minimum loss was observed by the treatment $N_1$ (1.26 kg $ha^{-1}$) during second year. There was also a loss of P during first and second year. But during second year, there was a gain of P in neemcake treated plots. A similar trend was observed in K nutrient balance.

21. The B:C ratio was maximum in $V_3$ (4.7 and 5.7 during first and second year of experiment, respectively) and was followed by $N_3$ (4.4 and 4.9 during first and second crop, respectively). The control recorded least B:C ratio of 2.6 and 1.2 during first and second year of experiment, respectively.

22. No serious pests and diseases were noted during the crop growth. But in certain pockets a mild attack by top shoot borer (*Conogethes punctiferalis*) was noted during the early stages of growth in both years of study. For controlling this pest, the affected shoots were removed and a fortnightly spray of nimbecidine 2 per cent was given. Apart from this, mild incidence of rhizome rot caused by *Pythium* sp. was also noticed in the field. Drenching the beds with two per cent *Pseudomonas flourescens* was done to prevent the spread of this disease. During second crop as a precautionary measure, 2 g *Trichoderma viride* per pit was applied along with rhizome bits while planting.

23. The residual effect of different organic manures on succeeding vegetable crop (amaranthus) was found significant. Treatments $N_3$ and $V_3$ were significantly superior and recorded a biomass yield of 11.39 t ha$^{-1}$ and 10.41 t ha$^{-1}$).

24. The microbial study showed that application of microbial inoculants highly influenced the growth characters of kasthuri turmeric. Combined application of bioinoculants like *Azospirillum*, AMF, *Pseudomonas* and *Trichoderma* ($T_{15}$) was found significantly superior and produced tallest plants, more number of leaves and tillers, maximum leaf area, rhizome spread, rhizome thickness, root spread, root length, root weight and number of fingers.

25. The combined application of microbial inoculants ($T_{15}$) increased fresh rhizome yield which was significantly superior and recorded an yield of 316.62 g plant$^{-1}$. This was followed by $T_{13}$ where the yield was 298.41g plant$^{-1}$. $T_{15}$ also recorded the highest dry rhizome yield of 98.97g plant$^{-1}$ at 240 DAP.

26. $T_{15}$ recorded highest top yield of 30.01g plant$^{-1}$ and 29.07g plant$^{-1}$ at 120 and 180 DAP, respectively. This was followed by $T_{14}$ (*Pseudomonas* + *Azospirillum* + *Trichoderma*) with a top yield of 29.95 g plant$^{-1}$ and 27.26 g plant$^{-1}$ at 120 and 180 DAP, respectively.

27. In treatment $T_{15,}$ the crop took minimum number of days (219.01 days) to mature, followed by $T_{14}$ (221.03 days).

28. Bio inoculant application highly influenced dry matter production throughout the growth stages. The DMP recorded by combined application ($T_{15}$) at 240 DAP was 81.46 g plant$^{-1}$.

29. There was significant influence of microbial inoculants on LAI.. At 60 DAP, $T_{11}$ (*Azospirillum* + AMF + *Pseudomonas*) recorded highest LAI and at other stages $T_{15}$ was superior.

30. $T_{15}$ was significantly superior and recorded the highest values of CGR,RGR, NAR and LAD.

31. $T_{15}$ recorded significantly superior rhizome : shoot ratio of 1.66 and 2.42 at 120 and 180 DAP, respectively.

32. $T_{15}$ recorded a harvest index of 0.93 which was significantly superior to all other treatments.

33. The anatomical characters like leaf cuticle thickness, number of vascular bundles and stomatal frequency were significantly influenced by the application of microbial inoculants. $T_{15}$ was found significantly superior and recorded maximum number of vascular bundles in rhizome and root both at 120 and 180 DAP and stomatal frequency on both abaxial and abaxial surface.

34. There was significant difference in chlorophyll content when$T_{15}$ treatment was tried and recorded highest chlorophyll 'a' and 'b'. But the total chlorophyll content was significantly superior $T_{14}$ at 120 DAP (0.721 mg $g^{-1}$) and in $T_{15}$ at 180 DAP (0.768 mg $g^{-1}$).

35. The quality parameters were highly influenced by microbial inoculants. $T_{15}$ was significantly superior and recorded a maximum curcumin content of 0.073 per cent and 0.082 per cent at 120 and 240 DAP, respectively. Treatment $T_{15}$ and $T_{14}$ were on par but significantly superior and recorded a volatile oil content of 4.57 and 4.54 per cent, respectively at 120 DAP. But at 180 DAP,$T_{15}$ was

found to be significantly superior recording a volatile oil content of 4.87 per cent. But $T_{15}$ recorded the least crude fibre content 1.94 and 1.79 per cent at 120 and 240 DAP, respectively. $T_{15}$ was superior and recorded maximum NVEE, starch, total carbohydrates and protein content at 120 and 240 DAP.

36. When microbial inoculants were applied, the microbial load increased. The bacterial load was maximum in the treatments $T_{15}$, $T_{14}$ and $T_{13}$ which were on par but significantly superior whereas the fungal load and actinomycetes load were maximum in $T_{15}$, which were superior to all other treatments.

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# Appendices

## Appendix - I

## Weather parameters during the cropping period (2006-2007)

| Month | Maximum temperature (°C) | Minimum temperature (°C) | Relative humidity (%) | | Rainfall (mm) |
|---|---|---|---|---|---|
| | | | Maximum | Minimum | |
| June | 30.5 | 25.1 | 91.9 | 76.6 | 187.9 |
| July | 29.9 | 24.5 | 91.5 | 76.4 | 158.6 |
| August | 30.1 | 23.6 | 93.2 | 80.2 | 111.7 |
| September | 30.2 | 23.1 | 91.9 | 79.8 | 379.0 |
| October | 30.1 | 22.8 | 95.3 | 81.8 | 594.8 |
| November | 30.5 | 22.9 | 94.9 | 79.4 | 221.2 |
| December | 30.5 | 21.4 | 92.3 | 67.1 | 6.00 |
| January | 31.7 | 21.4 | 95.2 | 60.4 | 0.60 |
| February | 31.8 | 21.6 | 90.6 | 60.1 | 34.6 |

## Appendix - II

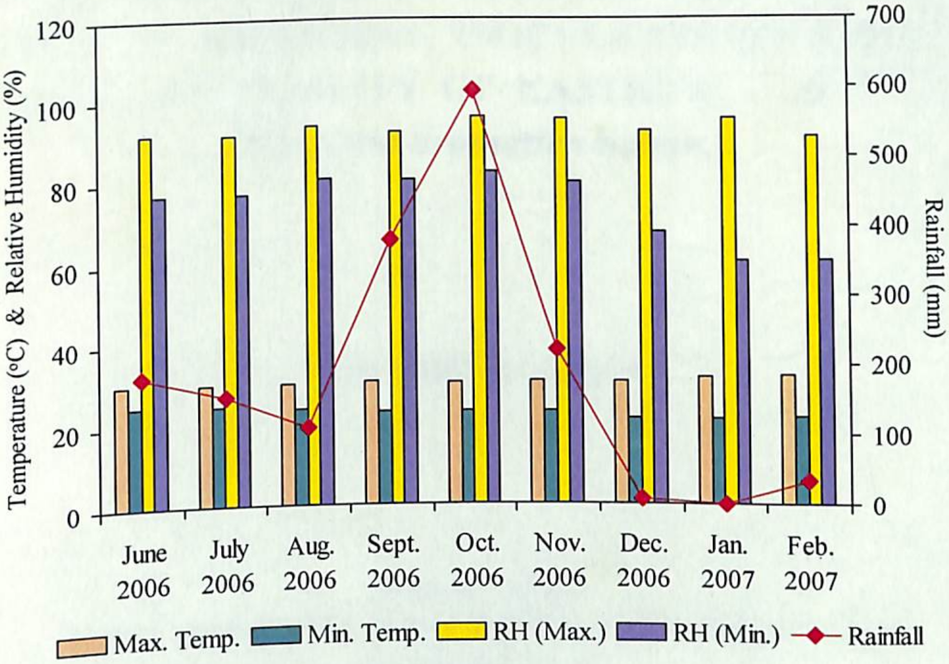
## Weather parameters during the cropping period (2007-2008)

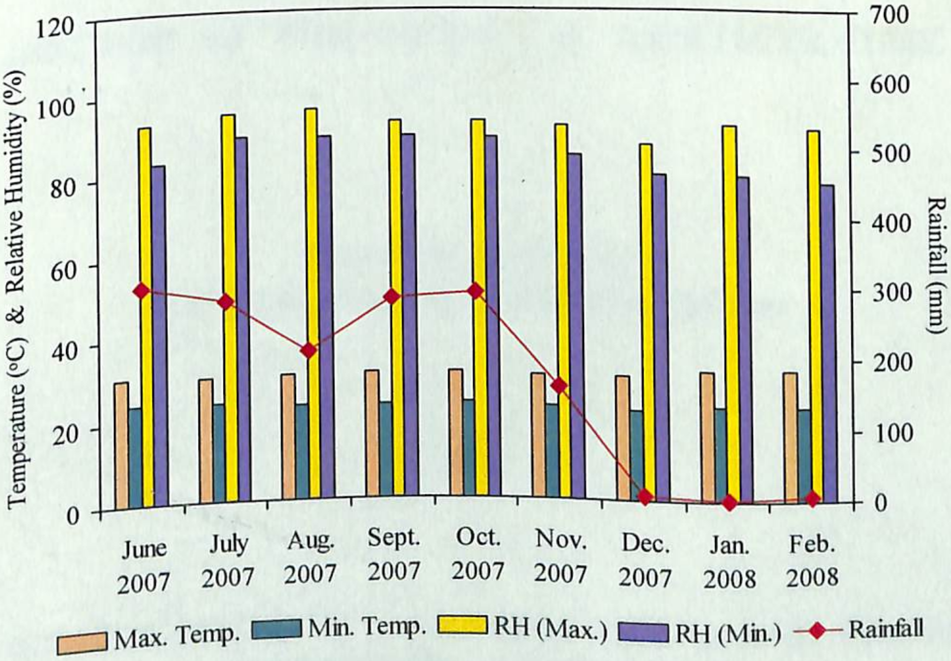
| Month | Maximum temperature (°C) | Minimum temperature (°C) | Relative humidity (%) | | Rainfall (mm) |
|---|---|---|---|---|---|
| | | | Maximum | Minimum | |
| June | 30.7 | 24.1 | 92.4 | 82.7 | 308.0 |
| July | 29.7 | 23.9 | 94.8 | 89.0 | 284.8 |
| August | 30.3 | 23.0 | 95.4 | 88.4 | 210.6 |
| September | 30.8 | 22.8 | 92.3 | 88.5 | 284.9 |
| October | 30.6 | 23.2 | 92.0 | 88.1 | 291.8 |
| November | 29.9 | 22.4 | 91.4 | 83.9 | 157.8 |
| December | 29.7 | 21.9 | 86.9 | 79.5 | 6.20 |
| January | 31.5 | 22.8 | 91.6 | 79.1 | 1.20 |
| February | 32.0 | 22.9 | 91.1 | 77.5 | 7.30 |

## Appendix - III

## Nutrient content (%) of organic manures used for first and second crop

| Organic manures | First crop | | | Second crop | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| FYM | 1.0 | 0.5 | 1.0 | 1.0 | 0.6 | 1.2 |
| Vermicompost | 1.2 | 1.0 | 1.6 | 1.2 | 0.9 | 1.5 |
| Coir pith compost | 1.0 | 0.2 | 1.6 | 1.0 | 0.4 | 1.7 |
| Neem cake | 2.2 | 0.9 | 1.5 | 3.3 | 0.8 | 1.6 |


First year of the study (2006-2007)


Second year of the study (2007-2008)

Weather parameters during the cropping period

# STANDARDISATION OF ORGANIC MANURES AND EFFECT OF MICROBIAL INOCULANTS ON GROWTH, YIELD AND QUALITY OF KASTHURI TURMERIC (*Curcuma aromatica* Salisb.)

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**Abstract of the**
**Thesis submitted in partial fulfillment of the requirement**
**for the degree of**

**DOCTOR OF PHILOSOPHY IN HORTICULTURE**

**Faculty of Agriculture**
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**2009**

**DEPARTMENT OF PLANTATION CROPS AND SPICES**
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# ABSTRACT

The studies on the “Standardization of organic manures and effect of microbial inoculants on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)” were carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2006-2008.

The investigation was taken up as four separate experiments. The first experiment was “Laboratory incubation studies of the organic manures.” The organic manures were FYM, vermicompost, coirpith compost and neemcake. The incubation study revealed that application of neem cake 6.0 t ha$^{-1}$ significantly influenced the available N content and was superior to all other treatments and showed an increasing trend throughout the incubation period whereas, vermicompost 25.0 t ha$^{-1}$ was superior to all other treatments and recorded the highest available $P_2O_5$ content. But the available $K_2O$ was significantly influenced by the application of vermicompost 25.0 t ha$^{-1}$ and neem cake 6.0 t ha$^{-1}$.

The second experiment was “Effect of organic manures on growth, yield and quality of kasthuri turmeric (*Curcuma aromatica* Salisb.)”, which was laid out in RBD with three replications and 13 treatments. Three levels of four organic manures *viz*., FYM (20.0, 30.0 and 40.0 t ha$^{-1}$), vermicompost (15.0, 20.0 and 25.0 t ha$^{-1}$), coirpith compost (20.0, 30.0 and 40.0 t ha$^{-1}$) and neemcake (3.0, 4.5 and 6.0 t ha$^{-1}$) with one absolute control were tried. The experiment was repeated during second year also.

The results showed that vermicompost 25.0 t ha$^{-1}$ and neemcake 6.0 t ha$^{-1}$ were signifiantly superior to all other treatments and recorded the

maximum plant height, number of tillers, number of leaves, leaf area, rhizome spread, rhizome thickness, root spread, root length, root weight and number of fingers.

Vermicompost 25.0 t ha$^{-1}$ was significantly superior and recorded the maximum fresh rhizome yield of kasthuri turmeric throughout the crop growth. At final harvest, this treatment recorded a fresh yield of 364.95 g plant$^{-1}$ and 396.33 g plant$^{-1}$, during first and second crop, respectively. But with respect to the dry rhizome yield, initially vermicompost 25.0 t ha$^{-1}$ was superior and towards the final harvest vermicompost 25.0 t ha$^{-1}$ and neemcake 6.0 t ha$^{-1}$ were on par and significantly superior to all other treatments. It was also observed that vermicompost 25.0 t ha$^{-1}$ and neem cake 6.0 t ha$^{-1}$ were significantly superior to all other treatments and recorded highest top yield, and also took minimum days for attaining maturity (222.58 and 223.13 days, respectively).

Physiological characters like DMP, LAI, CGR and RGR were found to be highly influenced by the application of vermicompost 25.0 t ha$^{-1}$ and neemcake 6.0 t ha$^{-1}$ which were significantly superior to all other treatments. But vermicompost 25.0 t ha$^{-1}$ was superior and recorded maximum values of LAD, HI, and rhizome : shoot ratio.

The anatomical characters also revealed that vermicompost 25.0 t ha$^{-1}$ and neemcake 6.0 t ha$^{-1}$ were significantly superior and recorded maximum leaf cuticle thickness, number of vascular bundles and stomatal frequency.

The biochemical analysis showed that curcumin content, volatile oil, non volatile ether extract (NVEE), crude fibre, starch, total carbohydrates and protein content were significantly influenced by the application of organic manures and vermicompost 25.0 t ha$^{-1}$ was found to be superior to all other treatments. The curcumin content of plants given vermicompost 25.0 t ha$^{-1}$ were 0.083 and 0.092 per cent during first and second crop, respectively and a volatile content of 6.58 and 6.73 per cent during first and second crop, respectively.

It was observed that organic manures improved the soil physical and chemical characters like bulk density, water holding capacity, electrical conductivity and soil pH. It was found that vermicompost 25.0 t $ha^{-1}$ was significantly superior and resulted in best values of these parameters. Neem cake 6.0 t $ha^{-1}$ was significantly superior in recording maximum available N content and also uptake of N. Available P and K content and uptake of P and K was significantly superior when vermicompost 25.0 t $ha^{-1}$ was applied.

The B:C ratio was influenced by the application of vermicompost 25.0 t $ha^{-1}$ which was superior to all other treatments and recorded a B: C ratio of 4.7 and 5.7 during first and second year, respectively followed by neemcake 6.0 t $ha^{-1}$ (4.4 and 4.9 during first and second crop, respectively)

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The third experiment was “Residual effect of different organic manures on succeeding vegetable crop (amaranthus)”. The results showed that as in the main crop, vermicompost 25.0 t $ha^{-1}$ and neemcake 6.0 t $ha^{-1}$ and were on par and significantly superior to all other treatments and recorded the maximum biomass yield of amaranthus (10.41 and 11.39 t $ha^{-1}$, respectively).

The fourth experiment was “Effect of microbial inoculants on growth, yield and quality of kasthuri turmeric *Curcuma aromatica* Salisb,” in CRD with 16 treatments and three replications.The microbial inoculants used were *Azospirillum brasilense*, Arbuscular Mycorrhizal Fungi, *Pseudomonas flourescens*, *Trichoderma harzianum* and their combinations.

The results revealed that combined application of bioinoculants like *Azospirillum*, AMF, *Pseudomonas* and *Trichoderma* was significantly superior to all other treatments and produced tallest plants with more number of leaves and tillers, maximum leaf area, rhizome spread, rhizome thickness, root spread, root length, root weight and number of fingers, with maximum fresh and dry rhizome yield as well as top yield and also took minimum days for attaining maturity. The quality parameters like curcumin, volatile oil, non volatile ether extract (NVEE), were also found to be highly influenced by the combined application of all these microbial inoculants, which was significantly superior.

To sum up, the results of two years study could standardize an organic manure dose in the cultivation of *Curcuma aromatica* Salisb. for getting better growth, yield and quality. The best dose identified was vermicompost 25.0 t ha$^{-1}$ or neem cake 6.0 t ha$^{-1}$ which were statistically superior to all other treatments. It was also observed that a combined application of microbial inoculants such as *Azospirillum,* AMF, *Pseudomona*s and *Trichoderma* was best for better growth, yield and quality of kasthuri turmeric.

Increase in the profitability of crop during the second year of experimentation and reduction in the intensity of pest and disease incidence indicate the feasibility of switching over from inorganic farming to organic farming.

Further studies using the higher levels of these organic manures and their split application along with microbial inoculants are necessary to develop an organic package of practices recommendations for getting good quality produce with maximum returns. Moreover, popularization of the crop and development of value added products and appropriate marketing strategy are necessary for making the crop more remunerative.