SOIL-PLANT-SHADE INTERACTION ON THE PRODUCTIVITY OF KACHOLAM

(Kaempferia galanga **L.***)*

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Soil-Plant-Shade interactions on the productivity of Kacholam (*Kaempferia galanga* L.)"** 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 to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled **"Soil-Plant-Shade interactions on the productivity of Kacholam (*Kaempferia galanga* L.)"** is a record of research work done independently by **Mrs. Hani G.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

INTRODUCTION

Growth and realised yield of a crop is the result of many physical and physiological processes, each of which are affected severally and jointly, to various degrees, by environmental factors. The actual yielding potential of a crop, although controlled genetically, is affected strongly by environmental influences. Environment has a decisive effect on both quantitative and qualitative components of yield, which are equally important in medicinal plants. The active principles in these plants are certain secondary metabolites like alkaloids, glycosides, coumarins or steroids, which are related with the ecology rather than the normal physiology of the plant. This was the basis for the use of ecophysiological approach in the optimisation of medicinal plant agrosystem suggested by Bernath (1990).

The soil and atmospheric environment which constitute the habitat is known to have enormous influence on the quality and quantity components of yield as well as their interrelations. Apart from anchorage, soil provides moisture as well as essential minerals required by the plant, which in turn depend upon content and form of elements as well as their interactions, redox state of soil, etc. Influences of weather variations govern the utilization of the elements as well as the metabolic processes leading to production. Analysis of the influence of habitat and the component factors will provide basic information on crop response and yield limiting factors, which will have applicability even in the context of general crop production.

To obtain a plant drug of specific quality, it is not sufficient to have the particular plant species, it will rather be necessary to develop cultivars according to the genetics of secondary plant products and to consider the morpho and ontogenetic variability as well as the environmental factors as they are able to modify the function of secondary substances and the quality of raw materials. So any improved method or management practice should be designed in such a way that it is not at the expense of quality of products.

Herbal medicines have always occupied an important position in India and other countries of the world. After having tapped the immense advantage of synthetic chemistry for more than a century, the situation has undergone a change and the use of native and natural products is now on the rise. The demand for traditional drug plants in India and abroad is ever increasing. In fact, among the developing countries, India occupies the foremost position in the export of drugs. Shortage in the availability of crude drugs of good quality is projected as the major limitation for the manufacture of herbal medicines to meet the increasing demand. To cope with the current trend and to provide good quality raw material at required levels, there is urgent need to scale up production by undertaking commercial cultivation. India has a vast geographical area with high production potential and varied agroclimatic conditions, and we possess many useful and economic species of medicinal plants still remaining unexploited and unimproved. Kacholam (*Kaempferia galanga* L.) is one among them in which not much research work and improvement has been done.

Kaempferia galanga L. is a high value medicinal and aromatic oil yielding plant belonging to the family Zingiberaceae and is widely distributed in the tropics and subtropics of Asia and Africa. It is an attractive rhizomatous spice plant used in culinary preparations. The economic part of the plant is the underground stem, the rhizome,.which finds an important place in indigeneous medicines as stimulant, expectorant, diuretic and carminative. It is an ingredient of some of the general tonics like "Chavanaprasam" and "Dasamoolarishtam". Recently, the consumption of rhizome by the medicinal and perfumery industries has shot up and the demand for the same has increased. It has attained the status of a cash crop of homesteads in Kerala. The annual consumption of the dried rhizome by various ayurvedic pharmacies in Kerala is about 16,000 kg with a unit price of Rs.275/kg, thus valued at Rs.0.38 million (Joseph, 2001).

The humid tropical climate and soil conditions prevailing in Kerala are highly suited for the cultivation of Kacholam. Farming in Kerala is characterised by small homesteads with coconut as an integral part. As coconut is widely spaced, nearly 75 per cent of the soil and about 50 per cent of solar energy remain unutilized which offers great scope for intercropping. Thus there is immense potential for the cultivation of Kacholam in the homesteads of Kerala.

Except for a few preliminary studies, no systematic work has been done on the influence of environmental factors on quantitative and qualitative traits of Kacholam. So an attempt was made to study the role of the environment on regulating the productivity of Kacholam ecotypes as well as rhizosphere nutritional variation, so as to develop a soil-plant- environment based management system to maximise input use efficiency as well as productivity of Kacholam intercropped in coconut gardens.

The specific objectives of the study were:

(a) To elucidate the interaction between soil, the plant and the atmosphere in the intercropping system that finally influence the developmental process and productivity.

(b) To assess the rhizosphere nutritional variation as affected by input combinations and their effect on yield and quality.

(c) To elucidate the functional association of elements to the interrelationship between quantity and quality under microvariate environments.

(d) To generate information on integration of the quantitative and qualitative components of production, which is vital in the cultivation of medicinal plants.

REVIEW OF THE LITERATURE

2. REVIEW OF LITERATURE

Medicinal plants are rich in secondary metabolites, which are potential source of alkaloids, glycosides, volatile oils and steroids. The growth pattern of these plants and biosynthesis of secondary metabolites, although controlled genetically, are affected strongly by environmental influences. Studies have been conducted in many crops with regard to the effect of genotype x environment interaction on various quantitative and qualitative parameters of the plant. However, published data on these aspects with respect to Kacholam (*Kaempferia galanga* L.) is meager and so an attempt is made here under to review the literature pertaining to the subject for related crops.

2.1 SOIL EFFECTS ON YIELD AND QUALITY

Soil provides physical anchorage to crops, is the reservoir of nutrients and water needed by them and is the source of warmth and aeration to roots. The various physical properties (soil texture, soil structure, soil depth etc.) and chemical properties (pH, nutrient composition, electrical conductivity etc.) have profound effect on yield and quality of crops.

2.1.1 Soil Depth

Most medicinal and aromatic plants are adapted to a wide range of soil depths. *Matricaria chamomilla* and *Papaver somniferum* and *Ocimum* sp. preferred shallow well drained porous soil (Singh, 1982a, 1982b). Similar reports have been reported in *Ocimum* sp. (Balyan *et al.*, 1982).

Mentha arvensis grows and spreads through numerous underground suckers and rhizomes. Hence it requires for optimum development a deep moist, loose and well drained soil (Mehra, 1982). *Saussura lappa* develops long thick roots, so a deep rich porous soil is preferred (Gulathi, 1982). Deep and moist soils were the most favourable condition for the growth of taproot and rhizomes of liquorice (Marzi *et al.*, 1992). Ipeac (*Cephalis ipecacuanhe*) and Ashwagandha (*Withania somnifera*) required deep soil for the better development of roots which were very deep, i.e., up to 40-45 cm into the soil (Chaterjee *et al.*, 1995; Nizam and Kandalker, 1995). Palmarosa and vetiver were adapted to grow in shallow soils and were recommended for growing over bunds and contours to control soil erosion (Gupta and Chadha, 1995). Liao *et al.* (1999) reported a reduction in spear head quality of asparagus with increase in soil depth. In saffron, maximum number of tillers, leaves and flowers per plant were obtained at a shallow depth of sowing of 7.5 cm (Nazir *et al.*, 2000).

2.1.2 Soil Texture and Structure

These are the most important physical properties in relation to plant growth because they influence water intake rate, water storage in the soil, aeration, porosity, penetrability etc. Bradu (1974) observed that sandy loam soil was better suited for cultivation of ocimum. Similar observation has been reported in opium poppy by Gupta (1984).

Rauvolfia serpentina was found to yield better in clay loam to silt loam soils rich in organic content (Maheshwari *et al.*, 1984). Bhardwaj *et al.* (1984) reported better performance of *Digitalis purpurea* with regard to glycoside content in silty loam to clayey loam.

Mohammed and Rehman (1985) reported that the root development and production of glycyrrhizin in liquorice were better in sandy loam soil compared to clayey loam soil. In Henbane, hycosyamin content increased significantly when grown in well drained, fertile, light loam to silt loam soil (Sharma et.al., 1998). In potato, Mackie *et al.* (1990) reported that tuber growth, root growth and nutrient uptake were all greater in the coarse rather than the fine textured soil.

2.1.3 Soil Reaction and Soil Nutrient Composition

Soil reaction and soil nutrient composition are the important factors for evaluation of the production potential of a soil. Pareek *et al.* (1980) reported that a rise in pH above 8.5 decreased the growth, and consequently, oil yield of Palmarosa (*Cymbopogan martini* Stapf. var. motia) but had no adverse influence on quality of the oil so produced. Vetiver is unique for its tolerance to soil alkalinity and periodic flooding and waterlogging. These conditions have been found to decrease root yield but have caused no adverse effect on oil content and oil composition of root (Nair *et al.*, 1982).

Neutral to slightly acidic pH was suitable for the cultivation of *Matricaria chamomilla* (Singh, 1982a). Patil and Patil (1983) found that increasing salinity reduced the K, Ca, Mg, Zn and Fe in the leaves and roots of *Syzygium cumini* and increased the content of leaf Na. Bhardwaj *et al.* (1984) reported that soil with neutral pH was best suited for better growth and higher production of glycoside in *Digitalis lanata.* A study on the yield and composition of tagetes oil (*Tagetes minuta*) revealed that inherent soil deficiencies of N, P and S were responsible for variation in the yield and composition.(Graven *et al., 1991)*

Dikshit and Pathak (1992) reported that with increasing levels of stress (sodicity and salinity), total free amino acids increased significantly while protein bound aminoacids showed a decreasing trend in Indian gooseberry. Soil with mean neutral pH, high organic matter and higher base saturation with Ca and Mg enhanced the productivity of pepper (Mathew *et al.*, 1995). *Lipia alba* cv. Kavach was reported to grow under wide range of soil pH (5.4-9.3) demonstrating its inborn stress tolerance (Bahl *et al.*, 2000).In *Rosa damascena*, Misra *et al.* (2001) reported that alkaline soils with low N and P content was found detrimental to rose oil quality and quantity in terms of 1-citronellol and geraniol (Misra *et. al.*, 2001).

2.1.4 Soil Moisture

The main role of soil moisture in crop growth is to meet the needs of transpiration and cellular hydration of plants. It also influences soil microbial activity and mineral nutrition, germination morphology and maturation of plants. Usually a limited water supply or water stress has negative effect on the development of the plant. It is expressed in the rate of vegetative growth, reproduction, flowering and yield (Kozlowski, 1968). However when focussing on the biosynthesis of secondary metabolites water stress is not always detrimental. Sharapov (1969) found that lobelia plants (*Lobelia sesilifolia*) grown in a field with soil water capacity at 90 per cent saturation produced only traces of alkaloids, while the highest content of nicotine was found in those plants grown under the lowest level of saturation (30%). Langenbein *et al.* (1979), studying the effect of moisture stress on composition and yield in leaf resin of *Hymenaea courbaril*, did not find large variation in yield. Although some change in composition occurred and leaf development was retarded, the resin content in dry leaf tissue showed some increase.

The study conducted by Yaniv and Palevitch (1982) also supported the fact that secondary metabolites generally increase under dry conditions. Pareek *et al.* (1991) found that moisture stress condition in rauvolfia and periwinkle led to larger root, impaired root:shoot ratio and produced higher total alkaloid content in the roots. Similar favorable influence of soil moisture stress on essential oil content and composition of Sweet basil was reported by Simon *et al.* (1992).

2.1.5 Soil Temperature

Soil temperature influences germination of seeds, root growth, nutrient availability and microbial activity in soil. Bradu (1974) observed that soil temperature and moisture had direct co-relationship with the essential oil content and total oil yield of ocimum. Many metabolic processes demonstrated a positive correlation with soil temperature and had a Q_{10} of 2-3 in the more common temperature range (Bowling, 1976).

Singh (1982a) reported that low mean soil temperature was a prerequisite for good quality essential oil synthesis in bergamont mint. Contrarily, in tobacco seedlings, higher temperature of 24°C promoted higher uptake of nutrients, particularly P, K and Mn, although temperature had little effect on N, Ca and Mg uptake (Roton *et al.*, 1994). Various studies had been conducted on the effect of soil temperature on growth, flower and fruit development, mineral uptake, translocation, plant hormone synthesis and cold hardiness (Chen and Tseng, 1996; Rosenfeld *et al.*, 1998). Sivaraman *et al.* (1999) reported that a higher temperature of 26-28°C promoted better root growth in pepper.

Mathur and Gupta (2000) found that higher temperature of soil and air during summer season promoted synthesis and accumulation of bacoside-A in majority of the accessions of *Bacopa monnieri* collected from different geographical locations in India. However a reverse trend was reported in *Rosa damascene* where the oil quality in terms of geraniol and phenyl ethyl alcohol were significantly increased at low soil temperature (Misra *et al.*, 2001).

2.1.6 Soil Loosening

Soil loosening influences plant growth and development through their effects on soil moisture, soil air, soil temperature and mechanical impediments to root development and shoot emergence. Loosening activities break the top soil and promote aeration and thus encourage microbial activity. Sub soil layer plays an important role in the plant nutrition process and has a great effect on the plant yield, thus, loosening of subsoil is an essential operation (Pabin, 2000). Soil loosening is found to be an indispensable operation for the proper development and better yield in several crops such as *Mentha arvensis* and *Dioscorea floribunda* (Mehra, 1982; Bammi and Gangadharan, 1982). However, no advantage was gained by excessive ploughing of the field in case of opium poppy (Singh, 1982b) and *Costus speciosus* (Sarin *et al.*, 1982) as the roots did not go very deep into the soil. Ploughing the field 3-4 times to get a good tilth was reported to be a prerequisite for increasing the yield in many crops such as ginger, turmeric, neelamiri (*Indigofera tinctoria*), chethikoduveli (*Plumbago rosea*) and *Piper longum* (KAU, 1996).

To study the effect of soil compaction on plant growth and soil properties, a study was conducted by Rahman (1999) and the results revealed that the nutrient uptake by the plant was significantly reduced as a result of increased level of soil compaction. Soil compaction also significantly increased the bulk density of the soil and reduced the water holding capacity and total porosity of soil. Mohr et al., (1999) observed increased soil moisture content and nitrogen mineralisation as a consequence of loosening which in turn facilitated increased root growth and yield in grape vines. Digging the pepper gardens twice a year increased berry yield and nutrient uptake (Sivaraman *et al.*, 1999).

2.2 PLANT EFFECTS ON YIELD AND QUALITY

The vegetative and reproductive attributes of a plant have a persistent and far reaching effect on total crop yield. The variation in yield and quality of different genotypes is due to the difference in these morphological traits.

2.2.1 Effect of Vegetative Attributes on Yield And Quality

Sreekumaran *et al.* (1980) reported that the number of tillers in 30 ginger cultivars had a positive correlation with rhizome yield. Nair *et al.* (1980) found increased number of productive tillers per plant as one of the important reasons for superiority of ODP-2 variety over ODP-1 variety of palmarosa with respect to oil yield and quality of oil.

Kalyansundaram and Dalal (1981) observed that seed yield was significantly correlated to total tiller per plant in Psyllium (*Plantago ovata*). A similar observation has been reported in palmarosa where tiller/plant is positively correlated with yield (Sheela *et al.*, 1981). Philip and Nair (1983) reported a high correlation of rhizome yield of turmeric with leaf characters. Taneka (1980) reported that an increase in the longevity of leaves seemed to be important to improve the source capacity in potato.

Work done by Myaetaly and Tamments (1984) in potato revealed that the tuber yield had positive and significant association with leaf area duration and number of productive haulms. Randhawa *et al.* (1985) indicated that leaf area is one of the important physiological traits, which determined the rhizome yield in turmeric. In an investigation conducted by Mukhopadyay and Roy (1986) in 25 cultivars of turmeric, a high correlation was observed between plant height and yield per plant at both the phenotypic and genotypic levels.

Saikia and Shadeque (1992) found that growth attributes like leaves per clump, tiller per clump and shoot height were positively correlated with rhizome yield and volatile oil in ginger. Singh and Mehey (1993) reported that oil content in seed was positively related to plant height and branches per plant in dill (*Anethum greveolens*).

Bhasker (1995) reported that leaf area index, leaf number and branch number per plant in patchouli were highly correlated to fresh herb yield and oil yield. In glory lily (*Gloriosa superba*), number of leaves and number of branches had direct negative effect on colchicium yield (Farooqi *et al.*, 1999). Path analysis study in ginger showed that leaf area, leaf number and plant height had very high positive direct effect on rhizome yield (Premananda *et al.*, 1999).

In vetiver, number of tillers per plant and number of leaves were found positively correlated with oil yield (Lal, 2000). Correlation studies conducted in German chamomilla (*Chamomilla recutita* L.) showed that plant height, fresh flower yield, spread area and days to flower were highly correlated to essential oil (Lal *et al.*, 2000). Jagadev *et al.* (2001) reported that leaf number has negative direct effect on total oil yield and positive indirect effect via plant height in palmarosa . Shanmugasundaram *et al.* (2001) found that in turmeric, number of tillers, leaf area and number of leaves per plant had positive direct effect on rhizome yield and leaf duration had negative direct effect.

Growth studies on elimicin containing grass *Cymbopogan pendulus* suggested that among the morphological characters, plant height, number of tillers per plant and number of leaves per plant exhibited significant correlation with essential oil yield per plant. Leaf area index and specific leaf weight did not exhibit significant correlation with essential oil yield (Sharma *et al.*, 2002).

2.2.2 Effect of Reproductive Structures on Yield and Quality

Total yield of crop is greatly influenced by the type, size, weight and number of reproductive structures. In turmeric, Govind *et al.* (1981) found that the number of rhizome fingers per plant, size of fingers and length of fingers had significant association with yield.

Philip and Nair (1983) reported that mother rhizome as planting material had higher yielding potential compared to finger rhizome in turmeric(*Curcuma longa*). In *Dioscorea floribunda,* under Kerala conditions, crown proved to be a superior planting material compared to median and tip tubers, both in terms of highest number of established plants and tuber yield (Devassay and Nair, 1983). Variation in cormel production in relation to the size and weight of mother corm was observed in gladiolus (Negi and Sharma, 1982; Khanna and Arora, 1986) and saffron (Dhar, 1991).

The use of rhizome bits of 6 cm length with growing tops and leaves as planting material in *Acorus calamus* produced maximum rhizome yield and essential oil yields compared to the use of rhizome bits of 3 cm length without gray tops and rhizome bits of 6 cm length without gray tops (Philip *et al.*, 1992).

Results of field trials conducted by Badiyala and Panwar (1992) in Kalazira (*Bunium persicum*) showed that grain yield as well as different yield attributes were positively correlated with initial bulb size at the time of planting. Singh and Mahey (1993) reported that umbels per plant, test weight and seed yield had positive direct effect on oil content in dill (*Anethum graveolens*). In saffron, Singh *et al.* (1994) found that both the production of cormels and yield of flowers were dependent on the initial size of corm at planting in saffron.

The results of a trial conducted by Szlachetka *et al.* (1995) showed that in tuberose (*Polianthus tuberosa*), single rhizome weighing over 40 g was the most valuable stock material with respect to the total yield, propagation rate and flower production compared to rhizome clusters. Planting of whole mother rhizome produced highest yield per unit area and most rapid growth followed by rhizome with 5-6 internodes and half cut mother rhizome in *Curuma longa* (Yothasiri *et al.*, 1997).

Maheswarappa *et al.* (1998) reported that growth, yield characters and yield of kacholam (*Kaempferia galanga*) were superior when mother rhizome was used as planting material compared to finger rhizome. Gunasankaran and Krishnaswamy (1999) found that large seeds were superior over medium and small seeds to the extent of 25 and 62 per cent respectively with respect to germination percentage in clove.

Runner cuttings of 8-9 cm length bearing 2-3 leaves produced more biomass yield compared to stem cuttings of 8-9 cm length bearing 3-4 pairs of leaves in Japanese mint (Kattimani and Reddy, 2000). The possibility of reducing the size of planting material in ginger using mini seed rhizome was investigated by Nizam and Jayachandran (2001). They concluded that rhizomes weighing 15 g recorded highest sprouting compared to 5g and 10g bits. A correlation study conducted in turmeric by Shanmugasundaram *et al.* (2001) indicated that the positive direct effect on rhizome yield was maximum for weight of primary rhizome followed by weight of secondary rhizomes and mother rhizome.

2.3 ATMOSPHERIC EFFECTS ON YIELD AND QUALITY

2.3.1 Light and Shade Effects

Light quality, duration and intensity affect plant development and plant processes to varying degrees in different plants,

2.3.1.1 Effect of Shade and Light on Growth and Yield Attributes

Rhizome yield was found to be significantly higher in open than under shade in turmeric(Ramadasan and Satheesan, 1980). Bai (1981) also reported that turmeric recorded higher yield under 50 per cent shade condition. The crop *Clocimum* came up well under partially shaded condition in Jammu, though the oil content was slightly lower under shaded conditions (Balyan *et al.*, (1982). Senanayake and Kirthisinghe (1983) reported largest shoot length in black pepper under 50 per cent light compared to 75 per cent and 25 per cent light. Vijayakumar *et al.* (1984) found that black pepper vines exposed to direct solar radiation developed physiological disorder even under favourable soil moisture condition.

Twenty four medicinal species were identified as potential intercrop in rubber during the pre-yielding period. Among these plants *Adathoda beddomei, Plumbago rosea and Kaempferia rotunda* were reported to come up well under deep shade (RRII, 1989).

Vijayakumar *et al.* (1989) observed that some shade tolerant species like *Holostemma annulare, Kaempferia galanga, Alpinia galanga* etc. could be successfully cultivated in rubber plantation.

Nair *et al.* (1991) showed that yield of plumbago, rauvolfia, catharanthus, and kacholam when grown under natural shade of coconut was on par with the yield obtained under open condition. Highest yield of patchouli (*Pogostemon patchouli*) was obtained when the plant was grown under 50 per cent shade (Radhakrishnan *et al.*, 1991). The dry weight of rhizomes of *Captis japonica* grown in the unshaded field was less than that in shaded fields (Shibata *et al.*, 1992).

A study on growth behaviour of the medicinal plant *Enicostemma littorale* under sun and canopy shade conditions showed that height of plant, leaf number, dry weight and fresh weight were enhanced in shade compared with plants grown in full sun, but flower number was reduced by shade (Sharma *et al.*, 1994). Field trials on the performance of mango ginger (*Curcuma amada*) conducted at Vellayani for two seasons under varying levels of shade revealed that rhizome yield under open and 25 per cent shade were on par indicating that the crop was shade tolerant and suitable for intercropping situation (Jayachandran *et al.*, 1998). Artificial overhead shade resulted in better crop growth and biomass production compared to open condition in *Valeriana wallichi* (Singh *et al.*, 2000).

Limitations in light availability primarily affected total dry mass production and allocation, without substantial effects on either primary or secondary carbon metabolites in *Aloe vera* (Paez *et al.*, 2000). Among the different light treatments (10, 35 and 60% light), 35 per cent light intensity produced more number of leaves, bigger sized leaves, higher photosynthetic efficiency and stomatal conductance in betel vine (Shivashankara *et al.*, 2000).

2.3.1.2 Effect of Shade and Light on Quality Attributes and Nutrient Uptake

Light intensity plays an important role in affecting quality and nutrient uptake of medicinal plants. In *Mentha piperita* under shaded condition, leaves recorded significantly higher levels of N and K than leaves of plants grown in full sunlight (Virzo and Alfani, 1980). According to Bai (1981), contents of N, P and K in all the plant components of ginger and turmeric increased with increase in shade. Curcumin content of turmeric rhizome showed a progressive decrease with increase in shade (Varugheese, 1989). Shade grown ginger recorded high value of oil and oleoresin content compared to that grown in open (George, 1992). In colocasia, oxalic acid and starch contents were higher in open compared to that under shade (Prameela, 1990). However, in *Captis* *japonica*, no significant difference in berberine alkaloid was observed (Shibata *et al.*, 1992).

An experiment conducted at AMPRS, Odakkali showed that though significant difference in N, P, K, Ca and Mg contents were noticed with varying levels of shade, only K content showed a persistant increase with shading of Clocimum. No definite pattern was noticed in the contents of other nutrients with change in the intensities of shade. Though the content of micronutrients was also influenced significantly by the treatments, no regular trend was observed (Pillai and Chinnamma, 1993).

Pillai and Chinnamma (1994) found that with increasing shade, percentage of oil in ocimum decreased though the quality of oil was not affected. Similarly, Gupta and Chadha (1995) reported that ample sunshine is a prerequisite for mint to synthesise higher content of oil and menthol. Contrary to this, in patchouli (*Pogostemon patchouli*) herbage yield and oil content were less in open condition than under shade (Radhakrishnan *et al.*, 1991).Shading decreased K, Ca, Mg, arginine content and essential oil percentage in *Codonopsis lanceolata* but the quality of essential oil was improved when grown in shaded condition compared to open condition (Seongphil *et al.*, 1996).

Screening of genetic resources of the medicinal and vegetable plant *Centella asiatica*, collected from different parts of India revealed that 50 per cent shading of plants resulted in higher yields of herbage and asiaticoside (Mathur *et al.*, 2000).Experiments conducted at Sadanandapuram, to study the influence of nutrients under different light intensities on growth of bush pepper (*Piper nigrum*) plants indicated that better expression of growth characters and response to nutrients was under 50 per cent light intensity (Devadas and Chandini, 2000). In *Valeriana wallichi,* higher essential oil and valepotriates were obtained under shaded condition compared to open condition (Singh *et al.*, 2000).

2.3.2 Temperature Effects on Yield and Quality

Temperature is one of the main ecological parameters influencing the physiology and biochemistry of plants. Bernath and Tetenyii (1980) reported that low temperature promoted accumulation of morphine but decreased higher methylated codeine and thebaine alkaloids in poppy (*Papaver somniferum*). The oil recovery and geraniol content in *Pelargonium graveolens* were comparitively higher during summer months than the winter months (Mani and Sampath, 1981).Hops (*Humulus lupulus*) require fairly high late summer temperature for the full development of oils and oleoresin (Mohan and Datta, 1982).

Hycoscyamine and hycoscine content in the oil was markedly higher in plants of *Hycoscyamus muticus* sown in summer compared to winter sown plants (Reda *et al.*, 1984). Low winter temperature of North Indian plains temporarily inhibited the growth of cymbopogan grasses, thus the plants remained dormant throughout the season and resumed vegetative growth with the advent of spring season when temperature was 30-33°C (Pareek and Gupta, 1985).

The effect of seasonal variation in temperature on flowering in pyrethrum at Kodaikanal hills was investigated by Mohandas *et al.* (1986). They found that plants exposed to lower minimum temperature in the year showed maximum flowering with higher dry matter content and high total pyrethrin content. Seasonal effects on secondary metabolites were seen to be compound specific. Each individual compound had its specific favourite season. In *Catharanthes roseus*, the highest quantity of ajmalicine was obtained during summer, lowest in winter, while, the total alkaloid was highest in winter and lowest in summer (Sen and Datta, 1986).

Fluctuation in relative humidity and temperature during the growth of young vines of hops (*Humulus lupulus*) did great damage and reduced the cone yield by 40 to 100 per cent (Arya, 1989). Bettray and Vomel (1992) reported that herb quantity and single flower head weight decreased with increase in air temperature and essential oil, chemazulene and epigenic content increased homogenously with rise in temperature in *Chamomilla recutita.*

A variability study for obtaining maximum oil yield and elemicin content in ocimum during different months of the calendar year was carried out by Khosla (1993) and the study revealed that essential oil content had direct relation with temperature, whereas elemicin content showed no such relation. It was found that oil content increased during summer and decreased during winter season.

2.3.3 Effect of Rainfall on Yield and Quality Of Crop

In agriculture, rainfall largely manifests itself through its influence on the edaphic factors *viz.*, soil moisture, soil temperature and soil aeration and through these factors it influences the growth, development and yielding potential of a crop.

Fluck (1955) observed that in lemon grass (*Cymbopogan citratus*), the yield of essential oil was 0.2 per cent in the rainy season and 0.35 per cent in the dry season. The essential oil content of *Pimenta racemosa* grown in Puerto Rico increased from 1.32-3.4 per cent with decreasing rainfall (Gerhenzon, 1978).Shai and Singh (1981) noticed that high rainfall is the major factor for significant reduction in oil content and yield of lemon grass (*Cymbopogan martinii*). The other climatological factors *viz.*,atmospheric temperature and relative humidity had no significant effect on oil content and quality.

A well distributed rainfall of 100 cm or more was considered ideal for growing *Catharanthes roseus* as a commercial crop (Datta, 1982). Dull cloudy or rainy weather tended to reduce not only the quality but quantity of opium (Singh, 1982b). The alkaloid content of *Chelidonium majus* was found to be highest in summer and again decreased during autumn (Kustrak *et al.*, 1982). Similarly, in hop plants (*Humulus lupulus*) sufficient rainfall was required at vegetative period. However, after flowering, heavy rains could result in reduction in the quality of cones (Mohan and Datta, 1982; Arya, 1989). Mathai (1983) reported that in black pepper, growth of fruit bearing lateral shoots and photosynthetic rate were maximum during peak monsoon in India.

The oil analysed for aldehyde citronellal content in *Cymbopogan winterianus* showed that post monsoon period was the best period for higher yield of aldehyde (Malwatker *et al.*, 1984). Granda *et al.* (1986) studying the foliage and root growth of *Rauvolfia tetraphylla* at bimonthly intervals, found that foliage growth increased markedly during rainy season and decreased during dry season. Any dry spell even for a few days, within the critical period of growth (flowering to fruit ripening) was found to result in low yield in pepper (Pillai *et al.*, 1988).

Maheshwari *et al.* (1988) reported that the winter rains helped in improving vegetative growth and prolonged maturity in Henbane (*Hycocyamus niger*). Khosla (1993) reported that oil yield of *Ocimum carnosum* was maximum during dry season and minimum during rainy season. Farooqi and Vasundhara (1995) opined that cloudy weather or rains at the time of blooming and prior to harvest substantially affected the oil yield of davana (*Artemisia pallens* Wall.). Amador *et al.* (1996) observed that ergoline alkaloid in the genus Cuscuta was found only during the rainy season .

2.4 ATMOSPHERE AND PLANT INTERACTIONS

Atmospheric factors and plants interact through several ways. According to Watson(1956), components of growth analysis varied significantly depending upon the environmental condition during the cropping period.

Milthorpe and Moorby (1979) reported that much of the variations in the genotype could be ascribed to the variation in the environmental factors. Prameela (1990) reported that different morphophytes of colocasia behaved differently in different light intensities. Genotypic response to light intensity has been studied in several other crops also. Differential response of cultivars to varying levels of shade was reported in ginger (George, 1992) and in turmeric (Paul, 1992).

A study conducted at RARS, Ambalavayal revealed that growth characters and yield components of pepper cultivars were positively correlated with maximum temperature and number of sunshine hours in the first fortnight of March, while it was negatively correlated with mean relative humidity and number of sunshine hours of the first fortnight of February (Pradeepkumar *et al.*, 1992).

Choudhary (1994) reported that in sweet potato, the tuber bulking rate (TBR), NAR and LAI of all the 8 cultivars tested were highly influenced by climatic factors. Rainfall and relative humidity had positive correlation with tuber bulking rate and LAI, whereas minimum air temperature had negative correlation with TBR and LAI.

Tuber yield of potato cv. Kufri Badshah was found negatively correlated with maximum, minimum and mean air temperatures in vegetative and tuber initiation phases at Anand. Tuber yield was positively correlated with growing degree days; accumulated heliothermel units and accumulated soil temperature (Nooruddin *et al.*, 1995). Assimilation capacity of patchouli genotypes varied according to light availability and it was observed that PP-4 was sensitive to low light intensity and PP-5 was sensitive to high light intensity (Vijayalatha and Rajasekaran, 1997).

2.5 PLANT AND SOIL INTERACTIONS

Interaction between plant and soil factors influences plant characters and soil properties directly or indirectly. Soil physical condition such as bulk density, particle size distribution and soil strength may affect nutrient uptake as well as total yield of a crops in a number of ways (Canell *et al.*, 1980).Pannigrahi and Patro (1985) reported that soil properties have significant effect on ginger yield. Soil properties such as pH, moisture and organic matter content exerted significant positive effect on the yield of ginger.A study conducted by Szewazuk (1994) showed that there was no correlation between soil pH and electrical conductivity and cone yield in hops. But leaves from plants of high pH and EC tended to have higher Mg, Ca and Zn contents and lower N, K and Mn contents than those of lower pH and EC.

Inderjit (1998) reported that allelochemicals secreted by *Pluchea lanceolata* decreased the soil pH and increased the soil phenolics.A number of soil characteristics in the soil profile interact with each other to dictate the exact edaphic environment upon which plant roots depend at a given point in time. The interrelationship between different soil parameters are extensive and effectively control all aspects of root and shoot growth (Rengasamy, 2000). The study conducted by Jobbagy and Jackson (2001) revealed that plant characteristics like tissue stoichiometry, biomass cycling rates, above and below ground allocation, root distribution and maximum rooting depth may all play an important role in shaping nutrient profile of soil.

2.6 SOIL AND ATMOSPHERE INTERACTIONS

The interactions between climatic and edaphic factors are of great importance in agriculture. Any change in edaphic factor may influence the climatic factors and vice versa.

Tamhane and Karale (1967) found that Maharashtra basaltic soils of the low rainfall region had high alkalinity and were base saturated while in high rainfall zone the soils were acidic and tended to develop lateritic characteristics. Gowaikar (1972) while studying the chemical composition of the lateritic soils of South India, found a reduction in SiO_2 and an increase in Fe_2O_3 and Al_2O_3 contents with increase in rainfall.

The soil cover has significant impact on composition and properties of atmospheric air. The cause of this phenomenon is the biochemical activity of soil microorganisms producing and consuming various gases. Any change of soil properties leads apparently to disturbances of dynamic balance of gases in composition of atmosphere and the modification of climate on earth (Ghadekar, 1991).

The rate and decomposition of organic matter and thus, the level of fertility of soils are greatly influenced by atmospheric temperature and humidity and rainfall. Thus, soils of humid region under forests have more and faster development of horizon, highly leached top soil, less humified organic matter and higher percentage of water stable aggregate while those of semi arid climate have dark uniform surface soils and in arid climate the soils are highly eroded (Venkataram and Krishnan, 1992).

The dynamics of soil moisture at the land surface is governed by weather and climatic factors. Similarily, the soil moisture variation influences the moisture thermodynamics, energetics and dynamics of the overlaying atmosphere (Entekhabi *et al.*, 1996). Climatic factors have a profound influence on the thermal regime of the soil, thus soils in temperate region are cooler than soils in tropical region. The exchange of heat between atmosphere and soil surface decide the diurnal temperature variation of soil surface (Das, 1996).

2.7 SOIL X PLANT X ATMOSPHERE INTERACTIONS

Soil plant atmosphere interactions are of very complex nature. These effects lead to very special and spectacular changes in atmosphere, plant system and in the pedoclimate.

Phenotypic stability for herb yield, leaf stem ratio, essential oil yield, oil content and menthol and menthone contents were estimated for 7 genotypes of *Mentha arvensis.* Over eight widely different environmental conditions a wide range of variability was observed in each character over environment but none of the environments was found to be best for all the characters. Genetic and environmental interactions were significant for all the agronomic traits and soil quality characters indicating the significant influence of the environment on these characters (Sharma *et al*., 1992)..

Twelve diverse genotype of sweet potato (*Ipomoea batatus* L.) were studied in five environments from 1988 to 1992 to identify suitable genotypes for the plateau region of Bihar. G x E interactions were significant with regard to vine length, number of branches, number of leaves and number of tubers and tuber weight (Rajesh *et al.*, 1993). Similar observations have been reported in lesser yam and cassava (Apte *et al.*, 1994).

A greenhouse experiment was conducted by Letchemo *et al.* (1995) to find the photosynthetic potential of *Thymus vulgaris* selection under two light regimes and three soil water levels. High net CO_2 accumulation was obtained from Sel-1 grown under 70 per cent field capacity. Lower net CO_2 accumulation was obtained from Sel-2 grown under natural shade at 50 per cent field capacity. Sel-1 had higher stomatal conductance and dry matter production under all growing conditions. The lowest level of water potential was recorded for Sel-2 grown under supplementary light at 50 per cent field capacity.

A nursery study was carried out to evaluate the effect of different shade levels (0, 30, 50 and 70%) and depths of sowing (2 and 4 cm) on the emergence, seedling growth and survival of *Virola surinamensis*, a multipurpose tree species. The shade levels affected emergence, seedling mortality, height and number of leaves. There was low mortality at 0 per cent shading. The highest emergence percentage was observed at 30 per cent shade and maximum number of leaves was produced under 50 per cent shading. The sowing depths did not affect the pattern of result (Rosa *et al.*, 1999).

A study on the effect of climatic and edaphic factors on oil quality and quantity of *Rosa damascena*, at two locations (CIMAP Research Farm, Lucknow and CIMAP Field Station at Almora); indicated that high altitude, low temperature favourable RH, low light intensity, acidic pH of soil favoured production of high quality flower and good quality monoterpene essential oil (Misra *et al.*, 2001).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study entitled "Soil-plant-shade interaction on the productivity of Kacholam (*Kaempferia galanga L.*) was carried out in KAU, at the Agricultural Research Station, Mannuthy during the year 2001-2002. The materials used and the methodology adopted for the study are described in this chapter.

3.1 LOCATION

The Agricultural Research Station, Mannuthy, located at 10°31' N latitude and 76°13' E longitude and at an altitude of 40.29 M above sea level, is situated about 6 km east of Thrissur town to the right side of Thrissur-Palakkad NH-47.

3.2 WEATHER AND CLIMATE

The area enjoys a typical humid tropical climate. The mean weekly averages of the important meteorological parameters observed during the experimental period are presented in Appendix I and Fig.1.

3.3 SOIL

Laterite loamy sand of the ultisol group is the soil type of the area. Soils are acidic in reaction with a pH of 5.3. The chemical characteristics of the soil of experimental fields of both locations are presented in Table 1.

3.4 CROPPING HISTORY OF THE FIELD

The experimental sites consisted of two coconut gardens, with palms at a spacing of 7.5 x 7.5 m. Intercropping had not been done in the previous year.

3.5 DETAILS OF EXPERIMENT

The experiments were laid out in randomized block design with four replications. Treatments constituted of combinations of three ecotypes of

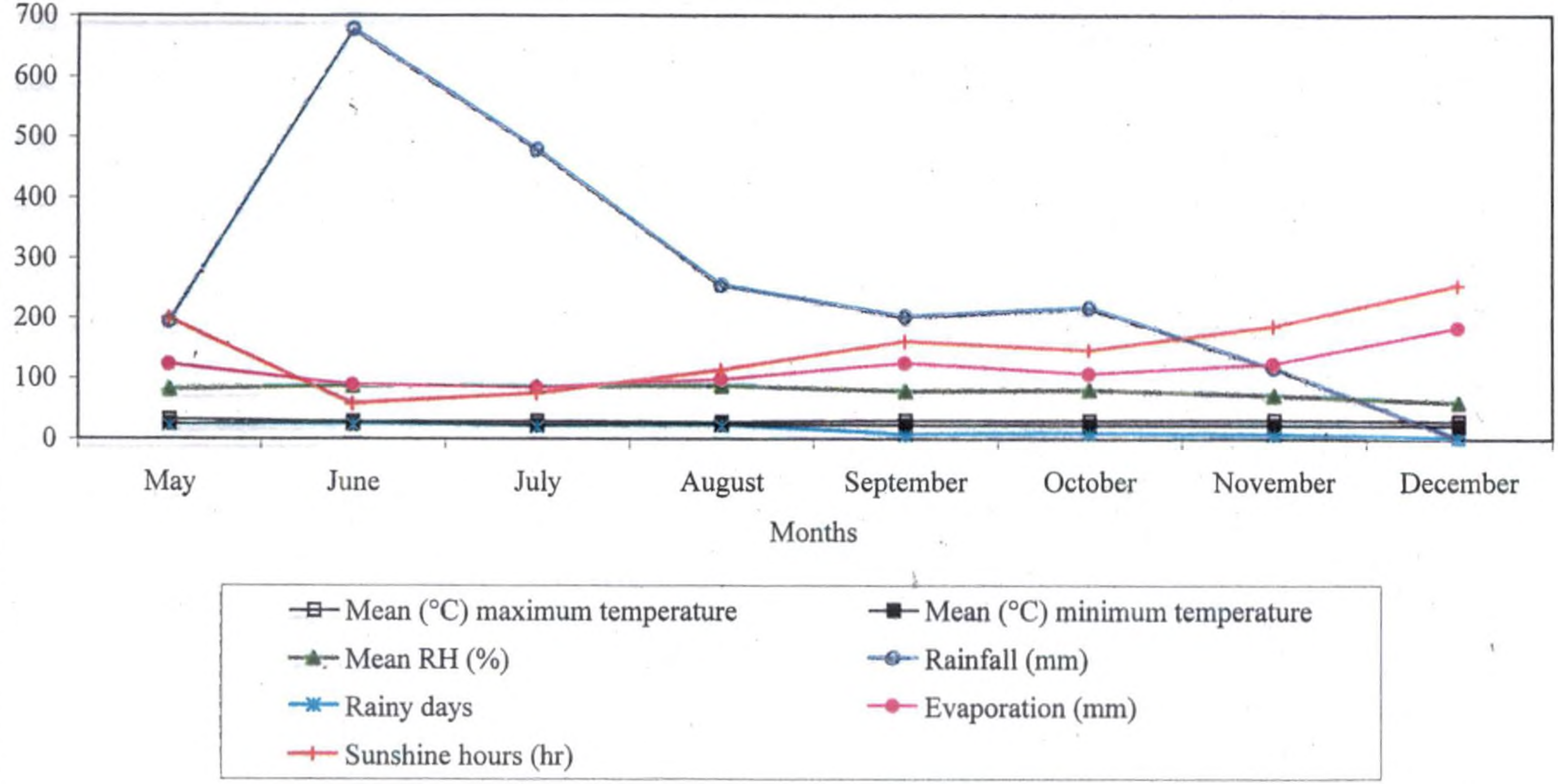


Fig. 1. Weather data for the crop period (May 2001 to December 2001)

kacholam, planted under two depths of preparatory soil loosening and two levels of shades in coconut gardens (Block F and Block N) of the Agricultural Research Station, Mannuthy.

3.5.1. Treatment Details:

Treatments included:

1. Three ecotypes of kacholam *viz.*, Echippara (E_1); Vellanikkara (E_2), Thodupuzha (E_3).
2. Soil loosening to 2 depths *viz.*, 10 cm (D_1) and 20 cm (D_2)
3. Two shade situations:
   i) Coconut garden with around 70 per cent shade (S_1)
   ii) Coconut garden with around 50 per cent shade (S_2)

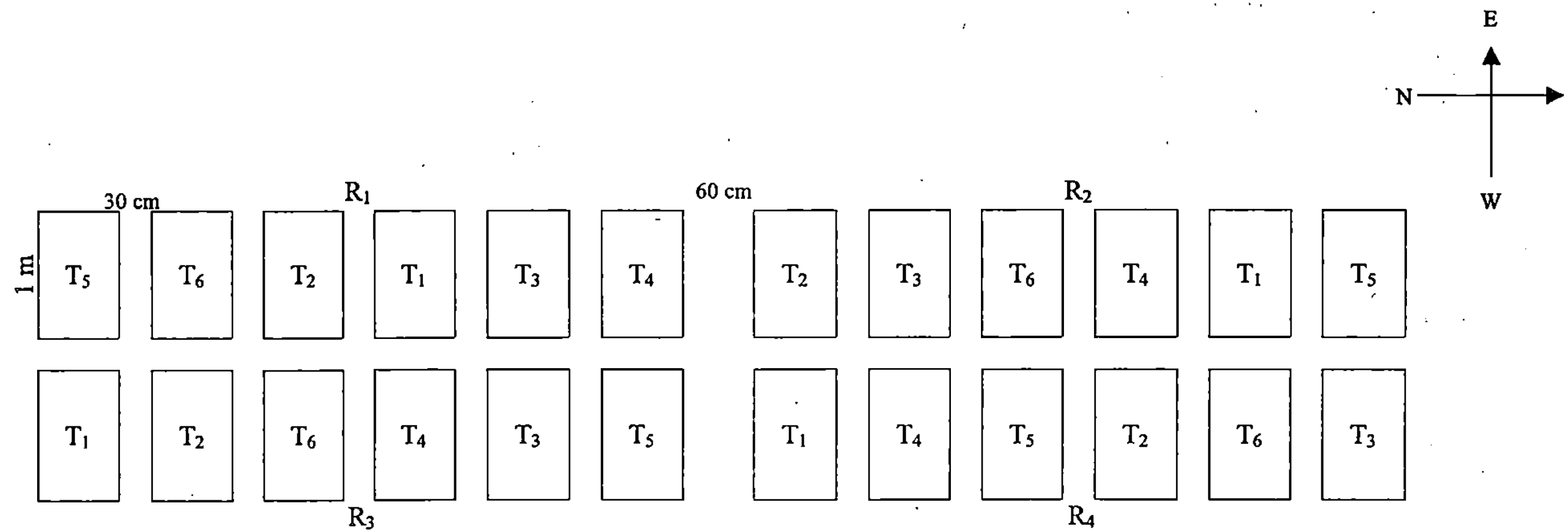
The treatment combinations were: -

$E_1 S_1 D_1$	$E_2 S_1 D_1$	$E_3 S_1 D_1$
$E_1 S_1 D_2$	$E_2 S_1 D_2$	$E_3 S_1 D_2$
$E_1 S_2 D_1$	$E_2 S_2 D_1$	$E_3 S_2 D_1$
$E_1 S_2 D_2$	$E_2 S_2 D_2$	$E_3 S_2 D_2$

Table 2. Details of Experiment field

1.	Date of planting	16-06-01
2.	Total number of beds per location	24
3.	Bed size Gross Net	3 x 1 m 2.7 x 0.6
4.	Total number of plants/bed	100
5.	Spacing	20 x 10 cm
6.	Design	RBD

Layout of the experiment field is given Fig.2.1 and Fig.2.2.



Ecotypes

E_1 : Echippara
E_2 : Vellanikkara
E_3 : Thodupuzha

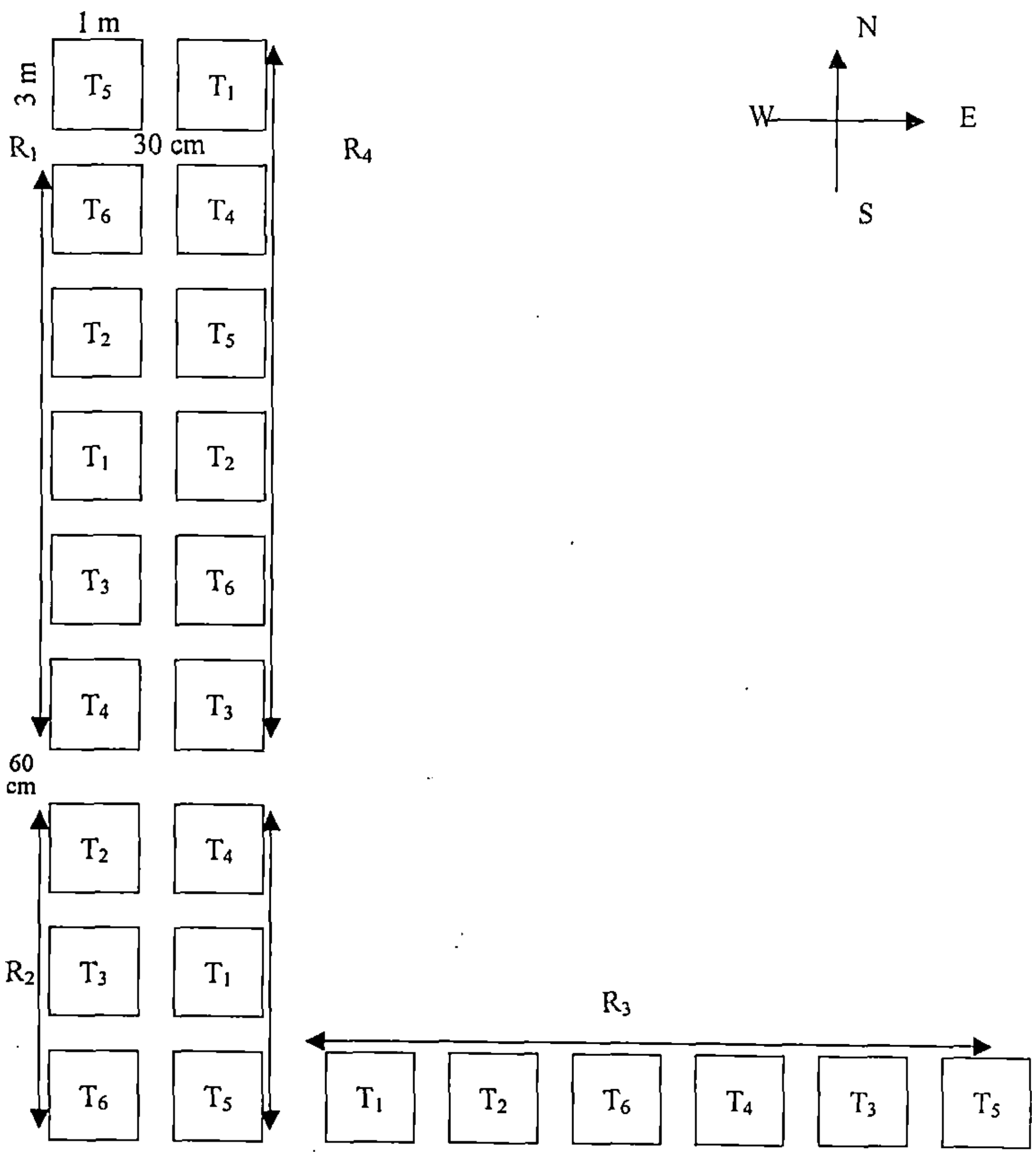
Soil Loosening Depths

D_1 = 10 cm
D_2 = 20 cm

Treatments

E_1D_1	T_1
E_1D_2	T_2
E_2D_1	T_3
E_2D_2	T_4
E_3D_1	T_5
E_3D_2	T_6

Fig. 2.1. Layout of Block F



Ecotypes

E_1 : Echippara
E_2 : Vellanikkara
E_3 : Thodupuzha

Soil Loosening Depths

D_1 = 10 cm
D_2 = 20 cm

Treatments

E_1D_1	T_1
E_1D_2	T_2
E_2D_1	T_3
E_2D_2	T_4
E_3D_1	T_5
E_3D_2	T_6

Fig. 2.2. Layout of Block - N (Near LO garden)

3.5.2 Site Selection

Based on the age of coconut palms sites were selected. Two gardens with 18-20 year old palms and 25-30 year old palms wherein the light infiltration was supposed to be 20% and 40% respectively were selected (Nair, 1979). The shade intensity under the coconut gardens was confirmed using digital luxmeter. The percentage of light infiltration and percentage shade in the coconut garden is given in Appendix II. It was seen to be 70% shade in Block N and 50% shade in Block F.

3.6 CROP CULTURE

The cultural operations were carried out as per the package of practices recommendations (KAU, 1996).

3.6.1 Land Preparation

The land was first dug to depths of 10 cm or 20 cm as per the treatments and the soil was brought to fine tilth. Raised beds of 3 x 1 m size and 25 cm height were prepared with 60 cm wide channel in between the beds.

3.6.2 Planting Material and Planting

Rhizomes were cut into small bits with a single bud each and sown in small pits at a spacing of 20 x 10 cm. Dried powdered cowdung at the rate of 20 t/ha was incorporated before planting. A population of 100 plants per gross plot was maintained. Similar crop management practices were given for both the locations. Mulching was done immediately after planting at the rate of 15 t/ha with leaves of Glyricidia. Weeding and earthing up were done twice at 60 days after planting and 90 days after planting. The crop was grown as a rainfed crop and received 2132 mm rainfall distributed over 105 rainy days.

Table 1.Chemical Properties of the Soil of the Experimental Fields

Properties	Soil depth	S1 (70% shade)	S2 (50% shade)
Ph	10 cm	5.3	5.5
Nitrogen (kg/ha)	10 cm 20 cm	255.85 249.75	257.70 253.85
Phosphorus (kg/ha)	10 cm 20 cm	18.0 14.5	20.65 17.80
Potassium (kg/ha)	10cm 20cm	290.65 275.5	265.40 260.45
Sulphur (kg/ha)	10 cm 20 cm	158.60 165.35	160.25 167.50
Calcium (kg/ha)	10 cm 20 cm	134.40 112.00	113.20 78.40
Magnesium (kg/ha)	10 cm 20 cm	89.60 77.20	77.20 44.80
Organic carbon (%)	10 cm 20 cm	0.53 0.48	0.50 0.46
Iron (kg/ha)	10 cm 20 cm	815.50 748.00	745.50 725.00
Manganese (kg/ha)	15 cm 30 cm	135.50 128.20	128.50 120.50
Zinc (kg/ha)	15 cm 30 cm	2.50 2.00	1.5 1.2

3.6.3 Incidence of Pests and Diseases

During the period of heavy rain in July and August, incidence of leaf spot caused by *Phytophthora* sp. was noticed. Spraying fytolan at the rate of 0.4 per cent gave good control.

Rodent attack was a severe problem four months after planting. The area was temporarily fenced with plastic nets and thorny shrubs to control the attack.

3.7 PLANT ANALYSIS

3.7.1 Sampling Techniques

Random sampling technique was adopted to select sample plants for recording various morphological characters and for doing chemical analysis. Five plants were selected at random from each plot (eliminating border rows) and were labelled. Monthly observations for each morphological character were recorded from the same five plants in each plot and the average was worked out. For chemical analysis, another five plants from each plot were uprooted and bulked together to get a representative sample.

3.7.2 Field Observations

3.7.2.1 *No. of shoots/tillers per plant*

Total number of shoots produced per plant was recorded at monthly intervals from the five sample plants. The average was worked out for each plot.

3.7.2.2 Number of Leaves Produced per Plant

Total number of leaves produced per plant was recorded at monthly intervals from the sample plants and the average was worked out for each plot.

3.7.2.3 Foliage Spread

Spread of the plant was measured using a tape in two radial directions viz., North-South and East-West and the mean was worked out.

3.7.2.4 Fresh Weight of Rhizomes

The sample plants were harvested separately from each treatment. The rhizome yield of individual plots was recorded and then expressed in per hectare.

3.7.2.5 Dry Weight of Rhizomes and Dryage Percentage

The rhizomes of the five selected samples were chopped into small bits and then dried to constant weight at 70°C to 80°C in a hot air oven. Dry rhizome yield per plot was recorded and expressed in per hectare. The dryage percentage was also worked out.

3.7.3 Plant Chemical Analysis

3.7.3.1 Nutrient Contents of Plants

Five plants were selected and uprooted at random from each treatment plot for analysis. Leaves were collected from the sample plants at active rhizome formation stage, while rhizomes were collected separately at harvest. These plant parts were cleaned, dried in a hot air oven at 70-80°C, powdered well and then analysed for major secondary and micronutrients. The method used for the analysis of different nutrients is given below in Table .3.1.

3.7.3.2 Essential Oil in Rhizomes

The essential oil in the dried rhizomes of sample plants was estimated by steam distillation adopting Clevenger trap method as per AOAC (1980) and expressed in percentage.

Table 3.1. Methods Used for Analysis of Plant Samples

Nutrient	Digestion procedure	Method of estimation	References
N	H_2SO_4 digestion	Distillation and titration	Jackson (1973)
P	2:1 HNO_3-$HClO_4$ diacid digestion	Vanado Molybdate yellow colour method using spectrophotometer	,,
K	,,	Direct reading using flame photometer	,,
Ca, Mg	,,	Titration using EDTA	Page (1982)
S	,,	Turbidimetry method using spectrophotometer	Hart (1961)
Fe, Zn, Mn	,,	Direct reading using AAS	Page (1982)

3.7.3.3 Oleoresin in Rhizomes

The oleoresin content was estimated by Soxhlet extraction as per AOAC (1980) and expressed in percentage

3.8. SOIL ANALYSIS

Soil samples were collected from both the experimental fields before and after cultivation, from 2 depths *viz.,* 10 cm and 20 cm for the determination of chemical properties. Details of the methods used for the chemical analysis of the same are given in Table 3.2.

Table 3.2. Methods Used for Soil Chemical Analysis

Character	Method used	Reference
Soil reaction pH	Soil water suspension of **1:2.5** and read in pH meter	Jackson(1973)
Organic carbon	Walkely and Black method	Walkely and Black(1934)
Available N	Alkaline permanganate method	Subbiah and Asija (1956)
Available P	Bray and Kurtz method	Bray and Kurtz (1945)
Available K	Neutral normal ammonium acetate extract using flame photometer	Jackson (1973)
Exchangeable Ca, Mg	EDTA titration	Page (1982)
Available S	$CaCl_2$ extract-turbidemitry method	Chesnin and Yien (1951)
Available Fe, Zn, Mn	DTPA extract method using AAS	Lindsay and Norwell,1978

3.9 STATISTICAL ANALYSIS

The data were statistically analysed using the analysis of variance technique for factorial RBD according to the procedure suggested by Panse and Sukhatme (1978). Path coefficient analysis was also done using Spar-1 software package to study the direct and indirect effects of yield contributing characters on yield as suggested by Deway and Lu (1959).

RESULTS

4. RESULTS

The results of the study on " Soil-Plant-Shade interaction on the productivity of Kacholam *(Kaemferia galanga L.)* conducted at Agricultural Research Station, Mannuthy during the year, 2001-2002 are presented below.

4.1 VEGETATATIVE GROWTH OF KACHOLAM

4.1.1 Number of Shoots per Plant

The data on number of shoots per plant observed at first, second, third, and fourth month are given in Tables 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5. In general throughout this period of observation, the three ecotypes showed similar pattern of production of shoots in the two shade situations. Although in the initial months ecotype Echippara showed superiority in terms of number of shoots produced, this difference disappeared in the later months. Pooled analysis also confirmed this result. However, in the fifth month Echippara and Vellanikkara ecotypes, had significantly more number of shoots than Thodupuzha in both shade situations and this was seen in the pooled analysis of data also. During this period, shallow depth of soil loosening facilitated production of more number of shoots than deeper soil loosening. This advantage was observed in each shade situation and pooled data confirmed it.

At the end of fifth month (Table 4.1.5) the pooled data revealed that the mean number of shoots produced under 10 cm soil loosening was 7.70 compared to 7.05 under 20 cm soil loosening. Echippara and Vellanikkara ecotypes produced a means of 7.51 number of shoots per plant, while, Thodupuzha had only 7.09 and this difference was significant. The shade situations did not influence the shoot production.

4.1.2 Number of Leaves per Plant

Leaf production showed a similar pattern as shoot production (Tables 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5.) Ecotypes showed more or less similar performance under both

Table 4.1.1 Number of shoots per plant (1MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.98	1.55	1.76	2.08	1.75	1.91	2.03	1.65	1.83
Vellanikkara E2	1.60	1.33	1.46	1.93	1.55	1.74	1.77	1.44	1.60
Thodupuzha E3	1.78	1.30	1.54	2.03	1.75	1.89	1.91	1.52	1.72
Mean	1.78	1.39	**1.59**	2.01	1.68	**1.85**	1.90	1.54	**1.72**
C.D for comparison of ecotype means	NS			0.11			0.01		
C.D for comparison of depth means	0.26			0.19			0.22		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.20

Table 4.1.2 Number of shoots per plant (2 MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	2.38	1.98	2.18	2.55	2.18	2.36	2.47	2.08	2.27
Vellanikkara E2	2.28	1.75	2.02	2.48	2.05	2.26	2.38	1.19	2.14
Thodupuzha E3	2.10	1.65	1.88	2.25	1.93	2.08	2.18	1.79	1.98
Mean	2.50	1.79	**2.03**	2.43	2.05	**2.23**	2.47	1.92	**2.13**
C.D for comparison of ecotype means	0.10			0.17			0.12		
C.D for comparison of depth means	0.16			0.13			0.15		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.1.3 Number of shoots per plant (3 MAP) as influenced by shade, ecotype and soil loosening depth

	70% shade			50% shade			Pooled		
Ecotypes	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	3.75	3.05	3.40	3.78	3.18	3.48	3.77	3.12	3.49
Vellanikkara E2	3.48	2.85	3.16	3.53	2.85	3.19	3.51	2.85	3.18
Thodupuzha E3	3.78	3.43	3.60	3.75	3.33	3.54	3.77	3.38	3.58
Mean	3.67	3.11	**3.39**	3.68	3.12	**3.40**	3.68	3.12	**3.54**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.37			0.25			0.22		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.1.4 Number of shoots per plant (4 MAP) as influenced by shade, ecotype and soil loosening depth

	70% shade			50% shade			Pooled over shade levels		
Ecotypes	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	5.88	5.15	5.51	6.05	5.39	5.72	5.97	5.27	5.62
Vellanikkara E2	5.78	5.23	5.50	6.03	5.48	5.75	5.91	5.36	5.63
Thodupuzha E3	5.55	4.65	5.10	5.73	4.88	5.30	5.64	4.77	5.20
Mean	5.73	5.01	**5.38**	5.93	5.25	**5.59**	5.83	5.13	**5.49**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.30			0.27			0.20		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.08

Table 4.1.5 Number of shoots per plant (5 MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	7.68	6.98	7.33	8.00	7.38	7.69	7.84	7.18	7.51
Vellanikkara E2	7.68	6.03	7.31	7.98	7.45	7.71	7.83	6.74	7.51
Thodupuzha E3	7.28	6.53	6.90	7.63	6.93	7.28	7.46	6.73	7.03
Mean	7.54	6.52	**7.18**	7.87	7.25	**7.56**	7.70	7.05	**7.37**
C.D for comparison of ecotype means	0.32			0.25			0.22		
C.D for comparison of depth means	0.26			0.20			0.10		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.2.1 Number of leaves per plant (1MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	2.85	2.65	2.75	3.33	2.75	3.04	3.09	2.70	2.82
Vellanikkara E2	2.63	2.23	2.43	3.05	2.78	2.88	2.84	2.50	2.82
Thodupuzha E3	2.85	2.38	2.60	3.00	2.48	2.76	2.92	2.43	2.60
Mean	2.77	2.42	**2.59**	3.13	2.66	**2.89**	2.95	2.54	**2.74**
C.D for comparison of ecotype means	0.18			0.15			0.10		
C.D for comparison of depth means	0.26			0.25			0.12		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.09

Table 4.2.2 Number of leaves per plant (2MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	6.63	6.10	6.36	6.65	6.30	6.48	6.64	6.20	6.42
Vellanikkara E2	6.45	5.95	6.20	6.65	6.10	6.38	6.55	6.03	6.29
Thodupuzha E3	6.15	5.78	5.96	6.35	5.70	6.03	6.25	5.74	6.00
Mean	6.41	5.94	**6.17**	6.55	6.03	**6.30**	6.48	5.99	**6.24**
C.D for comparison of ecotype means	0.04			0.03			0.02		
C.D for comparison of depth means	0.33			0.22			0.21		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of shade means : NS

Table 4.2.3 Number of leaves per plant (3MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	13.05	11.8	12.42	13.20	11.93	12.56	13.13	11.87	12.49
Vellanikkara E2	12.53	11.40	11.96	12.73	11.93	12.33	12.63	11.67	12.15
Thodupuzha E3	12.98	11.93	12.45	13.18	12.73	12.95	13.08	12.33	12.70
Mean	12.85	11.71	**12.28**	13.03	12.19	**12.62**	12.94	11.95	**12.45**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.43			0.38			0.27		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.02

Table 4.2.4 Number of leaves per plant (4MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	17.05	16.23	16.63	17.18	16.53	16.85	17.12	16.38	16.74
Vellanikkara E2	17.00	16.10	16.56	17.13	16.05	16.59	17.07	16.08	16.58
Thodupuzha E3	17.08	15.48	16.28	16.95	15.73	16.34	17.02	15.61	16.31
Mean	17.04	15.93	**16.49**	17.08	16.10	**16.59**	17.06	16.02	**16.54**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.56			0.47			0.34		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.2.5 Number of leaves per plant (5MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	28.33	24.18	26.26	29.18	25.38	27.28	28.76	24.78	26.77
Vellanikkara E2	27.53	22.98	25.26	27.55	25.10	26.33	27.54	24.04	25.79
Thodupuzha E3	25.80	2.93	23:22	26.85	24.91	25.73	26.18	22.92	24.48
Mean	27.12	22.70	**24.91**	27.76	25.13	**26.45**	27.49	23.91	**25.70**
C.D for comparison of ecotype means	0.62			0.42			0.32		
C.D for comparison of depth means	1.79			2.45			0.89		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.89

situation. In almost all the months Echippara maintained its superiority over Vellanikkara and Thodupuzha. Pooled analysis also confirmed this result.

Here also shallower depth of soil loosening facilitated higher production of leaves than deeper loosening in both the shade situations. The pooled analysis of data confirmed this result. At the end of fifth month, the mean number of leaves produced under 10 cm soil loosening was 27.49 compared to 23.91 under 20 cm soil loosening depth. Ecotype Echippara had 26.77 number of leaves and Vellanikara had 25.79 while Thodupuzha had 24.48.

4.1.3 North -South foliage Spread per Plant

Tables 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5 show the foliar spread of Kacholam ecotypes in N-S direction. From the tables it could be observed that among the ecotypes Thodupuzha showed more foliage spread in the initial growth period compared to Echippara and Vellanikkara. But in the later stages of growth period all ecotypes performed almost similarly. The same pattern of growth was observed under both shade situations. Pooled analysis further confirmed the result. When soil loosening was restricted to 10 cm, all the ecotypes showed superior performance than deeper depth of loosening, which was confirmed by the pooled data. At the end of fifth month, the mean foliage spread in N-S direction under 10 cm soil loosening was 33.17 cm while it was 26.32 cm when soil was loosened to 20 cm.

4.1.4 East -West Foliage Spread per Plant

The data on foliage spread in E-W direction for five months is given in table's 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5. Similar pattern of foliage spread was noticed in the E-W direction as in N-S foliage spread. Here also ecotype Thodupuzha showed more foliage spread in E-W direction in second month after planting compared to Echippara and Vellanikkara . However, in later months all three ecotypes performed similarly. More or

Table 4.3.1 North South foliage spread per plant (1MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	6.25	5.83	6.23	8.65	7.83	8.24	7.45	6.83	7.24
Vellanikkara E2	6.00	5.33	5.66	8.18	7.43	7.80	7.09	6.38	6.73
Thodupuzha E3	6.65	6.08	6.36	8.08	7.78	7.93	7.37	6.93	7.15
Mean	6.43	5.74	**6.08**	8.30	7.68	**7.99**	7.37	6.71	**7.04**
C.D for comparison of ecotype means	0.05			NS			0.04		
C.D for comparison of depth means	0.45			0.46			0.26		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.22

Table 4.3.2 North south foliage spread per plant (2MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	11.00	9.00	10.00	11.15	9.38	10.26	11.8	9.19	10.13
Vellanikkara E2	9.55	8.23	8.89	9.73	8.53	9.13	9.64	8.38	9.01
Thodupuzha E3	11.35	9.40	10.38	11.68	12.58	12.13	11.51	10.99	11.26
Mean	10.63	8.88	**9.76**	10.85	10.16	**10.51**	10.74	9.52	**10.14**
C.D for comparison of ecotype means	0.52			NS			0.44		
C.D for comparison of depth means	0.44			NS			0.36		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.01

Table 4.3.3 North South foliage spread per plant (3MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	19.53	18.58	19.05	19.25	18.83	19.04	19.39	18.71	19.05
Vellanikkara E2	19.03	18.10	18.56	19.08	18.30	18.69	19.06	18.20	18.63
Thodupuzha E3	19.30	18.73	19.01	19.35	18.83	19.09	19.33	18.78	19.05
Mean	19.28	18.47	**18.87**	19.23	18.65	**18.94**	19.26	18.56	**18.91**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.34			0.43			0.20		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.3.4 North South foliage spread per plant (4MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	24.25	18.93	21.59	24.08	19.48	21.78	24.17	19.18	21.69
Vellanikkara E2	21.18	18.50	19.84	24.00	19.08	21.54	22.59	18.79	20.69
Thodupuzha E3	24.28	20.13	22.00	24.48	21.05	22.76	24.38	20.58	22.38
Mean	23.23	19.18	**21.4**	24.18	19.87	**22.03**	23.71	19.53	**21.59**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	2.53			2.83			2.40		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.3.5 North South foliage spread per plant (5MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	32.65	25.73	29.19	33.18	26.63	29.90	32.92	26.18	29.55
Vellanikkara E2	29.70	23.40	26.55	31.83	24.53	28.18	30.77	23.97	27.37
Thodupuzha E3	36.35	28.23	32.29	35.33	29.43	32.38	35.84	28.83	32.34
Mean	32.9	25.78	**29.34**	33.44	26.86	**30.15**	33.17	26.32	**29.75**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	4.70			3.75			3.23		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.44

Table 4.4.1 East-West foliage spread per plant (1MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	6.53	6.00	6.26	8.23	7.73	7.98	7.38	6.87	7.12
Vellanikkara E2	5.95	5.15	5.55	7.95	7.38	7.66	6.95	6.27	6.61
Thodupuzha E3	6.58	5.85	6.21	7.95	7.53	7.74	7.27	6.69	6.98
Mean	6.35	5.67	**6.01**	8.05	7.54	**7.79**	7.20	6.61	**6.90**
C.D for comparison of ecotype means	0.52			NS			0.27		
C.D for comparison of depth means	0.43			0.36			0.22		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.18

Table 4.4.2 East-West foliage spread per plant (2MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	10.48	9.03	9.75	10.98	9.43	10.2	10.73	9.23	9.98
Vellanikkara E2	9.63	8.30	8.96	9.85	8.13	8.99	9.74	8.22	8.98
Thodupuzha E3	11.10	9.60	10.35	11.20	12.03	11.61	11.15	10.82	10.98
Mean	10.4	8.98	**9.69**	10.68	9.86	**10.27**	10.54	9.42	**9.78**
C.D for comparison of ecotype means	0.23			0.18			0.16		
C.D for comparison of depth means	0.87			NS			0.38		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.03

Table 4.4.3 East-West foliage spread per plant (3MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	19.25	18.20	18.73	18.88	18.65	18.76	19.07	18.43	18.75
Vellanikkara E2	18.90	17.85	18.22	18.88	18.38	18.63	18.89	18.12	18.30
Thodupuzha E3	19.30	18.38	18.63	19.25	18.48	18.86	19.28	18.43	18.75
Mean	19.15	18.14	**18.52**	19.00	18.50	**18.57**	19.08	18.32	**18.64**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	0.40			NS			0.13		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.4.4 East-West foliage spread per plant (4MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	22.00	19.3	20.65	22.63	19.93	21.28	22.32	19.62	20.95
Vellanikkara E2	21.58	18.63	20.10	22.13	19.23	20.68	21.86	18.93	20.39
Thodupuzha E3	24.88	20.65	22.76	23.63	21.33	22.48	24.26	20.99	22.62
Mean	22.82	19.53	**21.17**	22.79	20.16	**21.48**	22.81	19.85	**21.33**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	2.74			2.57			2.32		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.4.5 East-West foliage spread per plant (5MAP) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	34.95	23.95	29.45	34.40	23.43	28.91	34.68	23.69	29.18
Vellanikkara E2	30.33	22.45	26.39	29.05	25.08	27.06	29.69	23.77	26.73
Thodupuzha E3	34.45	29.40	31.93	35.03	29.08	32.05	34.74	29.24	31.99
Mean	33.24	25.27	**29.26**	32.83	25.86	**29.34**	33.04	25.57	**29.3**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	4.01			4.24			NS		
C.D for comparison of ecotype means within depth	NS			NS			3.15		

C.D for comparison of location means : NS

less similar pattern was observed under both shade situation, which was further confirmed by pooled analysis. Throughout the period of observation, shallow depth of soil loosening facilitated more foliage spread than deeper soil loosening. This observation was noticed in each shade situation and in the pooled data.

At the end of fifth month, the mean foliage spread in E-W direction, produced under 10 cm soil loosening was 33.04 cm which was significantly higher than 25.57 cm produced under 20 cm soil loosening. Among the ecotypes, even though there was no significant variation, the ecotype Thodupuzha showed superior performance (31.99 cm) followed by Echippara (29.18 cm) and Vellanikkara (26.73 cm), in the pooled analysis.

4.2 RHIZOME YIELD AND QUALITY COMPONENTS

4.2.1 Fresh Rhizome Yield

Under 70% shade situation, ecotype Thodupuzha produced 28% and 41% more fresh rhizome than the ecotype Echippara and Vellanikkara respectively which were statistically significant (Table 4.5). Shallower depth of loosening (10 cm) significantly encouraged rhizome production, which was 11.2% higher than deeper depth of digging (20 cm). Interaction effects of ecotype and depth of loosening were found to be non significant.

Under 50% shade situation also ecotype Thodupuzha produced significantly higher yield (27.3% and 44.9% higher than Echippara and Vellanikkara ecotypes respectively.). Under this situation also shallower depth of loosening produced higher yield which was 7.7% higher than that was obtained under deeper digging. The interaction effects of depth of loosening and ecotype were not perceptible.

When yield data, under both shade situations were pooled together, fresh rhizome yield showed significant variation due to shading Under 50% shade situation, 11% higher rhizome yield was produced compared to 70% shade situation. Pooled analysis further

Table 4.5 Fresh rhizome yield (tha $^{-1}$) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	5.07	4.53	4.80	5.84	5.29	5.57	5.46	4.91	5.19
Vellanikkara E2	4.25	3.62	3.94	4.33	4.09	4.21	4.29	3.86	4.08
Thodupuzha E3	7.08	6.40	6.74	7.96	7.35	7.66	7.52	6.87	7.20
Mean	5.47	4.85	**5.16**	6.04	5.58	**5.81**	5.75	5.21	**5.49**
C.D for comparison of ecotype means	1.15			1.01			1.27		
C.D for comparison of depth means	0.26			0.12			0.20		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.51

indicated that Thodupuzha ecotype recorded highest yield followed by Echippara and Vellanikkara . Fresh yield of the former was 27.3% and 43.3% higher than Echippara and Vellanikkara ecotypes respectively. The data also showed that, shallower depth produced 9.4% higher yield than deeper depth of soil loosening.

4.2.2 Dry Rhizome Yield

Under 70% shade situation (Table 4.6), dry rhizome yield was not remarkably varied due to the effects of ecotypes, depth of loosening and through interactions. But under 50% shade condition, dry rhizome yield was significantly affected by ecotypes and soil loosening depth. Ecotype Thodupuzha produced significantly higher yield, which was 28.2% and 45.63% higher than that of ecotypes Echippara and Vellanikkara respectively. Dry rhizome yield was significantly affected and it was 8.2% higher when soil was loosened to 10cm depth compared to 20cm.

Pooled data further indicated that (Table 4.6) effect of shading was significant on dry rhizome yield. Dry rhizome yield was significantly higher in the location with 50% shade compared to 70% shade. The dry rhizome yield of 1.55 tonnes per hectare under 50% shade was 11% higher than under 70% shade. Among the ecotypes, Thodupuzha ecotype produced significantly higher yield (1.96 tha^{-1}) followed by Echippara (1.35 tha^{1}) and Vellanikkara (1.11 tha^{-1}) ecotypes.

4.2.3 Dryage Percentage

The recovery of dry rhizome was not significantly affected due to variation in ecotypes, due to depth of soil loosening or the interaction effects of ecotypes and soil loosening under both the shade situations (Table 4.7). Pooled analysis also showed the same trend with respect to shade levels, depth of soil loosening, ecotypes and their interaction effects.

Table 4.6 Dry rhizome yield (tha $^{-1}$) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.29	1.12	1.21	1.47	1.49	1.48	1.38	1.37	1.35
Vellanikkara E2	1.12	1.06	1.09	1.18	1.06	1.12	1.15	1.06	1.11
Thodupuzha E3	1.96	1.75	1.86	2.21	1.91	2.06	2.09	1.83	1.96
Mean	1.46	1.31	**1.39**	1.62	1.49	**1.55**	1.54	1.40	**1.47**
C.D for comparison of ecotype means	NS			0.25			0.10		
C.D for comparison of depth means	NS			0.10			0.08		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.03

Table 4.7 Dryage Percentage as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	25.43	24.63	25.03	25.04	28.07	26.56	25.24	26.35	25.80
Vellanikkara E2	27.13	29.86	28.50	27.11	29.93	28.52	27.12	29.90	28.51
Thodupuzha E3	27.65	27.33	27.49	27.78	26.03	26.91	27.72	26.68	27.20
Mean	26.74	27.27	**27.01**	26.64	26.68	**27.33**	26.69	26.98	**27.17**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

4.2.4 Oleoresin Content

In densely shaded situation (70% shade), ecotype Echippara recorded significantly higher oleoresin content (5.22%) followed by Vellanikkara (4.42%) and Thodupuzha (3.37%) (Table 4.8). Rhizomes contained higher percentage of oleoresin when soil was loosened to 10cm and this was 7.5% higher than in rhizome produced under 20cm.

Under 50 per cent shade also highest oleoresin content was noticed in Echippara (4.22%) followed by Vellanikkara (3.32%) and Thodupuzha (2.55%). Here also shallower depth of loosening increased the oleoresin content of rhizome by 7.4%. compared to deeper digging. Ecotype and soil loosening treatments interacted significantly and higher oleoresin content was produced when ecotype Echippara was grown under shallow depth of soil loosening. All the ecotypes showed higher oleoresin content when soil was loosened to 10 cm.

Pooled analysis indicated that when crop was grown under 70% shade condition, oleoresin content was significantly more than in 50% shade situation. Densely shaded situation recorded 22.5% higher oleoresin content compared to lower shade situation. As observed in individual shade situations, ecotype Echippara recorded highest oleoresin content (4.72%) followed by Vellanikkara (3.57%) and Thodupuzha (3.85%). Interaction effects of depth of loosening and ecotype were non significant. Shallower depth of loosening resulted in 10.3% higher yield than deeper loosening.

4.2.5 Essential Oil Content

Under 70% shade situation (Table 4.9), ecotype Echippara registered highest essential oil content which was 26.4% and 54% more than Vellanikkara and Thodupuzha ecotypes respectively. When the soil was loosened to deeper depth (20 cm), essential oil content was found to be 12.5% more than 15cm soil loosening treatment. Interaction

Table 4.8 Oleoresin Content (%) as influenced by shade, ecotype and soil loosening depth.

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	5.43	4.90	5.22	4.56	3.87	4.22	4.99	4.39	4.72
Vellanikkara E2	4.55	4.30	4.42	3.42	2.23	3.32	3.99	3.27	3.87
Thodupuzha E3	3.44	3.30	3.37	2.86	2.24	2.55	3.15	2.77	2.96
Mean	4.51	4.17	**4.34**	3.61	3.11	**3.36**	4.06	3.64	**3.85**
C.D for comparison of ecotype means	0.50			0.22			0.19		
C.D for comparison of depth means	0.31			0.16			0.14		
C.D for comparison of ecotype means within depth	NS			0.28			NS		

C.D for comparison of location means : 0.25

Table 4.9 Essential Oil Content (%) as influenced by shade, ecotype and soil loosening depth.

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.63	1.86	1.75	1.49	1.68	1.59	1.56	1.77	1.67
Vellanikkara E2	1.20	1.38	1.29	1.09	1.24	1.17	1.15	1.31	1.23
Thodupuzha E3	0.76	0.84	0.80	0.66	0.75	0.71	0.71	0.80	0.76
Mean	1.19	1.36	**1.28**	1.08	1.22	**1.16**	1.14	1.29	**1.22**
C.D for comparison of ecotype means	0.14			0.08			0.03		
C.D for comparison of depth means	0.03			0.04			0.02		
C.D for comparison of ecotype means within depth	0.05			NS			NS		

C.D for comparison of location means : NS

effect of ecotype and soil loosening were also significant. All the ecotypes performed best when soil was loosened to 20 cm.

Under 50% shade situation also a similar trend was observed. Among the ecotypes Echippara produced 26.5% and 43.5% higher yield than ecotypes Vellanikkara and Thodupuzha respectively. Here also deeper soil loosening resulted in 11.4% higher essential oil content in ecotypes compared to shallower digging. The interaction effects of ecotypes and soil loosening were found to be non significant.

Pooled analysis showed that, essential oil content of rhizomes were higher in the situation with 70% shade which was 10.2% higher than that recorded in 50% shade. Essential oil content followed the trend of Echippara > Vellanikkara > Thodupuzha. Essential oil content in Echippara was 25.9% and 54.8% higher than in ecotypes Vellanikkara and Thodupuzha. Soil loosening to 20 cm resulted in higher essential oil content of 1.29% compared to 1.14% essential oil under 10 cm loosening . Interaction effects of ecotype and soil loosening on essential content were non significant.

4.3 ELEMENTAL CONTENTS IN LEAVES AND RHIZOMES

4.3.1 Nitrogen Content of Leaves

In densely shaded situation, ecotype and soil loosening depth did not significantly alter the leaf N content. Interaction effects of soil loosening and ecotypes were also found to be non significant (Table4.10.1).

However, when shade level was reduced to 50%, ecotype and soil loosening depth significantly altered the leaf N content. When soil was loosened to 20 cm depth, leaf N content was found to be 10.5% higher than in shallower depth of soil loosening. Among the ecotypes, Thodupuzha ecotype showed highest leaf N content (1.22%) followed by Echippara (1.16) and Vellanikkara (1.11). Interaction effects were found to be non significant.

Table 4.10.1 Nitrogen content (%) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.13	1.05	1.09	1.16	1.15	1.16	1.15	1.10	1.13
Vellanikkara E2	1.06	1.14	1.10	1.16	1.06	1.11	1.11	1.10	1.11
Thodupuzha E3	1.75	1.25	1.25	1.25	1.19	1.22	1.25	1.22	1.24
Mean	1.14	1.15	**1.15**	1.19	1.33	**1.16**	1.17	1.14	**1.16**
C.D for comparison of ecotype means	NS			0.04			0.02		
C.D for comparison of depth means	NS			0.0489			0.02		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.10.2 Nitrogen content (%) of rhizomes as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.06	1.00	1.03	1.06	1.06	1.06	1.06	1.03	1.05
Vellanikkara E2	1.00	0.94	0.97	1.28	1.01	1.15	1.14	0.98	1.06
Thodupuzha E3	1.11	1.08	1.10	1.15	1.10	1.13	1.13	1.09	1.11
Mean	1.06	1.00	**1.03**	1.16	1.05	**1.11**	1.11	1.03	**1.07**
C.D for comparison of ecotype means	NS			NS			NS		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.03

Pooled analysis showed that shade levels did not significantly affect leaf N content. But variation in ecotype, soil loosening depth and their interaction effects significantly affected the leaf N content. Leaf N content was more under shallow depth of soil loosening (1.17%) compared to deeper depth(1.14%). Among the ecotypes Thodupuzha had highest leaf N content (1.24%) followed by Echippara (1.13%) and Vellanikkara (1.11%), with the latter two remaining on par. All the three ecotypes showed better performance when shallow depth of soil loosening (10 cm) was adopted.

4.3.2 Nitrogen Content of Rhizomes

As observed in case of leaf N content, the N content in rhizomes remained unaltered in spite of difference in ecotype or depth of soil loosening and their interaction effects (Table 4.10.2). This situation prevailed under both the shade situation. Pooled analysis further confirmed the result. However, N content was found to be 7.2% higher in 50% shade than in 70% shade.

4.3.3 Phosphorus Content of Leaves

Under densely shaded situation, phosphorus content in leaves was not significantly affected by treatment effects (Table4.11.1). However, under 50% shade, leaf P content varied significantly due to variation in ecotypes. Ecotype Thodupuzha recorded highest P content (0.53%) followed by Vellanikkara (0.40%) and Echippara (0.34%). No significant variation was observed due to variation in depth of soil loosening and interaction effects of ecotypes and soil loosening depth.

When data were pooled, significant difference was observed in leaf P content due to variation in shade level. P content was 26% higher in50% shade situation compared to 70% shade situation. Ecotypes showed similar trend as shown under 50% shade. Among ecotypes, Thodupuzha recorded highest P content (0.46%) followed by Vellanikkara and Echippara, each recording 0.33% P. Phosphorus content was observed

Table 4.11.1 Phosphorus content (%) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm).	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.33	0.31	0.32	0.34	0.33	0.34	0.34	0.32	0.33
Vellanikkara E2	0.26	0.23	0.25	0.23	0.56	0.40	0.25	0.40	0.33
Thodupuzha E3	0.40	0.36	0.38	0.42	0.63	0.53	0.41	0.50	0.46
Mean	0.33	0.30	**0.32**	0.33	0.51	**0.42**	0.33	0.41	**0.37**
C.D for comparison of ecotype means	NS			0.02			0.02		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.02

to be more(0.41) when soil was loosened to deeper depth compared to shallow depth of loosening (0.33%). However, the difference was not significant.

4.3.4 Phosphorus Content of Rhizomes

Data in Table 4.11.2 showed that as in the case of P content in leaves, P content in rhizomes was also not altered due to treatment effect under densely shaded situation. However, under 50% shade situation, P content showed significant difference due to the effect of ecotype and soil loosening depth. Thodupuzha showed highest content (1.67%) followed by Echippara (1.61%) and Vellanikkara (1.56%). Shallow depth of loosening resulted in more P content (1.46%) compared to deeper digging (1.59%). No significant effect was observed due to interaction effects of ecotype and depth of soil loosening.

Pooled analysis showed that the degree of shade did not affect the P content in rhizomes. Ecotypes and soil loosening showed similar trend as shown under 50% shade. Interaction effects was found to be non significant.

4.3.5 Potassium Content of Leaves

Under 70% shade situation, Thodupuzha recorded highest K content (1.62%) followed by Echippara (1.53%) and Vellanikkara (1.5%) (Table 4.12.1). More K content was recorded in leaves of ecotypes when soil loosening was restricted to 10 cm.

Under 50% shade condition Thodupuzha ecotype contained more K content in leaves than Vellaninkkara but was statistically on par with Echippara. Under this shade situation also, 10cm soil loosening resulted in more content of K in leaves.

Pooled analysis also showed same effect with respect to ecotype and soil loosening depth. Analysis further indicated that when the crop was grown under 50%

Table 4.11.2 Phosphorus content (%) of rhizomes as influenced by shade and soil Loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.156	1.49	1.53	1.64	1.58	1.61	1.60	1.59	1.57
Vellanikkara E2	1.52	1.48	1.50	1.59	1.53	1.56	1.56	1.51	1.53
Thodupuzha E3	1.66	1.58	1.62	1.69	1.65	1.67	1.68	1.62	1.65
Mean	1.58	1.51	**1.55**	1.64	1.59	**1.61**	1.61	1.56	**1.58**
C.D for comparison of ecotype means	NS			0.02			0.02		
C.D for comparison of depth means	NS			0.02			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.12.1 Potassium content (%) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.56	1.49	1.53	1.64	1.58	1.61	1.60	1.54	1.57
Vellanikkara E2	1.52	1.48	1.50	1.59	1.53	1.26	1.56	1.51	1.54
Thodupuzha E3	1.66	1.58	1.62	1.69	1.65	1.67	1.68	1.62	1.65
Mean	1.58	1.51	**1.55**	1.64	1.59	**1.62**	1.61	1.56	**1.59**
C.D for comparison of ecotype means	0.06			0.08			0.01		
C.D for comparison of depth means	0.02			0.01			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.02

shaded condition, leaf K content was significantly more (1.62%) than in 70% shade situation (1.55%).

4.3.6 Potassium Content of Rhizome

Table (4.12.2) indicated that under 70% shade, the ecotype Thodupuzha had the highest K content in rhizome (1.96) which was significantly superior to Echippara and Vellanikkara ecotypes, the later two remaining significantly on par. Shallower depth of soil loosening resulted in 27% higher K content in rhizome than deeper depth of soil loosening. Interaction effects were not significant.

Under 50% shade situation also Thodupuzha contained more K content in rhizome than Echippara and Vellanikkara ecotypes, the latter two having more or less equal content. Effect of soil loosening depth and interaction effects were not significant.

Pooled data indicated that the rhizome contained more K under 50% shade situation (1.89%) than 70% shade situation (1.85%). Highest K content was observed in Thodupuzha (1.98%), which was superior to Echippara (1.83%) and Vellanikkara (1.81%) ecotypes. Shallower depth of soil loosening resulted in 2.1% higher K content compared to deeper loosening depth.

4.3.7 Calcium Content of Leaves

The result obtained under 70% as well as 50% shade situation (Table 4.13.1) revealed that under both the situations, the ecotype Thodupuzha contained more Ca in leaves than ecotypes Echippara and Vellanikkara with the latter two having similar K contents. Shallower depth of soil loosening resulted in higher Ca content in leaves in both the shade situations.

Table 4.12.2 Potassium content (%)of rhizomes as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	1.86	1.79	1.82	1.85	1.82	1.84	1.86	1.80	1.83
Vellanikkara E2	1.79	1.78	1.78	1.83	1.82	1.83	1.81	1.80	1.81
Thodupuzha E3	1.99	1.92	1.96	2.03	1.96	2.00	2.01	1.94	1.98
Mean	1.88	1.83	**1.85**	1.90	1.87	**1.89**	1.89	1.85	**1.87**
C.D for comparison of ecotype means	0.04			0.06			0.03		
C.D for comparison of depth means	0.04			NS			0.02		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.01

Table 4.13.1 Calcium content of (%) leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.75	0.69	0.72	0.71	0.67	0.69	0.73	0.68	0.71
Vellanikkara E2	0.74	0.68	0.71	0.70	0.64	0.67	0.72	0.66	0.69
Thodupuzha E3	0.83	0.76	0.80	0.79	0.74	0.77	0.81	0.75	0.78
Mean	0.77	0.71	**0.74**	0.73	0.68	**0.71**	0.75	0.70	**0.73**
C.D for comparison of ecotype means	0.03			0.05			0.02		
C.D for comparison of depth means	0.01			0.03			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.02

Pooled analysis further confirmed the results. The ecotype Thodupuzha had significantly higher Ca content (0.78%) compared to Echippara and Vellanikkara ecotypes, which were on par. The mean content of Ca was 0.75% when soil was loosened to 10 cm depth compared to 20cm loosening depth where the content was 0.70%. Pooled analysis indicated that more calcium content was concentrated in leaves under 70% shade compared to 50% shade situation.

4.3.8 Calcium Content of Rhizome

Rhizome Ca content showed a very similar pattern to that in the case of leaf Ca content (Table 4.13.2). Under both shade situations, Thodupuzha ecotype showed more Ca content followed by Echippara and Vellanikkara which were on par. Shallower depth of loosening favored more Ca content in rhizomes in both the shade situations.

Pooled data further confirmed the result. The mean Ca content in rhizomes was 0.56% in Thodupuzha which was significantly higher than Echippara and Vellanikkara. The 10 cm depth of soil loosening resulted in 0.58% Ca. in rhizome compared to 0.53% under 20 cm soil loosening. Analysis showed that 70% shade favored accumulation of Ca significantly over 50% shade situation.

4.3.9 Magnesium Content of Leaves

Under both shade situations leaf Mg content varied due to ecotype and soil loosening effects (Table 4.14.1). Both under densely and sparsely shaded situation as well as on pooling of data from both situations, ecotype Echippara accumulated more S content in leaves followed by Thodupuzha and Vellanikkara, which were on par.

Effect of soil loosening was similar under 70% and under pooled condition where shallower depth of loosening resulted in more accumulation of Mg in leaves. However under 50% shade, Mg content in leaves was found to be more or less equal for both soil

Table 4.13.2 Calcium content of rhizome(%) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.57	0.53	0.55	0.54	0.51	0.55	0.56	0.52	0.54
Vellanikkara E2	0.58	0.52	0.54	0.53	0.48	0.51	0.56	0.50	0.53
Thodupuzha E3	0.63	0.58	0.60	0.58	0.54	0.56	0.58	0.53	0.55
Mean	0.58	0.54	**0.56**	0.55	0.51	**0.53**	0.58	0.53	**0.55**
C.D for comparison of ecotype means	0.03			0.04			0.02		
C.D for comparison of depth means	0.01			0.03			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.02

Tabel 4.14.1 Magnesium content (%) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.20	0.18	0.19	0.18	0.16	0.17	0.19	0.17	0.18
Vellanikkara E2	0.12	0.15	0.16	0.14	0.13	0.13	0.13	0.14	0.14
Thodupuzha E3	0.18	0.16	0.17	0.14	0.13	0.14	0.16	0.15	0.15
Mean	0.18	0.16	**0.17**	0.15	0.14	**0.15**	0.17	0.15	**0.16**
C.D for comparison of ecotype means	0.15			0.02			0.01		
C.D for comparison of depth means	0.01			0.01			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.01

loosening treatments. Pooled analysis indicated that densely shaded situation favored more Mg accumulation in leaves.

4.3.10 Magnesium Content of Rhizomes

Under 70% and 50% shade as well as in pooled analysis the results showed that ecotype Echippara recorded highest Mg content in rhizome followed by Vellanikkara and Thodupuzha (Table 4.14.2). Mg content was more or less equal whether the depth of soil loosening was 10 cm or 20 cm in 50% shade condition. However, under 70% shade deeper depth of loosening resulted in higher Mg accumulation in rhizomes which was again confirmed in pooled analysis. Pooled analysis further indicated that Mg content in rhizome was 0.19% under 70% shade situation, which significantly differed from 0.17% observed under 50% shade.

4.3.11 Sulphur Content of Leaves

Sulphur content of leaves showed similar trend under both the shade situation as well as when the data was pooled (Table 4.15.1.). In all the cases only the ecotype exerted its influence on leaf S content. Under both shade conditions Echippara recorded highest S content and the least content was seen in the Thodupuzha ecotype. Pooled analysis showed that Echippara ecotype had 0.18% S while Vellanikkara had 0.16% and Thodupuzha had 0.13%.

4.3.12 Sulphur Content of Rhizomes

Table (4.15.2) showed that in both shade situations as well as in pooled analysis, S content in rhizome varied significantly due to difference in ecotypes. Among the ecotypes, Echippara and Vellanaikkara accumulated more content of S in rhizome than Thodupuzha in both shade situations.

Table 4.14.2 Magnesium content (%) of rhizome as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.21	0.22	0.22	0.18	0.19	0.19	0.20	0.20	0.20
Vellanikkara E2	0.17	0.20	0.19	0.15	0.17	0.16	0.16	0.19	0.18
Thodupuzha E3	0.15	0.17	0.16	0.14	0.15	0.15	0.5	0.16	0.16
Mean	0.18	0.20	**0.19**	0.16	0.17	**0.17**	0.17	0.18	**0.18**
C.D for comparison of ecotype means	0.01			0.02			0.01		
C.D for comparison of depth means	0.07			0.01			0.01		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 0.01

Table 4.15.1 Sulphur content (%) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.20	0.17	0.19	0.18	0.18	0.18	0.19	0.18	0.18
Vellanikkara E2	0.16	0.15	0.16	0.15	0.15	0.15	0.16	0.15	0.16
Thodupuzha E3	0.12	0.11	0.12	0.13	0.15	0.14	0.13	0.13	0.13
Mean	0.16	0.14	**0.16**	0.15	0.16	**0.16**	0.16	0.15	**0.16**
C.D for comparison of ecotype means	0.01			0.02			0.01		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Table 4.15.2 Sulphur content (%) of rhizomes as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	0.38	0.39	0.38	0.29	0.33	0.31	0.34	0.36	0.35
Vellanikkara E2	0.33	0.37	0.35	0.32	0.33	0.33	0.33	0.35	0.34
Thodupuzha E3	0.22	0.24	0.23	0.20	0.21	0.21	0.21	0.23	0.22
Mean	0.31	0.33	**0.32**	0.28	0.28	**0.28**	0.29	0.30	**0.30**
C.D for comparison of ecotype means	0.02			0.04			0.02		
C.D for comparison of depth means	0.01			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : NS

Effect of soil loosening depth was significant only under 70% shade situation and non-significant under 50% shade and under pooled condition. Under 70% shade situation, 20 cm depth loosening favored more accumulation of S in rhizome. Pooled analysis further confirmed the effect of ecotypes. It also indicated that shade situation as well as soil loosening depth did not cause significant variation in rhizome S content.

4.3.13 Manganese Content of Leaves

Under 70% shade, ecotype Echippara registered significantly higher Mn content in leaf which was 18.3% and 32.3% higher than ecotypes Velannikkara and Thodupuzha respectively (Table 4.16.1). Deeper depth of loosening resulted in significantly higher Mn content (546ppm) compared to shallower depth of loosening (511ppm). Same trend was seen in 50% shade condition. Under this situation, ecotype Echippara registered 24.2% and 38.5% higher Mn content compared to Vellanikkara and Thodupuzha ecotypes respectively. Effects of soil loosening were not significant.

Pooled analysis showed that 70% shade situation resulted in 18.24% higher Mn content in leaves compared to 50% shade situation. The pooled data indicated that Echippara registered highest Mn content (592ppm) followed by Vellanikkara (467ppm) and Thodupuzha (383ppm). Deeper depth of soil loosening resulted in 4.2% higher Mn content than shallower depth of loosening. Interaction effect was not significant.

4.3.14 Manganese Content of Rhizomes

The ecotype Echippara registered 21.4% and 28.48% higher Mn content than Vellanikkara and Thodupuzha ecotype respectively in densely shaded situation (Table 4.16.2). However, effects of soil loosening and interaction effects of ecotypes and soil loosening were non significant.

Table 4.16.1 Manganese content (ppm) of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	628.75	645.25	637.00	539.75	555.00	547.38	584.25	600.13	597.19
Vellanikkara E2	491.75	548.75	520.25	408.25	420.25	414.50	450	484.5	467.38
Thodupuzha E3	415.00	446.75	430.83	328.25	344.75	336.50	371.63	395.75	383.69
Mean	511.83	546.92	**529.38**	429.58	436.00	**432.79**	470.71	491.46	**481.09**
C.D for comparison of ecotype means	34.86			36.88			19.40		
C.D for comparison of depth means	23.26			NS			15.87		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 14.53

Table 4.16.2 Manganese content (ppm) of rhizome as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	556.00	6.5.0	580.50	348.75	432.00	390.38	452.38	518.50	485.44
Vellanikkara E2	451.50	461.00	456.25	366.50	380.25	373.38	409.00	420.63	414.81
Thodupuzha E3	411.25	419.00	415.13	298.50	300.50	299.50	354.88	359.75	357.31
Mean	472.92	495.00	**483.96**	337.92	370.92	**354.42**	405.42	432.96	419.19
C.D for comparison of ecotype means	31.06			69.15			25.95		
C.D for comparison of depth means	NS			19.65			21.19		
C.D for comparison of ecotype means within depth	NS			34.04			NS		

C.D for comparison of location means : 16.44

Under 50% shade situation, Echippara registered 4.3% and 24.2% higher Mn content in rhizomes than ecotypes Vellanikkara and Thodupuzha respectively. When soil was loosened to deeper depth, higher Mn content in rhizome was observed (370 ppm) compared to shallow depth of loosening (337 ppm). All the ecotypes performed better when soil was loosened to 20 cm depth.

Pooled analysis indicated that 70% shade favored higher Mn content in rhizomes (483 ppm) compared to 50% shade (354 ppm). Highest Mn content was observed in Echippara ecotype followed by Vellanikkara and Thodupuzha ecotypes. Deeper depth of soil loosening favored more Mn content in rhizome.

4.3.15 Iron Content of Leaves

Analysis of individual shade situations and the pooled data showed that Fe content in leaves varied only due to ecotype effect (Table 4.17.1). Under both shade situations Vellanikkara and Echippara ecotypes accumulated more Fe in leaves than Thodupuzha ecotype. The mean content of Fe in leaves was 910 ppm in Vellanikkara 902 ppm in Echippara and 344 ppm in Thodupuzha ecotype. Pooled analysis further showed that more leaf Fe content was observed under 50% shade (908 ppm) compared to 70% shade (863 ppm).

4.3.16 Iron Content of Rhizomes

Under 70% shade, there was no significant difference in iron content in rhizome due to effects of ecotype, soil loosening or their interaction effects Table (4.17.2). Under 50% shade, ecotype Echippara showed highest content (805 ppm) and Thodupuzha (693ppm), the least. Under 50% shade,. ecotype Echippara showed highest content (805 ppm) and Thodupuzha (693 ppm). Pooled analysis further confirmed the result. Analysis further indicated that 50% shade favored more iron content (750 ppm) in rhizome compared to 70% shade (684 ppm). Effects of soil loosening depth and interaction were not significant.

Table 4.17.1 Iron content of leaves (ppm) as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	886.25	874.75	880.50	918.75	931.25	925.00	902.25	903.00	902.75
Vellanikkara E2	899.25	889.50	894.38	921.25	930.25	925.75	910.25	909.88	910.06
Thodupuzha E3	809.00	823.75	816.38	863.00	883.75	873.38	836.38	853.75	844.88
Mean	864.83	862.67	**863.75**	901.00	915.08	**908.04**	882.92	886.88	**885.89**
C.D for comparison of ecotype means	50.68			44.38			23.81		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means :12.82

Table 4.17.2 Iron content of rhizome (ppm) as influenced by shade, ecotype and soil loosening depth.

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	714.50	750.50	732.50	800.25	810.00	805.13	757.38	780.25	768.82
Vellanikkara E2	702.25	732.75	717.50	748.00	756.50	752.25	725.13	744.63	734.88
Thodupuzha E3	599.00	608.75	603.88	683.25	703.00	693.13	641.13	655.88	648.51
Mean	671.92	697.33	**684.63**	743.83	756.50	750.17	**707.88**	726.92	717.40
C.D for comparison of ecotype means	NS			23.09			21.90		
C.D for comparison of depth means	NS			NS			NS		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 10.18

4.3.17 Zinc Content of Leaves

Under 70% shade (Table4.18.1), ecotype effect and the interaction effect of ecotype and soil loosening resulted in variation in Zn content in leaf. Ecotype Echippara registered significantly higher Zn content (85 ppm) followed by Vellanikkara ecotype (79 ppm) and the Thodupuzha ecotype(66ppm). Highest Zn content of leaves (89 ppm) was recorded when Echippara ecotype was grown under 20cm soil loosening depth.

Under 50% shade also, ecotype Echippara recorded highest Zn content which was superior to Vellanikkara and Thodupuzha ecotypes. When soil was loosened to deeper depth, Zn content was formed to be more (74 ppm) than shallower depth of loosening (67ppm).

Pooled analysis also showed the same trend with respect to effect of ecotype and depths of soil loosening. The analysis further confirmed that more Zn content was recordedunder 70% shade (77 ppm) than under 50% shade (70 ppm).

4.3.18 Zinc Content of Rhizome

Table (4.18.2) revealed that under 70% shade, significantly higher Zn content in rhizome was observed in ecotypes Echippara (60ppm) which was superior to Vellanikkara ecotype (60ppm) and Thodupuzha ecotype (47ppm). When soil was loosened to 20 cm depth, Zn content significantly increased by 8%.

Under 50% shade situation, ecotype Echippara showed 12.9% and 29.7% higher Zn content than ecotypes Vellanikkara and Thodupuzha respectively. Soil loosening depth and interaction effects were not significant. Pooled analysis showed that 70% shade favoured higher Zn content (54ppm) than 50% shade 42.21%. Among ecotypes, Echippara recorded highest Zn content (55 ppm). When soil was loosened to 20cm

Table 4.18.1 Zinc content (ppm)of leaves as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	82	89.75	85.88	72.5	78.75	75.63	77.25	84.25	80.75
Vellanikkara E2	76.25	80	79.13	70.25	73	71.65	74.25	76.50	75.38
Thodupuzha E3	65.78	63	66.38	59.50	70.75	65.13	62.64	66.88	65.75
Mean	76.67	77.58	**77.13**	66.42	74.14	**70.79**	72.04	75.88	73.96
C.D for comparison of ecotype means	5.09			5.33			3.03		
C.D for comparison of depth means	NS			6.42			2.47		
C.D for comparison of ecotype means within depth	3.92			NS			2.05		

C.D for comparison of location means : 2.04

Table 4.18.2 Zinc content (ppm)of rhizome as influenced by shade, ecotype and soil loosening depth

Ecotypes	70% shade			50% shade			Pooled over shade levels		
	D1 (10cm)	D2 20(cm)	Mean	D1 (10cm)	D2 (20cm)	Mean	D1 (10cm)	D2 (20cm)	Mean
Echippara E1	58.75	62.50	60.63	99.00	51.25	50.13	53.88	56.88	55.38
Vellanikkara E2	51.00	59.50	55.25	39.75	43.50	41.63	45.38	51.38	48.44
Thodupuzha E3	47.00	48.50	47.75	33.75	36.00	34.88	40.38	42.25	41.31
Mean	52.25	56.83	**54.54**	40.83	43.58	**42.21**	46.54	50.21	**48.38**
C.D for comparison of ecotype means	5.10			4.87			2.86		
C.D for comparison of depth means	3.14			NS			2.33		
C.D for comparison of ecotype means within depth	NS			NS			NS		

C.D for comparison of location means : 2.08

depth, Zn content was 7.3% more than shallower depth of loosening (10 cm). Interaction effects were not significant.

4.4 SOIL NUTRIENT STATUS

Data on soil nutrient content before planting and after the harvest of the crop at the two shade levels are presented in Table 4.19. A higher content was noted in the top 10 cm of soil for all nutrients. A decrease in nutrient content was generally observed after cropping. The depletion was higher in the case of K and Ca, working out to 8.7 and 4.2 per cent in the top 10 cm layer and 5.5 per cent and 0.63 per cent in the next 10 cm layer, in the two shade levels respectively. Corresponding figures for Ca were 25 and 20.8 per cent in the top 10 cm and 31.3 and 1.5 per cent in the 10 to 20 cm layer depth of soil. However, the organic carbon content registered a slight increase in both the soil depths after the harvest of the crop.

4.5 PATH ANALYSIS

Individual step down regression analysis was done to find out the optimal subgroup of variables that influence the various quantity and quality parameters. Using this optimal subgroup of variables, path coefficient analysis was separately carried out.

Firstly step down regression analysis was done to know the important chemical constituents in plants, which had significantly influenced the various quantity, and quality parameters at both shade levels. Four important dependent characters were taken for the study viz., fresh rhizome yield, dry rhizome yield, oleoresin content and essential oil content. The results of analysis are as follows:

Table 4.19 Soil Nutrient Composition

Nutrients	Soil Depth	S1 (70% Shade)		S2 (50% Shade)	
		Pre harvest ($kgha^{-1}$)	Post harvest ($kgha^{-1}$)	Pre harvest ($kgha^{-1}$)	Post harvest ($kgha^{-1}$)
Nitrogen ($kgha^{-1}$)	10cm	255.85	238.75	257.70	241.55
	20cm	249.75	235.65	253.85	239.20
Phosphorus ($kgha^{-1}$)	10cm	18.0	17.5	20.65	18.75
	20cm	14.5	13.8	17.80	17.0
Potassium ($kgha^{-1}$)	10cm	290.65	265.40	285.50	273.50
	20cm	275.50	260.45	270.20	268.5
Calcium ($kgha^{-1}$)	10cm	134.40	100.70	113.20	89.60
	20cm	112.0	77.20	78.40	77.20
Magnesium ($kgha^{-1}$)	10cm	89.60	89.60	77.20	77.20
	20cm	77.20	77.20	44.80	44.80
Sulphur ($kgha^{-1}$)	10cm	158.60	155.75	160.25	158.50
	20cm	165.35	163.50	167.5	161.25
Iron ($kgha^{-1}$)	10cm	815.50	810.50	745.5	738.0
	20cm	748.0	747.50	725	723.0
Manganese ($kgha^{-1}$)	10cm	135.50	131.50	128.5	120.0
	20cm	128.20	126.0	120.5	118.5
Zinc ($kgha^{-1}$)	10cm	2.5	2.1	1.5	1.3
	20cm	2.0	1.9	1.2	1.0
Organic Carbon (%)	10cm	0.53	0.56	0.5	0.54
	20cm	0.48	0.49	0.46	0.47

4.5.1 At 70 Per Cent Shade Level

4.5.1.1 Correlation with Fresh Rhizome Yield

The path coefficient study revealed that maximum positive direct contribution was by dry rhizome yield (1.0051), followed by S in rhizomes (0.5045), P in leaves (0.4484) and Mg in rhizomes (0.3876). Mn in leaves (-0.7234) showed highest negative direct effect followed by S in leaves (-0.2786) and Zn in rhizomes (-0.2240) (Table 4.20.1.1).

Comparing the values of correlation coefficient, P and Ca content of leaves and K content of rhizomes showed high positive correlation with yield as also did the dry rhizome yield probably due to positive indirect effect of P and Mn in leaves and dry rhizome yield. However, other elements viz., Mn in leaves, Mg in rhizomes and S and Zn in leaves and rhizomes were negatively correlated with fresh rhizome yield. Oleoresin content was also highly correlated negatively with yield. This may be due to negative indirect effect of P, Mn and S in leaves, Zn in rhizomes and dry rhizome yield.

4.5.1.2 Correlation with Dry Rhizome Yield

Maximum direct and positive contribution to dry rhizome yield was by fresh rhizome yield (0.7047) followed by Mn in leaves (0.6673), K in leaves (0.2464) and Ca in leaves (0.2454). Mg in rhizome showed highest negative direct contribution (-0.327) followed by Mg in leaves (-0.2245), oleoresin percentage (-0.2176) and low negative direct contribution by Zn in leaves (-0.1656) followed by P in leaves (-0.1396) (Table 4.20.1.2).

The net effect of fresh rhizome yield was found to be significantly positive possibly because of its own direct effect, reinforced by indirect positive effect of K and Ca in leaves, Mg in rhizomes and oleoresin content of rhizomes. Similarly, correlation coefficient values were highly positive for P, K and Ca in leaves which was enhanced by

Table 4.20.1.1. Direct and indirect effect of fresh rhizome yield determining factors at 70% shade level

	P in leaves	K in rhizomes	S in leaves	S in rhizome	Ca in leaves	Mg in leaves	Mg in rhizomes	Mn in leaves	Zn in leaves	Zn in rhizomes	Oleorisin	Dry rhizome yield	rc
P in leaves	**0.4484**	-0.1308	0.0926	-0.3370	-0.1059	0.0812	-0.1294	0.1975	-0.0771	0.0779	-0.0689	0.6928	0.7413**
K in rhizomes	0.3515	**-0.1668**	0.1597	-0.4078	-0.1292	0.0500	-0.2523	0.4180	-0.1082	0.1291	-0.1098	0.8322	0.7665**
S in leaves	-0.1491	0.0956	**-0.2786**	0.4009	0.0629	0.0824	0.2670	-0.5587	0.1159	-0.1455	0.1630	-0.6582	-0.6023**
S in rhizomes	-0.2994	0.1348	-0.2214	**0.5045**	0.1286	0.0202	0.2978	-0.6101	0.1365	-0.1770	0.1585	-0.8403	-0.7672**
Ca in leaves	0.2836	-0.1287	0.1046	-0.3874	**-0.1675**	0.0658	-0.2176	0.4435	-0.1015	0.1513	-0.0858	0.7543	0.7146**
Mg in leaves	0.1725	-0.0395	-0.1088	0.0483	-0.0522	**0.2111**	0.0304	-0.2530	0.0359	-0.0267	0.0722	0.0182	0.1085
Mg in rhizomes	-0.1497	0.1085	-0.1919	0.3877	0.0940	0.0166	**0.3876**	-0.6129	0.1039	-0.1650	0.1366	-0.5947	-0.4794**
Mn in leaves	-0.1224	0.0964	-0.2152	0.4255	0.1027	0.0738	0.384	**-0.7234**	0.1294	-0.1774	0.1591	-0.6254	-0.5486**
Zn in leaves	-0.2063	0.1077	-0.1927	0.4111	0.1015	0.0453	0.2404	-0.5588	**0.1676**	-0.1614	0.1402	-0.6775	-0.5831**
Zn in rhizomes	-0.1560	0.0961	-0.1810	0.3988	0.1132	0.0251	0.2856	-0.5732	0.1208	**-0.2240**	0.1275	-0.6525	-0.6196**
Oleorisin	-0.1518	0.0900	-0.2234	0.3933	0.0707	0.0750	0.2603	-0.5661	0.1155	-0.1404	**0.2034**	-0.6279	-0.5015**
Dry rhizome yield	0.3090	-0.1381	0.1825	-0.4218	-0.1257	0.0038	-0.2293	0.4502	-0.1130	0.1454	-0.1270	**1.0051**	0.9411**

Residual : 0.0155

Table 4.20.1.2. Direct and indirect effect of dry rhizome yield determining factors at 70% shade level

	P in	K in	Ca in	Mg in	Mg in	Mn in	Zn in	Oleoresin	Fresh	rc
P in leaves	**-0.1396**	0.1619	0.1553	-0.0864	0.1081	-0.1822	0.0762	0.0737	0.5224	0.6893**
K in leaves	-0.0917	**0.2464**	0.1943	-0.0440	0.1813	-0.3786	0.0871	0.0957	0.5553	0.8458**
Ca in leaves	-0.0883	0.1951	**0.2454**	-0.0701	0.1817	-0.4091	0.1003	0.0918	0.5036	0.7504**
Mg in leaves	-0.0537	0.0482	0.0766	**-0.2246**	-0.0254	0.2334	-0.0355	-0.0773	0.0765	0.0181
Mg in rhizomes	0.0466	-0.1380	-0.1378	-0.0176	**-0.3237**	0.5654	-0.1027	-0.1461	-0.3378	-0.5917**
Mn in leaves	0.0381	-0.1398	-0.1505	-0.0786	-0.2742	**0.6673**	-0.1279	-0.1703	-0.3866	-0.6223**
Zn in leaves	0.0643	-0.1297	-0.1487	-0.0482	-0.2007	0.5154	**-0.1655**	-0.1500	-0.4109	-0.6741**
Oleoresin	0.0473	-0.1084	-0.1036	-0.0798	-0.2174	0.5222	-0.1141	**-0.2176**	-0.3534	-0.6247**
Fresh rhizome	-0.1035	0.1941	0.1754	-0.0244	0.1552	-0.3661	0.0965	0.1091	**0.7047**	0.9411**

Residual : 0.0208

indirect positive effect of fresh rhizome yield and their own direct effect.

However, Mg in leaves and rhizomes, Mn in leaves, Zn in leaves and oleoresin percentage were found negatively correlated with dry rhizome yield which was supplemented by negative indirect effect of all other parameters except P and Mn in leaves and their own direct effects. The positive direct effect of Mn in leaves was counteracted by negative indirect effect of Mg in rhizomes, Zn in leaves, oleoresin percentage and fresh rhizome yield so that the net effect was negative.

4.5.1.3 Correlation with Oleoresin Content

Essential oil content had maximum positive direct effect on oleoresin content (1.3215) followed by Ca in rhizome (0.4386) and N in rhizomes (0.4132). Maximum negative direct effect was by P in leaves (-0.4707) followed by Mn in rhizomes (-0.2273) (Table 4.20.1.3.). Correlation coefficient value showed high positive values for Mn in rhizomes, and essential oil content. Even though N in rhizomes and Ca in rhizomes showed a positive direct effect, it was marginalized by the negative indirect effect of essential oil content and P in leaves, resulting in a net negative effect. Similarly, the net effect of P in leaves was also found to be negative possibly because of its own direct and indirect effects of essential oil content.

4.5.1.4 Correlation with Essential Oil Content

Path analysis revealed that Mn in rhizomes had maximum direct positive contribution to essential oil content (0.4507) followed by Zn in rhizomes (0.3286), oleoresin percentage (0.3094) and S in leaves (0.1925). The maximum direct negative contribution was by S in rhizomes (-0.3829) followed by Ca in rhizomes (-0.2849) and N in rhizomes(-0.1391) (Table 4.20.1.4).

S content of leaves and rhizomes, Mn and Zn contents in rhizomes and oleoresin

Table 4.20.1.3. Direct and indirect effect of oleoresin determining factors at 70% shade level

	N in rhizome	P in leaves	Ca in rhizome	Mn in rhizome	Essential oil	rc
N in rhizome	**0.4132**	-0.3106	0.2624	0.0395	-0.6395	-0.2349
P in leaves	0.2726	**-0.4707**	0.3311	0.0260	-0.4977	-0.3386*
Ca in rhizome	0.2364	-0.3398	**0.4586**	0.0897	-0.8130	-0.3680*
Mn in rhizome	-0.0719	0.0539	-0.1810	**-0.2273**	1.1297	0.6985**
Essential oil	-0.1999	0.1772	-0.2821	-0.1934	**1.3218**	0.8237**

Residual : 0.1764

Table 4.20.1.4. Direct and indirect effect of essential oil determining factors at 70% shade level

	N in rhizome	S in leaves	S in rhizome	Ca in rhizome	Mn in rhizome	Zn in rhizome	Oleoresin	rc
N in rhizome	**-0.1391**	-0.0681	0.2117	-0.1630	-0.0789	-0.1742	-0.0727	-0.4838**
S in leaves	0.0492	**0.1925**	-0.3043	0.0919	0.2999	0.2135	0.2481	0.7857**
S in rhizome	0.0769	0.1530	**-0.3829**	0.2104	0.3123	0.2597	0.2412	0.8706**
Ca in rhizome	-0.0796	-0.0621	0.2827	**-0.2849**	-0.1778	-0.1795	-0.1139	-0.6150**
Mn in rhizome	0.0242	0.1260	-0.2653	0.1124	**0.4507**	0.1867	0.2161	0.8509**
Zn in rhizome	0.0737	0.1251	-0.3026	0.1556	0.2561	**0.3286**	0.1940	0.8305**
Oleorisin	0.0327	0.1544	-0.2985	0.1048	0.3148	0.2061	**0.3094**	0.8237**

Residual : 0.1624

content favourably affected essential oil content in densely shaded situation. This was supplemented by indirect positive influence of all other parameters except S in rhizomes. N and Ca had mutually inhibitory effect, which was reflected in the net correlation value.

4.5.2 At 50 Per Cent Shade Level

4.5.2.1 Correlation with Fresh Rhizome Yield

Data in Table 4.20.2.1 showed that essential oil content had highest direct positive effect (1.2493) followed by P in rhizomes (0.8626), K in leaves (0.5995) and Mn in leaves (0.3399). K in rhizomes (0.2343) and Zn in rhizomes (0.155) had medium direct positive effect. Maximum negative direct effect was shown by oleoresin content (-0.8368) followed by Mg in rhizomes (-0.8263), Mn in rhizomes (-0.5933) and N in leaves (-0.4703). Dry rhizome yield (-0.4314), S in rhizome (-0.2384), S in leaves (-0.1393) and iron in leaves (-0.1019) had medium negative direct effect.

Correlation coefficient values revealed that major nutrients had high positive relation with fresh rhizome yield possibly due to enhanced indirect effect of P in rhizomes, K in leaves, Mg and Mn in rhizomes. The positive indirect effect of P and Mn in rhizomes, K in leaves and oleoresin content nullified the negative direct effect of dry rhizome yield, which resulted in a net positive effect. However, secondary and minor nutrients and quality components had negative correlation with rhizome yield. S and Mn in rhizomes and Fe in leaves had highest negative correlation with yield. This may be possibly due to negative indirect effects through Mg and Mn in rhizomes, oleoresin content, K in leaves and rhizome, P in rhizomes and their own direct effect.

4.5.2.2 Correlation with Dry Rhizome Yield

The maximum direct positive contribution to dry rhizome yield was by P in rhizome (0.5685) followed by K in leaves (0.4809) and essential oil content (0.4802) and the maximum direct negative contribution was by oleoresin percentage (-0.5636) followed by Mg in rhizomes (-0.1967) (Table 4.20.2.2).

Table 4.20.2.1. Direct and indirect effect of fresh rhizome yield determining factors at 70% shade level

	N in leaves	P in rhizomes	K in leaves	K in rhizome	S in leaves	S in rhizome	Mg in rhizome	Mn in leaves	Mn in rhizome	Iron in leaves	Zn in rhizome	Essential oil	Oleoresin	Dry rhizome yield	rc
N in leaves	**-0.4703**	0.5290	0.4076	0.1510	0.0099	0.1387	0.3485	-0.1164	0.3265	0.0266	-0.0486	-0.5806	0.2539	-0.2875	0.6883**
P in rhizome	-0.2884	**0.8626**	0.4395	0.1437	0.0159	0.1469	0.1301	-0.0714	0.2406	0.0561	-0.0499	-0.4844	0.1171	-0.3645	0.8940**
K in leaves	-0.3197	0.6324	**0.5995**	0.1423	0.0191	0.1180	0.2244	-0.1147	0.3503	0.0434	-0.0621	-0.6402	0.1942	-0.3606	0.8263**
K in rhizome	-0.3030	0.5291	0.3640	**0.2343**	0.0382	0.1797	0.4692	-0.1975	0.2262	0.0519	-0.0866	-0.8778	0.4804	-0.3349	0.7682**
S in leaves	0.0334	-0.0985	-0.0820	-0.0642	**-0.1393**	-0.0893	-0.4113	0.2314	-0.2122	-0.0217	0.1098	0.8175	-0.4403	0.1183	-0.2486
S in rhizome	0.2735	-0.5314	-0.2968	-0.1766	-0.0522	**-0.2384**	-0.2824	0.1792	-0.2559	-0.0533	0.0681	0.8198	-0.4896	0.3068	-0.7292**
Mg in rhizome	0.1984	-0.1358	-0.1628	-0.1396	-0.0694	-0.0815	**-0.8263**	0.2323	-0.1338	-0.0294	0.1165	0.9485	-0.4278	0.1468	-0.3559**
Mn in leaves	0.1610	-0.1812	-0.2023	-0.1361	-0.0948	-0.1257	-0.5646	**0.3399**	-0.3665	-0.0419	0.1360	1.1332	-0.6970	0.1940	-0.4460**
Mn in rhizome	0.2587	-0.3498	-0.3540	-0.0893	-0.0498	-0.1028	-0.1863	0.2100	**-0.5933**	-0.0391	0.0920	0.7986	-0.4090	0.2287	-0.5855**
Iron in leaves	0.1229	-0.4746	-0.2555	-0.1194	-0.0297	-0.1246	-0.2382	0.1399	-0.2273	**-0.1019**	0.0906	0.7215	-0.3163	0.2272	-0.5855**
Zn in rhizome	0.1372	-0.2584	-0.2234	-0.1218	-0.0918	-0.0974	-0.5777	0.2775	-0.3277	-0.0554	**0.1666**	1.0254	-0.5562	0.2095	-0.4937**
Essential oil	0.2186	-0.3344	-0.3072	-0.1646	-0.0912	-0.1564	-0.6274	0.3083	-0.3793	-0.0589	0.1367	**1.2493**	-0.6709	0.2536	-0.6238**
Oleoresin	0.1427	-0.1207	-0.1391	-0.1345	-0.0733	-0.1395	-0.4225	0.2831	-0.2900	-0.0355	0.1107	1.0016	**-0.8368**	0.2029	-0.4539**
Dry rhizome yield	-0.3134	0.7288	0.5011	0.1819	-0.0382	0.1696	0.2813	-0.1529	0.3146	0.0537	-0.0809	-0.7345	0.3936	**-0.4319**	0.9496**

Residual : 0.0104

Table 4.20.2.2. Direct and indirect effect of dry rhizome yield determining factors at 70% shade level

	P in rhizome	K in leaves	Mg in rhizome	Essential oil	Oleoresin	Rc
P in rhizome	**0.5686**	0.3525	0.0310	-0.1862	0.0789	0.8448**
K in leaves	0.4169	**0.4809**	0.0534	-0.2461	0.1308	0.8359**
Mg in rhizome	-0.0896	-0.1306	**-0.1967**	0.3646	-0.2882	-0.3404*
Essential oil	-0.2205	-0.2464	-0.1493	**0.4802**	-0.4519	-0.5879**
Oleoresin	-0.796	-0.1116	-0.1006	0.3850	**-0.5636**	-0.4704**

Residual : 0.0679

High positive correlation coefficients of 0.8448 and 0.8359 were obtained with P in rhizomes and K in leaves respectively probably due to their own direct and indirect effects. However, Mg in rhizomes, essential oil and oleoresin contents were negatively related to dry rhizome yield and the negative relation was marginally supplemented by Mg and P in rhizomes, K in leaves and oleoresin content.

4.5.2.3 Correlation with Oleoresin Content

Among the characters studied, the essential oil content showed highest positive direct contribution to oleoresin content (1.662) followed by P in rhizome (0.9176), K in leaves (0.6658) and Mn in leaves (0.4334) (Table 4.20.2.3). K in rhizomes (0.2990) and Zn in rhizomes (0.2887) had medium positive direct effect. The maximum negative direct effect was by Mg in rhizomes (-0.9959) followed by fresh rhizome yield (-0.9425) and Mn in rhizomes (-0.6930).

Major nutrients and fresh and dry rhizome yield had manifested high negative correlation with oleoresin content because of very high negative effect of essential oil content, fresh rhizome yield and N and Mn in leaves. However, secondary nutrients, minor nutrients and essential oil content had shown positive correlation with oleoresin content possibly due to high positive indirect effect of essential oil content, nitrogen in leaves, fresh and dry rhizome yield, Mn in leaf and Zn in rhizome.

4.5.2.4 Correlation with Essential Oil Content

Path analysis showed that Mg in rhizome (0.5569) had maximum positive direct effect followed by oleoresin content (0.5682), fresh rhizome yield (0.5293), Mn in rhizomes (0.4066), dry rhizome yield (0.3253) and N in leaves (0.3101). S in leaves (0.1637) and rhizomes (0.1187) and iron in rhizome (0.1131) and leaves

Table 4.20.2.3. Direct and indirect effect of oleoresin determining factors at 70% shade level

	N in leaves	P in rhizome	K in leaves	K in rhizome	S in leaves	S in rhizome	Mg in rhizome	Mn in leaves	Mn in rhizome	Iron in leaves	Iron in rhizome	Zn in rhizome	Essential oil	Fresh rhizome yield	Dry rhizome yield	rc
N in leaves	**-0.5298**	0.5629	0.4525	0.1926	0.0195	0.1134	0.4201	-0.1484	0.3816	0.0375	0.0727	-0.0842	-0.7725	-06488	-0.3724	-0.3034**
P in rhizome	-0.3249	**0.9178**	0.4879	0.1834	0.0313	0.1201	0.1568	-0.0910	0.2812	0.0790	0.0641	-0.0865	-0.6444	-0.8427	-0.4721	-0.1399
K in leaves	-0.3602	0.6728	**0.6655**	0.1815	0.0375	0.0965	0.2704	-0.1462	0.4095	0.0612	0.0846	-0.1076	-0.8517	-0.7789	-0.4671	-0.2321
K in rhizome	-0.3414	0.5630	0.4041	**0.2990**	0.0751	0.1469	0.5599	-0.2517	0.2644	0.0732	0.1099	-0.1501	-1.1680	-0.7241	-0.4338	-0.5741**
S in leaves	0.0376	-0.1048	-0.0911	-0.0819	**-0.2741**	-0.0730	-0.4957	0.2950	-0.2480	-0.0306	-0.0726	-0.1902	1.0877	0.2343	0.1532	0.5262**
S in rhizome	0.3082	-0.5653	-0.3294	-0.2253	-0.1027	**-0.1950**	-0.3404	0.2284	-0.2992	-0.0751	-0.1126	-0.1180	1.0907	0.6873	0.3974	0.5851**
Mg in rhizome	0.2235	-0.1445	-0.1807	-0.1679	-0.1364	-0.0666	**-0.9959**	0.2961	-0.1564	-0.0414	-0.1079	0.2019	1.2620	0.3355	0.1902	0.5113**
Mn in leaves	0.1814	-0.1928	-0.2245	-0.1737	-0.1866	-0.1028	-0.6805	**0.4334**	-0.4284	-0.0591	-0.1486	0.2357	1.5078	0.4204	0.2513	0.8330**
Mn in rhizome	0.2915	-0.3722	-0.3929	-0.1140	-0.0980	-0.0841	-0.2246	-0.2677	**-0.6935**	-0.0550	-0.1062	0.1595	1.0625	0.5519	0.2962	0.4888**
Iron in leaves	0.1384	-0.5049	-0.2836	-0.1523	-0.0584	-0.1019	-0.2871	0.1783	-0.2657	**-0.1436**	-0.1043	0.1570	0.9600	0.5518	0.2943	0.3780**
Iron in rhizome	0.2045	-0.3126	-0.2991	-0.1744	-0.1057	-0.1165	-0.5709	0.3421	-0.3911	-0.0795	**-0.1883**	0.2106	1.3821	0.5085	0.2642	0.6739**
Zn in rhizome	0.1546	-0.2749	-0.2480	-0.1554	-0.1806	-0.7970	-0.6963	-0.3538	-0.3831	-0.0781	-0.1374	**0.2887**	1.3643	0.4653	0.2714	0.6646**
Essential oil	0.2462	-0.3558	-0.3410	-0.2101	-0.1794	-0.1279	-0.7562	0.3931	-0.4433	-0.0829	-0.1566	0.2370	**1.6622**	0.5880	0.3285	0.8018**
Fresh rhizome yield	-0.3647	0.8205	0.5499	0.2297	0.0681	0.1422	0.3545	-0.1933	0.4060	0.0841	0.1016	-0.1425	-1.0369	**-0.9425**	-0.5306	-0.4539**
Dry rhizome yield	-0.3531	0.7754	0.5563	0.2321	0.0752	0.1387	0.3390	-0.1949	0.3677	0.0756	0.0891	-0.1402	-0.9772	-0.8950	**-0.5588**	-0.4704**

Residual: 0.0052

(0.0893) had low positive direct effect. Negative direct effects were observed with P, K and Zn in rhizomes and K in leaves (Table 4.20.2.4).

Correlation coefficient values indicated that major nutrients and fresh and dry rhizome yields were negatively correlated with essential oil content probably because of negative indirect effect of P, Mg and Mn in rhizomes, K in leaves and oleoresin content. Contrary to this, the secondary nutrients, minor nutrients and oleoresin content had shown positive correlation with essential oil content and the probable reason may be the positive direct effect of P, Mg and Mn in rhizomes and oleoresin content.

4.5.3 Pooled Over Shade Levels

Pooled analysis of the same variables was then done for both locations together to identify those with maximum influence on quantity and quality parameters. The dependent variables were the fresh rhizome yield, dry rhizome yield, essential oil content and oleoresin content.

4.5.3.1 Correlation with Fresh Rhizome Yield

Path analysis showed that P in rhizome had highest positive direct effect (0.4436) followed by Mn in leaves (0.4020), K in leaves (0.3539) and P in leaves (0.1997). Highest direct negative influence was registered by essential oil content (-0.3443) followed by Zn in rhizome (-0.1460) and S in leaves (-0.1174) (Table 4.20.3.1),(Fig. 3.1.)

Correlation coefficient values revealed that major nutrients had positive correlation with fresh rhizome yield which could be attributed to positive indirect effect of essential oil content, P in leaves and rhizome and K and S in leaves. However, S and Mn in leaves, Zn in rhizomes and essential oil content had shown negative correlation with fresh rhizome yield possibly as a result of negative indirect effect of P and K in

Table 4.20.2.4. Direct and indirect effect of essential oil determining factors at 70% shade level

	N in leaves	P in rhizome	K in leaves	K in rhizome	S in leaves	S in rhizome	Mg in rhizome	Mn in leaves	Mn in rhizome	Iron in leaves	Iron in rhizome	Zn in rhizome	Oleoresin	Fresh rhizome	Dry rhizome	rc
N in leaves	0.3101	-0.3181	-0.2625	-0.1133	-0.0116	-0.0690	-0.2476	0.0794	-0.2237	-0.0233	-0.0438	0.0499	-0.1724	0.3644	0.2169	-0.4648**
P in rhizome	0.1902	-0.5187	-0.2831	-0.1079	-0.0187	-0.0731	-0.0924	0.0487	-0.1649	-0.0491	-0.0387	0.0513	-0.0795	0.4732	0.2750	-0.3877**
K in leaves	0.2108	-0.3803	-0.3862	-0.1068	-0.0224	-0.0587	-0.1594	0.0782	-0.2401	-0.0380	-0.0510	0.0638	-0.1319	0.4374	0.2721	-0.5124**
K in rhizome	0.1998	-0.3182	-0.2345	-0.1758	-0.0449	-0.0894	-0.3297	0.1346	-0.1550	-0.0455	-0.0662	-0.0890	-0.3262	0.4067	0.2527	-0.7027**
S in leaves	-0.0220	0.0593	0.0529	0.0482	0.1637	0.0444	0.2921	-0.1577	0.1454	0.0190	0.0438	-0.1128	0.2990	-0.1316	-0.0893	0.6544**
S in rhizome	-0.1804	0.3195	0.1912	0.1325	0.0613	0.1187	0.2006	-0.1221	0.1754	0.0467	0.0679	-0.0699	0.3325	-0.3860	-0.2315	0.6562**
Mg in rhizome	-0.1308	0.0817	0.1049	0.0988	0.0815	0.0406	0.5869	-0.1583	0.0917	0.0257	0.0651	-0.1197	0.2905	-0.1884	-0.1108	0.7593**
Mn in leaves	-0.1062	0.1089	0.1303	0.1022	0.1114	0.0625	0.4010	-0.2317	0.2512	0.0367	0.0896	-0.1397	0.4737	-0.2361	-0.1464	0.9071**
Mn in rhizome	-0.1706	0.2204	0.2280	0.0671	0.0585	0.0512	0.1324	-0.1432	0.4066	0.0342	0.0640	-0.0945	0.2777	-0.3099	-0.1726	0.6392**
Iron in leaves	-0.0810	0.2854	0.1646	0.0896	0.0349	0.0620	0.1692	-0.0954	0.1558	0.0893	0.0629	-0.0931	0.2148	-0.3099	-0.1714	0.5776**
Iron in rhizome	-0.1197	0.1767	0.1736	0.1026	0.0631	0.0701	0.3364	-0.1829	0.2293	0.0494	0.1135	-0.1248	0.3829	-0.2856	-01539	0.8315**
Zn in rhizome	-0.0905	0.1554	0.1439	0.0914	0.1079	0.0485	0.4104	-0.1892	0.2246	0.0485	0.0828	-0.1711	0.3776	-0.2613	-0.1581	0.8208**
Oleoresin	-0.0941	0.0726	0.0896	0.1010	0.0861	0.0694	0.3001	-0.1930	0.1988	0.0337	0.0765	-0.1137	0.5682	-0.2403	-0.1531	0.8018**
Fresh rhizome yield	0.2135	-0.4637	-0.3191	-0.1351	-0.0407	-0.0865	-0.2089	0.1033	-0.2381	-0.0523	0.0613	0.0845	-0.2979	0.5293	0.3091	-0.6238**
Dry rhizome yield	0.2067	-0.4382	-0.3228	-0.1365	-0.0449	-0.0844	-0.1998	0.1042	-0.2156	-0.0470	-0.0537	0.0831	-0.2673	0.5027	0.3255	-0.5879**

Residual: 0.0018

Table 4.20.3.1. Direct and indirect effect of fresh rhizome yield determining factors (Pooled over location)

	N in rhizome	P in leaves	P in rhizome	K in leaves	S in leaves	Mn in leaves	Zn in rhizome	Essential oil	rc
N in rhizome	-0.0879	0.0136	0.1172	0.0805	0.0267	-0.1202	0.0550	0.1041	0.1889
P in leaves	-0.0060	0.1997	0.1456	0.1502	0.0251	-0.2736	0.0944	0.1797	0.5151**
P in rhizomes	-0.0232	0.0655	0.4436	0.2336	0.0310	0.1140	0.0467	0.1335	0.8167**
K in leaves	-0.0200	0.0847	0.2928	0.3539	0.0322	-0.2281	0.0867	0.1984	0.8006**
S in leaves	-0.0200	-0.0427	-0.1171	-0.0971	-0.1174	0.2421	-0.0640	-0.2426	-0.4189**
Mn in leaves	-0.0263	-0.1359	-0.1258	-0.2008	-0.0707	0.4020	-0.1234	-0.3032	-0.5316**

Residual : 0.1339

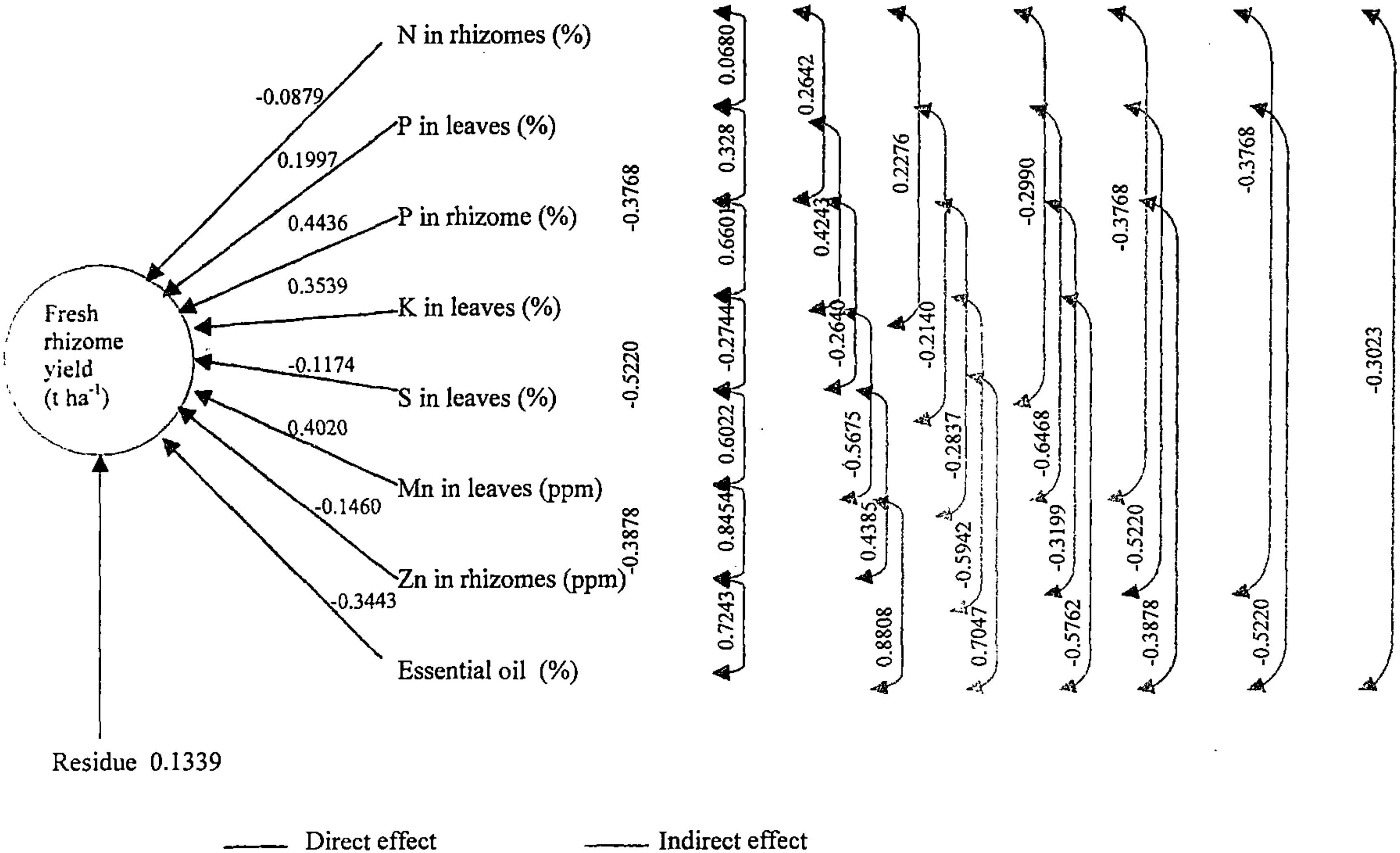


Fig. 3.1. Direct and indirect effect of fresh rhizome yield (t ha^{-1}) determining factors pooled over locations

leaves, P and Zn in rhizomes and essential oil content.

4.5.3.2 Correlation with Dry Rhizome Yield

Data in Table 4.20.3.2 and Fig. 3.2 shows that the fresh rhizome yield had maximum positive direct effect (0.6709) on yield. This was followed by K in rhizomes (0.2631), Ca in leaves (0.2121), Fe in rhizomes (0.2073) and P in rhizomes (0.1014). Major direct negative influence was exerted by Mg in leaves (-0.2656), followed by P in leaves (-0.1646), N in rhizomes (-0.1280) and Fe in leaves (-0.0845).

Correlation coefficient value was highest for fresh rhizome yield (0.9478), P in rhizomes (0.7821) and Ca in leaves (0.6680). Highest negative correlation was obtained for Fe in rhizomes and leaves followed by Mg in leaves. The indirect effect of fresh rhizome yield, K in rhizome and Ca in leaves contributed significantly to high positive correlation of N, P, K in rhizome, P and Ca in leaves and fresh rhizome yield with dry rhizome yield. The net effect due to Mg in leaves and Fe in leaves turned out to be negative mainly due to indirect effect of fresh rhizome yield and their own direct effect. The positive direct effect of iron in rhizomes was neutralized by negative effect of K in rhizomes, Ca in leaves and fresh rhizome yield and thus resulted in a net negative effect. More than 95 per cent of the process of dry rhizome yield formation could be explained by the influence of the independent variables selected for the analysis (Fig3.2).

4.5.3.3 Correlation with Oleoresin Content

Data in Table 4.20.3.3 and Fig. 3.3 revealed that essential oil content exerted highest positive direct effect (0.5403) on oleoresin content followed by S in rhizomes (0.459), Ca in rhizomes (0.2708) and Mg in leaves (0.2179). Major direct negative effect was shown by Fe in rhizomes (-0.2015) followed by N in leaves (-0.0766)(Table 4.20.3.3)(Fig3.3). Highest positive correlation was obtained for essential oil content

Table 4.20.3.2. Direct and indirect effect of dry rhizome yield determining factors. (pooled over location)

	N in rhizome	P in leaves	P in rhizome	K in rhizome	Ca in leaves	Mg in leaves	Iron in leaves	Iron in rhizome	Fresh rhizome yield	rc
N in rhizome	**-0.1280**	-0.0112	0.0268	0.0826	0.0209	0.0592	0.0046	-0.0017	0.1268	0.1799
P in leaves	-0.0087	**-0.1646**	0.0333	0.1369	0.0163	0.1377	0.0004	-0.0164	0.3456	0.4804**
P in rhizomes	-0.0338	-0.0540	**0.1014**	0.1773	0.1267	-0.0420	0.0350	-0.0753	0.5479	0.7821**
K in rhizome	-0.0402	-0.0857	0.0683	**0.2631**	0.1271	0.0189	0.0374	-0.1026	0.5196	0.8060**
Ca in leaves	-0.0126	-0.0126	0.0606	0.1577	**0.2121**	-0.0676	0.0397	-0.1303	0.4210	0.6680**
Mg in leaves	0.0285	0.0854	0.0164	-0.0187	0.0540	**-0.2656**	0.0145	-0.0020	-0.0519	-0.1393
Iron in leaves	0.0070	0.0007	-0.0419	-0.1164	-0.0998	0.0457	**-0.0845**	0.1467	-0.2505	-0.3930**
Iron in rhizome	0.0010	0.0131	-0.0368	-0.1302	-0.1332	0.0025	-0.0598	**0.2073**	-0.2778	-0.4140**
Fresh rhizome yield	-0.0242	-0.0848	0.0828	0.2038	0.1331	0.0205	0.0316	-0.0859	**0.6709**	0.9478**

Residual : 0.0489

Table 4.20.3.3. Direct and indirect effect of oleoresin determining factors (Pooled over location)

	N in leaves	N in rhizome	S in rhizome	Ca in rhizome	Mg in leaves	Iron in rhizome	Essential oil	rc
N in leaves	**-0.0766**	0.0245	-0.3024	0.1352	-0.0216	0.0892	-0.3325	-0.4893**
N in rhizome	-0.0188	**0.0997**	-0.1213	0.0514	-0.0486	0.0016	-0.1633	-0.1993
S in rhizome	0.0505	-0.0263	**0.4591**	-0.1378	0.0464	0.0842	0.4186	0.7182**
Ca in rhizome	-0.0383	0.0189	-0.2336	**0.2708**	0.0827	0.0016	-0.2264	-0.0078
Mg in leaves	0.0076	-0.0222	0.0977	0.1028	**0.2179**	-0.0922	0.2316	0.6373**
Iron in rhizome	0.0320	-0.008	0.2100	-0.1588	-0.021	**-0.2015**	0.3272	0.2061
Essential oil	0.0220	0.0266	0.2430	0.0016	0.2153	0.0385	**0.5403**	0.7709**

Residual : 0.1409

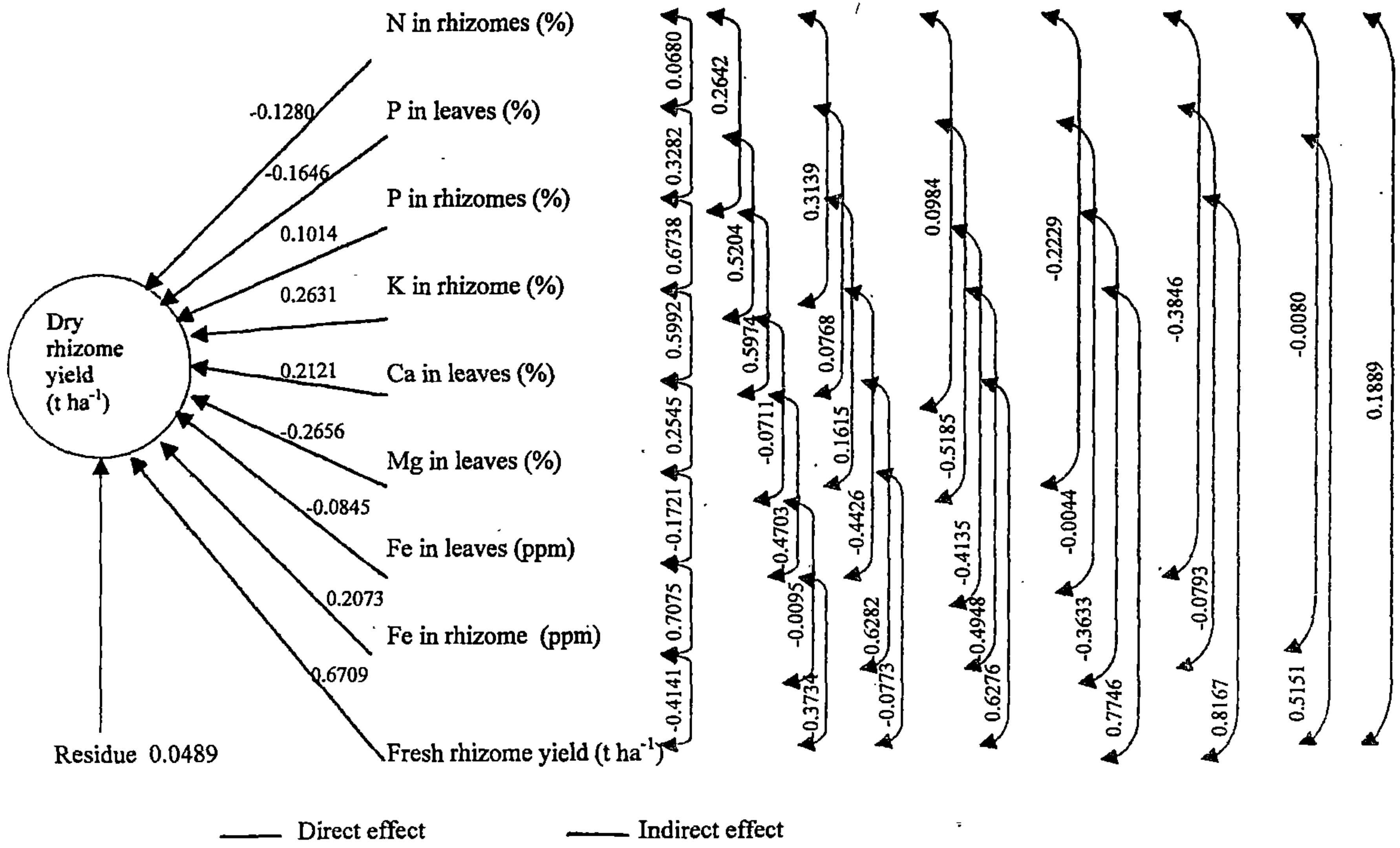


Fig. 3.2. Direct and indirect effect of dry rhizome yield (t ha^{-1}) determining factors pooled over locations

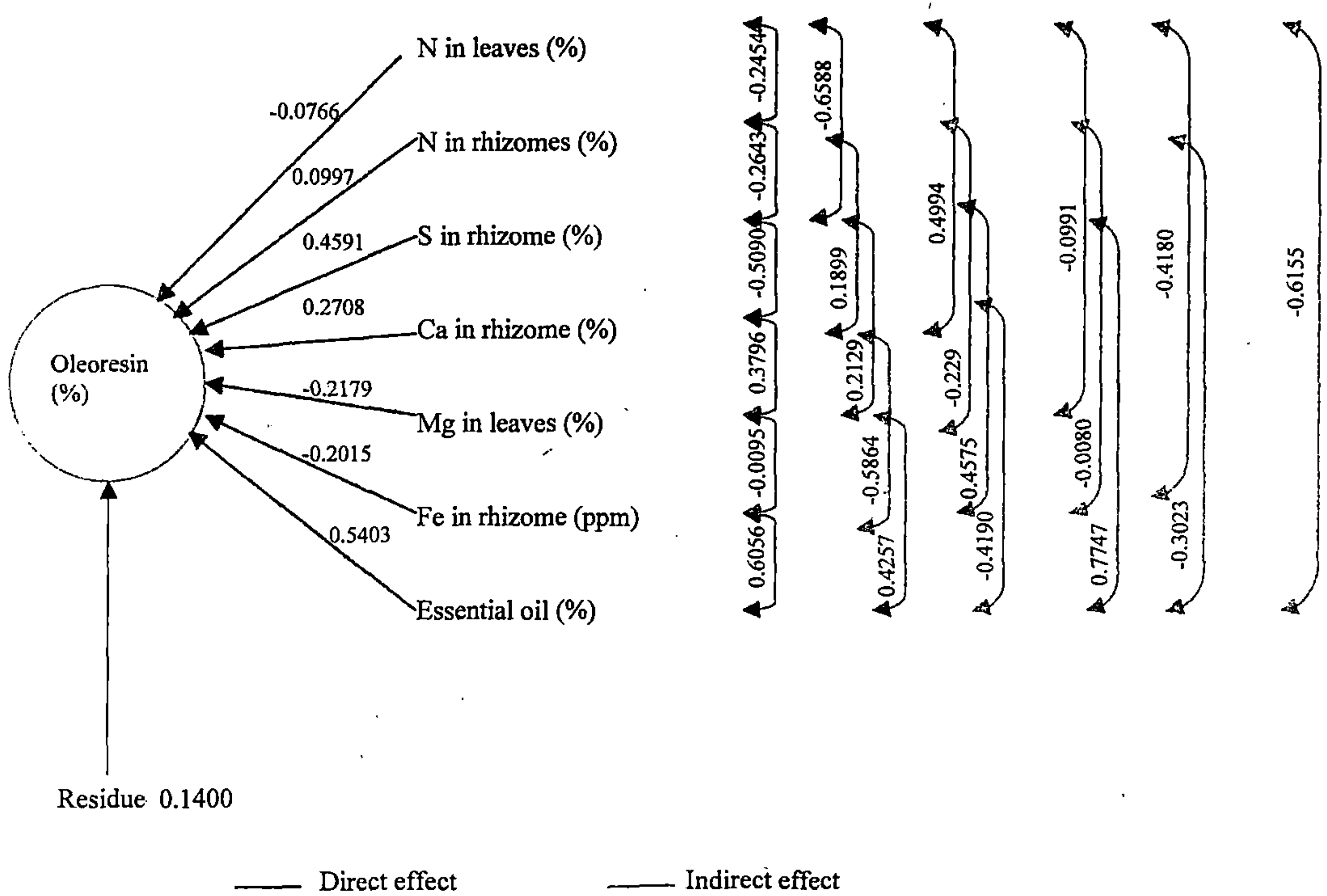


Fig. 3.3. Direct and indirect effect of oleoresin (%) determining factors pooled over locations

(.7709) followed by S in rhizome (0.7182); Mg in leaves (0.6373) and iron in rhizome (0.2061). This could be attributed to the positive indirect effect of essential oil content and their own direct positive effect. The net effect of N in leaves and rhizomes and Ca in rhizomes was found negative due to the indirect effect of essential oil content and S in rhizomes.

4.5.3.4 Correlation with Essential Oil Content

Highest positive direct effect on essential oil content was attributed to the Mn content of the leaves (0.4102). This was followed by the oleoresin content and iron and magnesium content in rhizomes. Direct negative influence was exerted only by Ca in rhizomes (-0.1618) and in leaves (-0.0932) (Table 4.20.3.4) and (Fig. 3.4.).

Highest correlation coefficient value was obtained for Mn in leaves (0.8808) followed by Mg in rhizomes (0.7855) and oleoresin content (0.7709). Correlation coefficient for S in leaves was 0.7057, while for Fe in rhizomes it was 0.6056. The positive correlation of these factors with essential oil percentage may probably due to the positive indirect effect of Mg and Fe in rhizomes, Mn in leaves and oleoresin content. Ca in leaves and rhizomes had negative influence on essential oil content, followed by P in the rhizomes which could be attributed to negative indirect effect due to Ca and Fe in rhizomes and Mn in leaves. A low residual value of 0.0751 indicated that most of the independent variables affecting essential oil production in rhizomes had been included in the path coefficient analysis.

Table 4.20.3.4. Direct and indirect effect of essential oil determining factors (pooled over location)

	P in rhizome	S in leaves	Ca in leaves	Ca in rhizome	Mg in rhizome	Mn in leaves	Iron in rhizome	Oleoresin	rc
P in rhizome	**0.0529**	-0.0218	-0.0557	-0.0803	-0.0387	-0.1164	-0.0682	-0.0598	-0.3878**
S in leaves	-0.0140	**0.0825**	0.0305	0.0509	0.0816	0.2470	0.0989	0.1273	0.7047**
Ca in leaves	0.0316	-0.0270	**-0.0932**	-0.1103	-0.0484	-0.1183	-0.1170	-0.0397	-0.5232**
Ca in rhizome	0.0262	-0.0259	-0.0635	**-0.1618**	-0.0299	-0.0523	-0.1101	-0.0018	-0.4190**
Mg in rhizome	-0.0133	0.0439	0.0294	0.0316	**0.1531**	0.3340	0.0494	0.1574	0.7855**
Mn in leaves	-0.0150	0.0497	0.0269	0.0206	0.1247	**0.4102**	0.0700	0.1937	0.8808**
Iron in rhizome	-0.0192	0.0435	0.0555	0.0948	0.0403	0.1531	**0.1877**	0.0469	0.6056**
Oleoresin	-0.0139	0.0461	0.0162	0.0013	0.1059	0.3489	0.0387	**0.2277**	0.7709**

Residual : 0.0751

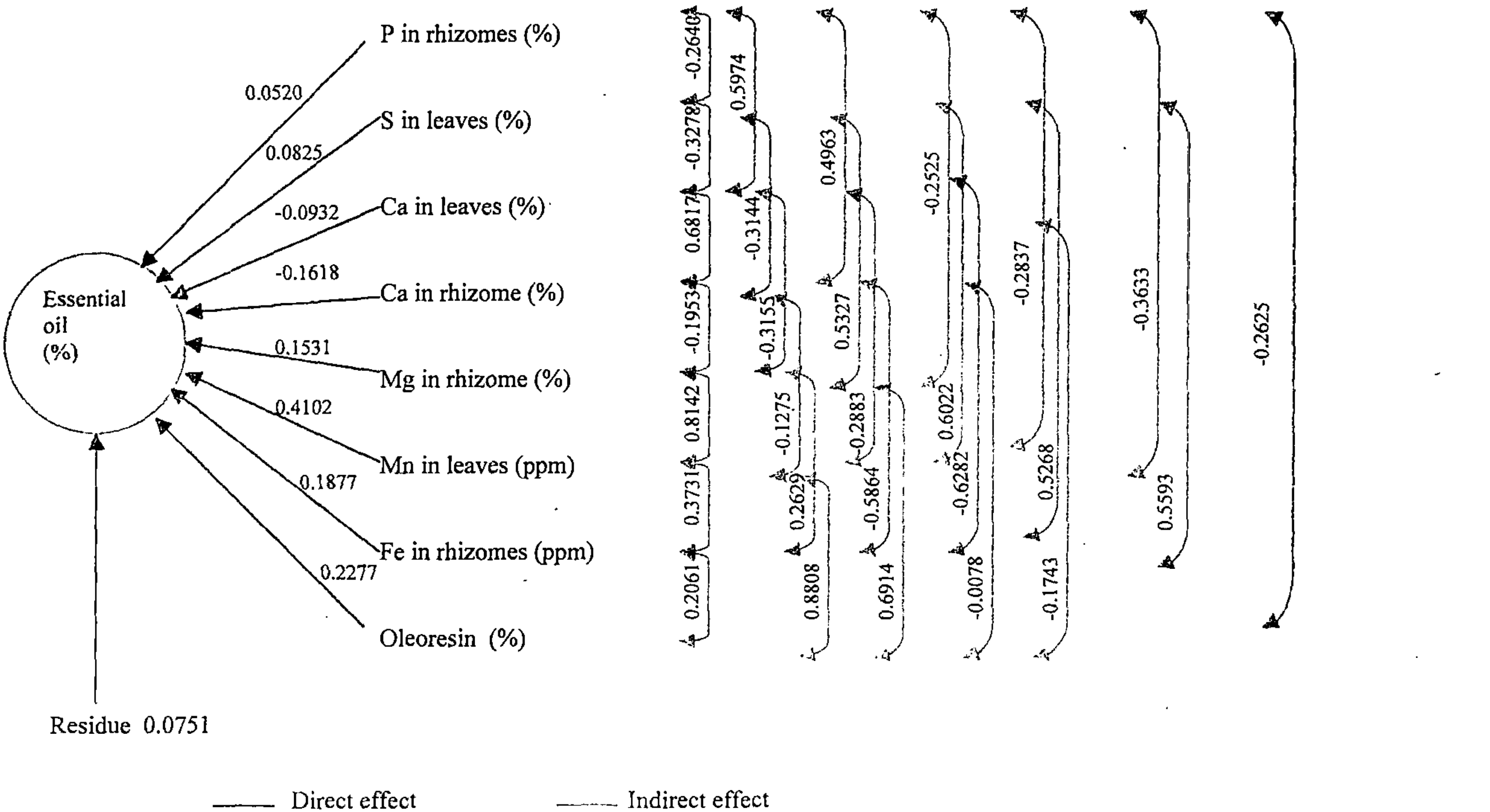


Fig. 3.4. Direct and indirect effect of essential oil (%) determining factors pooled over locations

DISCUSSION

5.DISCUSSION

The research results obtained in the study on "Soil plant shade interaction on the productivity of Kacholam (*Kaempferia galanga* L.) conducted during 2001-2002 at Agricultural Research Station, Mannuthy are discussed in this chapter.

5.1 VEGETATIVE GROWTH

Kaempferia galanga grown in two situations, similar except for the level of shade imposed by intercropping in coconut gardens of two age groups, did not show significant variation in the vegetative characters studied (Table 4.1.1 to 4.4.5). The degree of light penetrating under 50 per cent or 70 per cent shade situation was not a significant factor affecting leaf and shoot production and spread of leaves under shaded conditions. Open conditions, however, have been reported to increase the number of leaves produced and spread of leaves as compared to shaded situation (Latha, 1994).

The ecotype grown, however, had a pronounced effect on the rate of increase of shoot and leaf number and the foliage spread. The Echippara ecotype was found to perform better than the other two ecotypes in production of shoots and leaves. The leaves produced, however, were observed to be narrower (Plate 1). However, when foliage spread was considered, the Thodupuzha ecotype was found to exert its superiority. Thus the Echippara ecotype was observed to produce more number of smaller, narrower leaves while the Thodupuzha ecotype was characterized by less number of bigger, broader leaves and the Vellanikkara ecotype was found to resemble the former.

Expanded vegetative structure is a sign of quantitative development in any crop, and this is evident from the high rhizome yield in ecotype Thodupuzha (Table 4.5). Expanded leaf surface area for more effective photosynthesis is substantiated in this

a

b

c

Plate 1. Kacholam ecotypes

a. Echippara
b. Vellanikkara
c. Thodupuzha

ecotype which produced 28 per cent and 43.5 per cent more fresh rhizome yield than the Echippara and Vellanikkara ecotypes respectively. Production of photosynthates and their conversion to qualitative components occur in plants of qualitative value. Here, the structural development is meant only for re-synthesizing the secondary product from the primary product, and leaf and shoot development is likely to be less. This is evident in the Echippara and Vellanikkara ecotypes, which produced higher contents of oleoresin and essential oil. Hence, more number of smaller leaves in medicinal plants can be linked to higher quality.

Soil loosening is related to nutrient availability in two ways. Loosening to deeper depths will facilitate leaching of elements to lower layers of soil, and this is particularly significant in laterite soils where microelements like Fe and Mn, present in large quantities, adversely affect yield expression in crops like rice. The upper layer of soil is subject to air entry, and subsequent oxidation of some elements like Fe may occur, making them unavailable to plants. In deeper layers, reduced environment prevails, and these elements are therefore rendered more available to plants. Thus,oxidative unavailability rules the upper layer of soil, this character is conveyed to lower layers by loosening the soil to greater depths. Soil loosening is also of significance in rhizome forming crops like *Kaempferia*, as it facilitates physically, the formation of these underground structures.

Loosening of soil restricted to the top 10 cm was found to promote the development of vegetative characters. Increased availability of Fe and Mn in laterite soils has been reported to interfere with N metabolism in crops leading to inhibited growth and yield process (Musthafa,1995; Bridgit,1999). Oxidation of these elements into unavailable forms thus promotes utilization of absorbed N and development of vegetative structures and yield. Increasing the depth of soil loosening was found to produce a negative effect on development of vegetative characters. Planting of Kacholam was done after the onset of the south-west monsoon and loosening of soil to lower depths would have facilitated leaching of N, reflected in the lower N content and subsequent poorer vegetative growth.

5.2 YIELD- QUANTITATIVE AND QUALITATIVE

Yield of a crop is two dimensional, consisting of quantity and quality, and it is the net effect of the influence of climate and soil on its physiology and metabolism. Quantity and quality should both be combined in a plant and one should not be allowed to develop at the expense of the other. Synchronized progressive development is necessary to ensure optimum levels of both.

Data in Table 4.5. and Fig. 4.1 showed that shading significantly affected the rhizome yield, with less shade promoting higher yield. Though the influence on vegetative development was negligible, the intensity of sunlight received had a significant bearing on the photosynthate accumulation in rhizomes. Increased yields in situations of higher light incidence as compared to shaded areas have been reported in *Kaempferia* (Latha,1994) as well as in other rhizomatous crops like mango ginger (Jayachandran and Nair, 1998) and turmeric (Ramadasan and Satheesan, 1980). The effect on qualitative components, viz., oleoresin and essential oil, was the reverse, with the highly shaded situation recording higher contents of both (Fig. 4.2). This inverse relationship has been observed in a number of medicinal plants (Pareek and Gupta, 1985, Yadav et al., 1982, Dey and Choudhari, 1984) and is only to be expected as secondary products result from the breakdown and re-synthesis of primary products.

Anatomical study of the leaf revealed that Kacholam is a C_4 plant, a fact which has to be further confirmed by enzymatic studies (Plate 2). The presence of typical bundle sheath cells with chloroplasts and closely arranged mesophyll cells were confirmed (Bidwell, 1979). The C4 pathway is a pre-addition to the Calvin cycle which promotes carbon dioxide utilization. In Kacholam, primary photosynthates in the leaves are broken down and translocated to the rhizomes where they are re-synthesised as

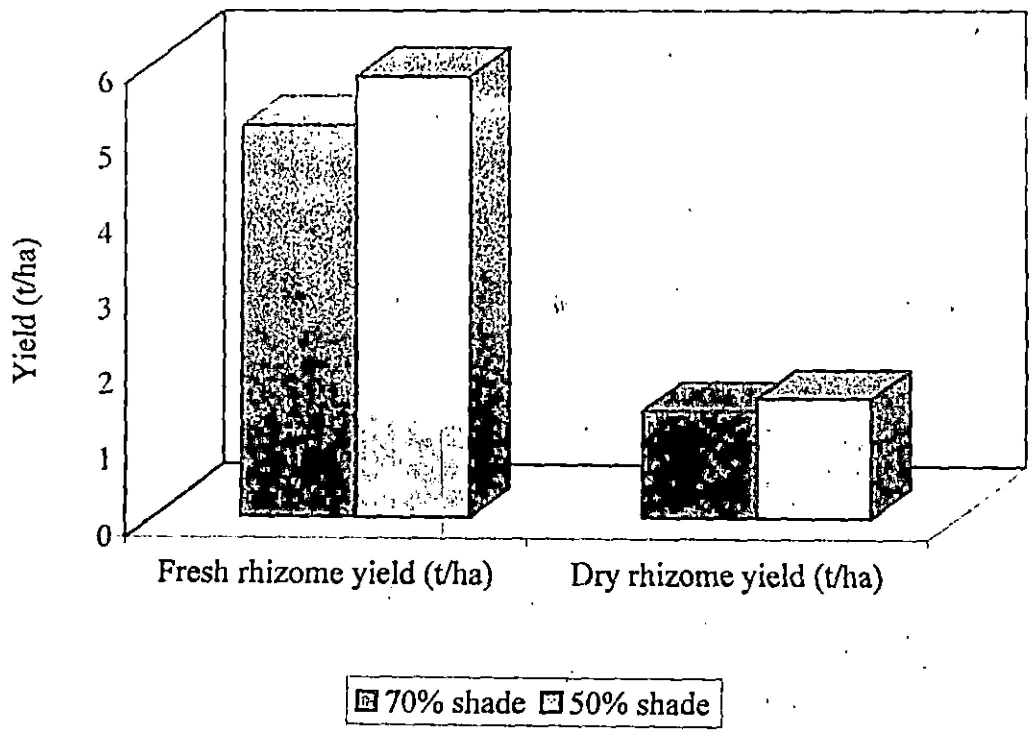


Fig. 4.1. Effect of shading on rhizome yield of kacholam

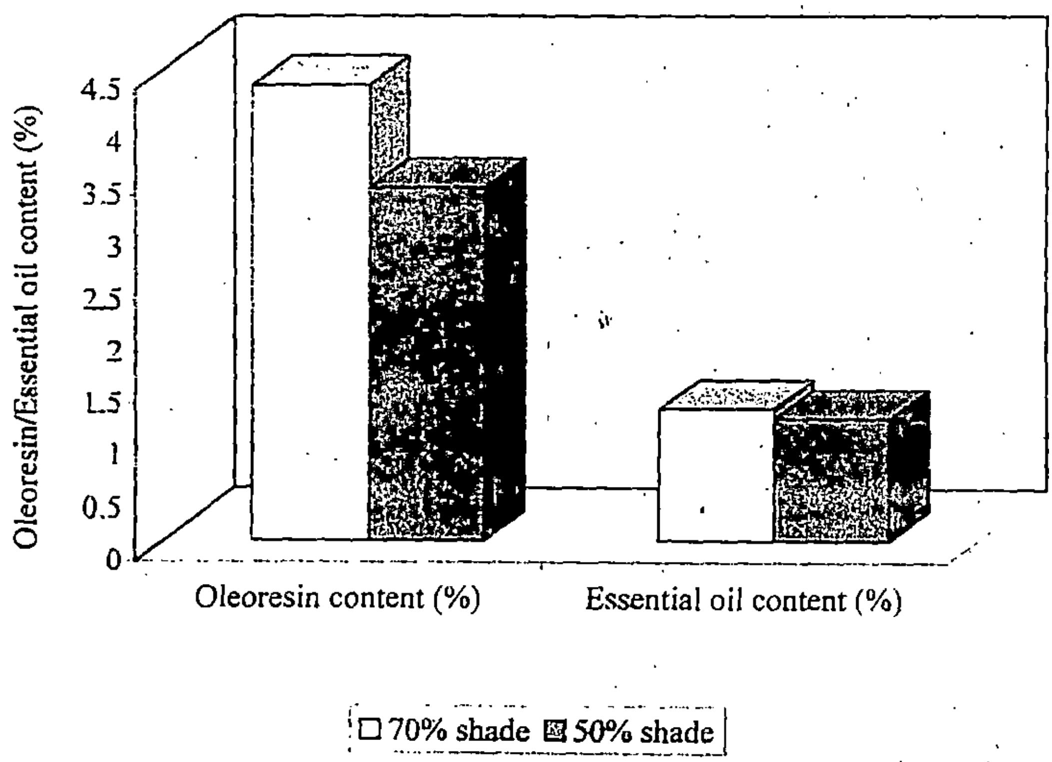


Fig. 4.2. Effect of shading on quality components of kacholam

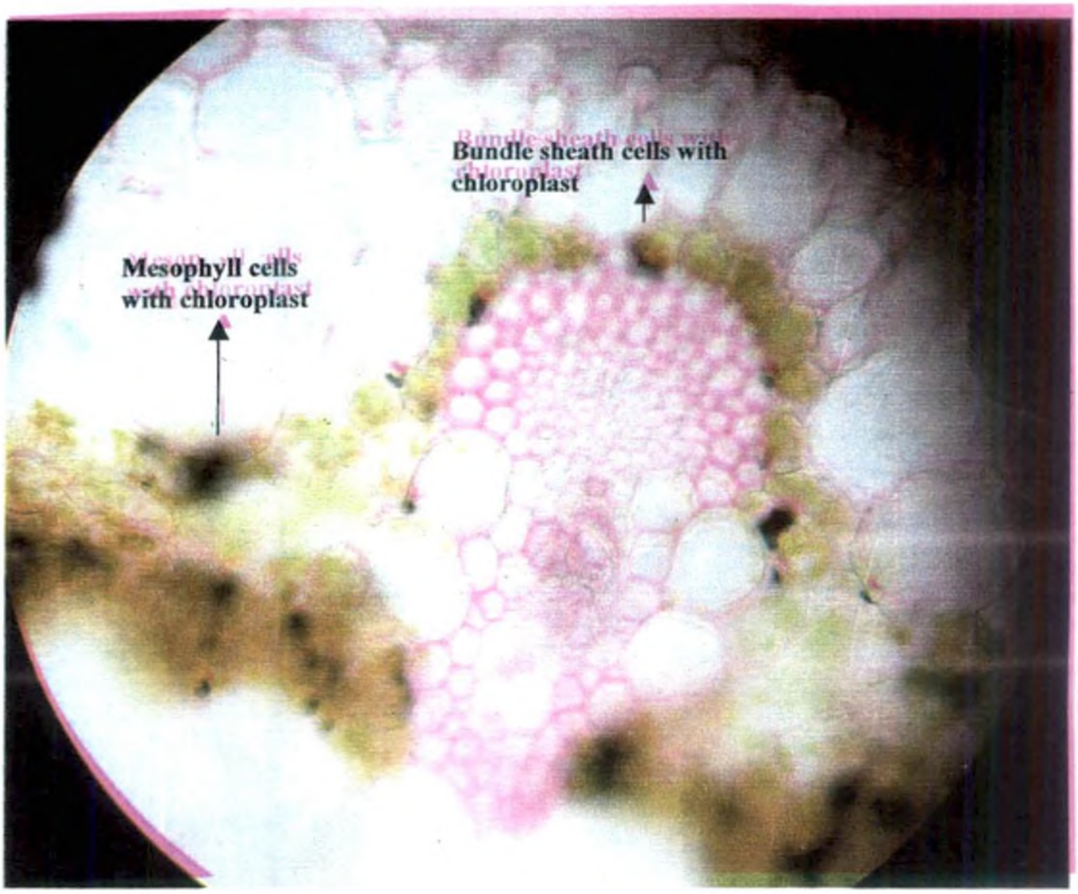


Plate 2. Cross section of kacholam leaf

secondary metabolites. So there are two center of demand, and energy is diverted to both these centers so that the entire process is slowed down. In such a situation, priority will be for the lower sink, i.e., the rhizome formation. Kacholam being a C_4 plant where both C_3 and C_4 pathways operate, the processes of breakdown and re-synthesis occur simultaneously with maximum utilization of carbon dioxide. The stressed rainfed conditions in which the crop is usually cultivated do not interfere with the physiological processes in the plant mainly because of the peculiar nature of the crop.

Shaded conditions promote the biosynthesis of oleoresin and essential oil in the rhizomes while situations with more light promote quantitative development. If open conditions were provided in the initial stages of growth, followed by imposition of shade during rhizome development, more quantity with increased quality could be assured. But this is not a practical proposition and manipulative nutritional management to bring about such a result is the only feasible alternative.

5.3 NUTRITIONAL CHARACTERISTICS AND PRODUCTIVITY

The most conspicuous observation on the effect of shade on nutritional contents was the absence of any effect on the N content of leaf and rhizome (Table 4.10.1 and 4.10.2). Higher shade intensity was found to favour contents of Ca, Mg, Mn and Zn in the leaf and rhizome, while P and K contents were found to be higher when the degree of light intensity increased. Thus, the former secondary and micronutrients contents were linked to the development of qualitative components, while the major elements P and K were associated with higher quantitative development. Significantly higher Fe content in the 50 percent shaded situation indicated that more than Fe, it is some other micronutrient which is involved in secondary metabolite synthesis. Menon and Potty (1999) have reported the involvement of Mn in the biosynthesis of amino acids in medicinal rice, 'Njavara'.

Ecotypic variation in elemental contents followed the trend of shade levels.

Higher contents of major elements and Ca were seen in the higher yielding Thodupuzha ecotype while Mg, Mn, Fe and Zn contents were higher in the Echippara ecotype. The role of micronutrients in the development of quality is again strongly brought home.

Higher contents of major nutrients and Ca brought about by loosening the top 10 cm of soil is again linked to higher yield of rhizomes. However, increased availability and subsequent contents of Mg in the rhizome and Mn and Zn in both rhizomes and leaves by loosening soil up to 20 cm depth was again closely related to quality increase.

The production of higher quantitative yields in the location receiving more light in the ecotype Thodupuzha, when the soil was loosened to a depth of 10 cm was again observed when interaction effects were considered. Though most of the interaction effects were non-significant, involvement of N, P, K and Ca in higher yield production and that of Mg, S and micronutrients, viz., Mn and Zn in lower rhizome yields with higher oleoresin and essential oil content were strongly indicated.

Studies on the production physiology of Kacholam revealed that vegetative growth parameters viz., leaf number and area, and thereby, the leaf area index, the relative growth rate and crop growth rate increased upto the second month after planting and then gradually declined (AICRP on M & AP, 2002).

Rhizome formation in *Kaempferia galanga* begins at the fourth month after planting and it is at this stage that a shift in the metabolic pathway occurs and carbohydrate accumulation is replaced by carbohydrate utilization, and oleoresin and essential oil are formed in the rhizomes. Variation in production pathways for quantitative and qualitative yields have been reported in Njavara (*Oryza sativa*) by Menon and Potty (1998). This shift is evidently influenced by light, the ecotype and the depth of soil loosening, i.e., nutrient availability. Vegetative growth is a pre-requisite for rhizome formation and quality development, and is apparently not influenced to any great extent by external factors. Thus, quality is a function shaped by the habitat. Decreased rhizome yield with increased quality suggest that oleoresin and essential oil are produced at the expense of rhizome yield.

5.4 NUTRITIONAL RELATION TO PRODUCTIVITY AND INTERRELATIONS AMONG ELEMENTS

The most striking observation on path coefficient analysis was the very low residual value obtained in all the cases, indicating that the interrelations among elements was the predominant factor affecting quantitative and qualitative yield parameters. The effect of N on increasing fresh rhizome yield was evident only in the 50 per cent shaded situation and even there, the direct individual effect was negative. The effect of N was more pronounced on oleoresin and essential oil contents, where inhibitory influence was seen. Phosphorus and K, however, had strong positive influence on increasing rhizome yield, while their effect on accumulation of essential oil and oleoresin was inhibitory, especially in the 50 per cent shaded situation. Calcium was seen to have a similar effect, but only in the densely shaded situation. Thus, the major nutrients and Ca were involved only in accumulation of photosynthates, and their role in quality development was negative. The significance of these elements in the early growth, particularly of vegetative organs is indicated.

The micronutrients, particularly Mn and Zn were clearly observed to play an opposite role in the development of Kacholam(Fig 5). Mg and Zn in the rhizomes and Mn content in both leaves and rhizomes inhibited rhizome formation and promoted oleoresin and essential oil development in both shade situations. In the 70 per cent shaded situation, Fe content in the leaves reduced rhizome yield, while both oleoresin and essential oil contents were positively influenced by Fe in the leaves and rhizomes.

The major and minor elements therefore had diametrically opposite roles to play in the development of the plant. Path coefficient analysis of the data pooled over the two shade situations further reduced the number of factors contributing to yield.

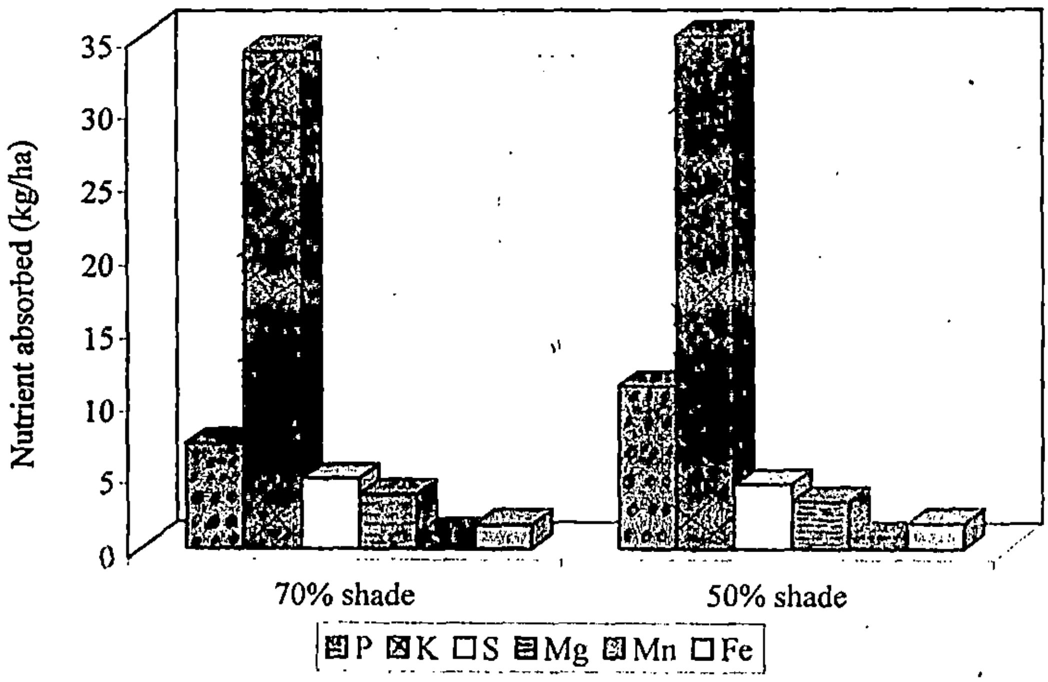


Fig. 5. Absorption of P, K, S, Mg, Mn and Fe (kg/ha) for producing one tonne of rhizome yield under 70 percentage and 50 percentage shade levels

Nitrogen was seen to be non-significant, while P and K had high positive influence on both fresh and dry rhizome yields. S and Mn in leaves and Zn in the rhizomes had high negative relation with fresh weight of rhizomes while dry weight was inhibited by the Fe content in the leaves and rhizomes. High Fe content in plants is a consequence of the high content in laterite soils and Fe is known to interfere with N metabolism, leading to poor yields. S, Mn and Zn are probably involved in the biosynthesis of quality components from accumulated photosynthates and hence are negatively correlated with rhizome yield.

The involvement of Mg and S in the accumulation of oleoresin and essential oil in the rhizomes is indicated by the strong positive relation with the same. While S in the rhizomes and Mg in the leaves were indicated to have significant positive relation with oleoresin content, it was the reverse with essential oil content, with S in the leaves and Mg in the rhizomes having significant effect. Mn and Fe, which are inherently high in laterite soils were partly responsible for essential oil development in the rhizomes. The role of climate and soil in the evolution of ecotypes of plants is indicated. High rainfall and subsequent leaching of bases from the soil resulting in high contents of Fe and Mn in the soil is a characteristic feature of laterite soils and thus there is elemental association to the evolving of plant types. Fe and Mn are available in the same soil environment. Mn becomes available more quickly than Fe because it has seven oxidation states and is mobile, while Fe has only three oxidation states and is not mobile. Adaptability of an ecotype to a particular environment is mediated by the mineral association to which it is linked. The development of different ecotypes of Kacholam may also be related to the soil nutritional characters of the site of evolution and thus one of the factors contributing to biological diversity in the association of soil elements to the specific metabolic pathways. A similar observation has been made in medicinal rice (Menon et al., 1997).

The processes leading to development of quantity and quality were mediated by distinctly different elements and not by variations in the concentrations of individual elements. Qualitative characters were seen to be totally independent of vegetative growth. They are thus two distinct phenomena with different metabolic pathways, i.e., shifting metabolism is a characteristic feature of kacholam. The involvement of P and K in the initial growth stages and development of the crop, and that of Mg and S in the development of qualitative components call for the development of a phasic nutritional management system in the crop. Accumulation of minerals in rhizome is a positive sign of yield increase and is negatively related to quality. Here, P and K management holds the key to higher yield and not N. Top dressing of these two elements in the initial stages, say at 1½ or 2 months stage would be beneficial for improving rhizome yield. These elements would favour vegetative growth which is seen to increase only up to the second month after planting after which it gradually declined again indicating that qualitative components are synthesized from already accumulated photosynthates and this occur in the later stages of growth of the crop. Oleoresin and essential oil, i.e., quality development of the crop commences at around 4 months age and at this stage application of $MgSO_4$ would favour the production of these components. Application of S would be an alternative, which would promote acidification of soil and release of Fe and Mn, which are also positively linked to quality development. Adoption of a bimodal phasic management system to promote quantity and quality has been recommended in medicinal rice, Njavara (Menon and Potty, 2001). Here, bi-directional development is possible because the two processes are separated by time. This is exploited by phasic nutritional management.

From the above discussion it is evident that a nutritional management system that ensures adequate contents of variable elements at different phases of growth would maximize quantity and quality development in *Kaempferia galanga.* Thus soil fertility management for productivity in the crop should be based on the following:

1. N is not a limiting factor for yield expression in Kacholam, and the current recommendation of 20 tonnes per hectatre of farmyard manure is sufficient to

meet the N requirement of the crop.

2. P and K are required for vegetative growth and rhizome production and supply of the same during the initial stages of growth, i.e., at 1 ½ to 2 months after planting by way of fertilizers is indicated.

3. Magnesium, S, Fe, Mn and Zn are involved in secondary metabolite synthesis and thereby, in quality production. As Fe, Mn and Zn are already available in the soil, supply of Mg and S as $MgSO_4$, or S in the form of elemental S during rhizome formation stage would promote development of oleoresin and essential oil in the rhizomes.

SUMMARY

Experiment of the research project entitled "Soil- plant-shade interaction on the productivity of Kacholam (*Kaempferia galanga* L.)" was conducted during the year 2001-2002 at Agricultural Research Station, Mannuthy. In this study, the effect of shade and depth of soil loosening on yield and quality of Kacholam ecotypes as well as rhizosphere nutrition variation were investigated. The salient research results obtained are presented below.

1. The level of shade imposed did not significantly affect the vegetative growth of *Kaempferia galanga.*

2. The Echippara ecotype produced more number of shoots and leaves while the Thodupuzha ecotype had greater foliage spread, and the Vellanikkara ecotype resembled the growth habit of the former.

3. Expanded leaf surface area in Kacholam is linked with greater rhizome yield, while more number of smaller leaves is associated with higher quality.

4. Soil loosening reduces the plant content of Fe and Mn as they are rendered unavailable, and promotes vegetative growth of the crop.

5. Lower shade level promoted higher rhizome yields while increased shading intensity led to increase in qualitative contents in rhizomes.

6. Kacholam was seen to be a C_4 plant, showing the presence of typical bundle sheath cells with chloroplasts and closely arranged mesophyll cells.

7. The process of breakdown of photosynthates and resynthesis as qualitative components occur simultaneously with maximum utilization of carbon dioxide in this plant.

8. Provision of open conditions during the initial stages of growth, followed by imposition of shade during the rhizome development phase could result in production of more quantity with increased quality.

9. Shading had no effect on the N content of the leaf and rhizome, while contents of Ca, Mg, Mn and Zn in the leaf and rhizome were found to be increased by higher shade intensity.

10. P and K contents were found to be higher when the level of light penetration was increased.

11. Higher contents of major elements and Ca were seen in the higher yielding Thodupuzha ecotype while Mg, Mn, Fe and Zn contents were higher in the qualitatively superior Echippara ecotype.

12. Loosening of the top 10 cm of soil resulted in higher contents of major nutrients and Ca, which were linked to higher rhizome yield.

13. Involvement of N, P, K and Ca in higher rhizome yield production and that of Mg, S and micronutrients viz., Mn and Zn in lower rhizome yield with higher oleoresin and essential oil contents were strongly indicated.

14. With the beginning of rhizome formation at the fourth month after planting, a shift in the metabolic pathway occurs and carbohydrate accumulation is replaced by carbohydrate utilization. This shift is influenced by the degree of light incidence, the ecotype and the depth of soil loosening.

15. The very low residual value obtained in path coefficient analyses indicate that interrelations among elements was the predominant factor affecting quantitative and

qualitative yields.

16. S in the rhizomes and Mg in the leaves had significant positive relation with oleoresin content, while essential oil content was influenced by S in the leaves and Mg in the rhizomes.

17. Elemental association to specific metabolic pathways in plants, and thus to evolution of plant types, is indicated.

18. Involvement of different elements at different growth phases of the crop call for the formulation of a phasic nutritional management system in Kacholam.

19. Top dressing of P and K at initial stages of growth, i.e., at 1 ½ to 2 months after planting would improve vegetative growth and rhizome yield.

20. Application of $MgSO_4$ at the stage of formation of rhizomes, i.e., 4 months after planting, would favour the development of qualitative components in the rhizomes.

21. The present level of application of farmyard manure, i.e., 20 tonnes per hectare is sufficient to meet the N requirement of the crop.

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*Originals not seen.

APPENDIX-I

Weather Data For The Crop Period (May 2001 To December 2001)

Months	Mean (°C) maximum temperature	Mean (°C) minimum temperature	Mean RH	Rainfall (mm)	Rainy days	Evaporation (mm)	Sunshine hours (hr)
May	32.3	24.5	81	192.6	22	121.7	198.4
June	28.4	23.1	87	676.2	23	87.8	57.0
July	29.0	22.7	85	477.7	19	83.5	73.5
August	27.5	23.1	87	253.2	21	96.7	112.3
September	30.8	23.2	79	200.9	6	124.0	160.3
October	30.7	23.0	81	215.8	8	105.9	145.5
November	31.6	23.1	72	115.8	6	122.2	184.9
December	29.5	22.2	60	0	0	181.7	252.4

APPENDIX II

Semi Diagonal Change in Shade (%) under Coconut Garden

	BLOCK F				BLOCK N			
Time	Luxmeter Readings(100lux)		Light %	Shade %	Luxmeter Readings(100lux)		Light %	Shade %
	Inside	Outside			Inside	Outside		
6am	2	4	50	50	1	4	25	75
7am	8	15	53	47	5	15	34	66
8 am	85	162	52	48	35	162	22	78
9 am	105	255	42	58	65	255	26	79
10 am	145	298	49	51	110	298	37	63
11 am	195	455	43	57	135	455	30	70
12 am	245	605	40	60	180	605	30	70
1pm	190	425	45	55	125	425	29	71
2pm	140	345	41	59	110	345	32	68
3pm	75	110	68	32	30	110	27	73
4pm	60	135	44	56	35	135	26	74
5pm	60	90	67	33	30	90	33	67
6pm	15	35	43	57	15	35	17	83
Average				**51**				**71.6**

SOIL-PLANT-SHADE INTERACTION ON THE PRODUCTIVITY OF KACHOLAM
(Kaempferia galanga L.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The effect of soil and atmospheric environment on productivity of ecotypes of Kacholam (***Kaempferia galanga L.***) was investigated during the year 2001-2002 at the Agricultural research station, Mannuthy. The objective of the study was to assess the interaction effect of soil loosening and shade in the coconut intercropping system that finally influence development process and productivity of kacholam ecotypes and generate information on integration of the quantitative and qualitative components of production, which is vital in the cultivation of medicinal plants.

The results showed that the level of shade imposed did not significantly affect the vegetative growth of ***Kaempferia galanga.*** However, it was observed that lower shade level promoted higher rhizome yield while increased shading intensity led to higher content of qualitative components in rhizomes. A study of the anatomy of the leaf revealed the possibility of kacholam being a C_4 plant, which is of advantage in the stressed rainfed condition in which the crop is usually grown.

The ecotype grown had a pronounced effect on vegetative growth and nutrient uptake. The Vellanikkara and Echippara ecotypes produced more number of shoots and leaves while the Thodupuzha ecotype had greater foliage spread. Expanded leaf surface area in Kacholam is linked with greater rhizome yield, which is evident from the high rhizome yield in Thodupuzha. However ecotype Echippara and Vellanikkara with smaller leaves produced higher content of oleoresin and essential oil; thus more number of smaller leaves in medicinal plants can be linked to higher quality.

Nutrient availability to plants was affected by shading and soil loosening treatments. With regards to N content of leaf and rhizome, shading had no effect, while contents of Ca, Mg, Mn, and Zn in the leaf and rhizome were found to be increased by

higher shade intensity. However, P and K contents were found to be higher when the level of light penetration was increased. Shallower loosening of soil i.e., up to 10cm resulted in higher contents of major nutrients while the contents of Fe and Mn were reduced as they were rendered unavailable. However, deep loosening to 20cm resulted in leaching of nutrients and ultimately produced lower yield.

Low residual value obtained in path co-efficient analysis indicated that interrelation among elements was the predominant factor affecting quantitative and qualitative yields. N, P, K and Ca had high positive relation with rhizome yield while Mg, S, and micronutrient, viz; Mn and Zn were positively correlated with oleoresin and essential oil contents.

The involvement of P and K in the initial growth and development of the crop and that of Mg and S in the formation of qualitative components call for the formulation of phasic nutritional management system in the crop. Top dressing of P and K at initial stages of growth, i.e, at $1^{1}/_{2}$ to 2 months after planting could improve vegetative growth and rhizome yield. Application of $MgSO_4$ at the stage of formation of rhizome, i.e 4 months after planting, would favour the development of qualitative components in the rhizome. The experimental results also show that the present level of application of farmyard manure, i.e., 20 tonnes per hectare is sufficient to meet the N requirement of the crop.