INFLUENCE OF SOIL MOISTURE REGIMES ON GROWTH AND YIELD IN BUSH PEPPER

(*Piper nigrum* L)

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

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Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF HORTICULTURE
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2000

DECLARATION

I hereby declare that this thesis entitled **"Influence of soil moisture regimes on growth, and yield in bush pepper (*Piper nigrum* L)"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title, of any other University or Society.

Place : *Vellanikkara*
Date : *29-2-2000*

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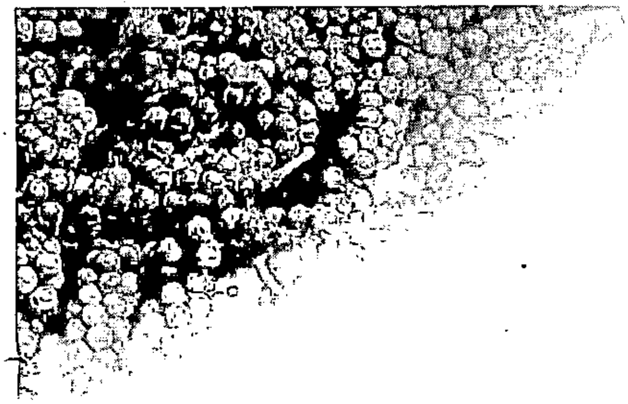
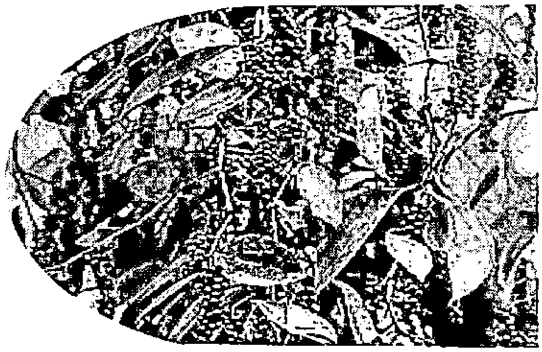
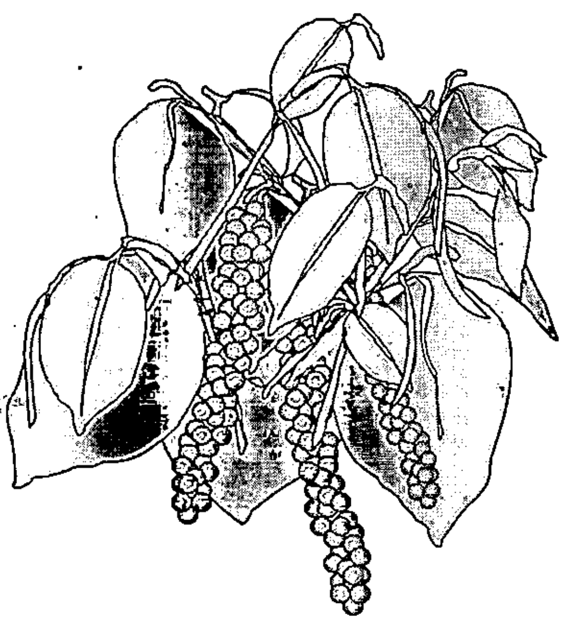






Dedicated to

MY FAMILY

MY FAMILY

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Introduction

INTRODUCTION

Black pepper (*Piper nigrum* L) is the most valued spice crop of India earning Rs. 634.7 crores of foreign exchange. India accounts for fifty per cent of the area (3,63,100 ha) and 30 per cent of world production (1,89,269 tonnes). Kerala with more than 95 per cent of the national area (1.72 lakh ha) and production (53,770 t) in India, has the monopoly of cultivation of this crop.

There are two morphologically different types of the crop, *viz.* "bush pepper" and "vine pepper". Regeneration by planting laterals (plagiotropic branches) results in bush pepper, while vine pepper results from planting of runner/terminal vines (orthotropic branches). Traditionally the farmers grow vine pepper, which is a climber and needs live or dead support. Most of the area under black pepper in India is occupied by vine pepper trailed on live standards like *Ailanthus triphysa* (Dennst.) Alston, *Erithrina indica* Lamk, *Garuga pinnata* Roxb., *Grevillea robusta* A. Cunn, *Thespasia populnea* (L) *Soland ex Correa*, *Artocarpus hetrophyllus* Lamk, *Artocarpus hirsutus* Lamk, *Macarange peltata* Roxb., *Mangifera indica* L. etc.

Bush pepper derives its name from its bushy nature of growth. It needs no supports, and can be harvested without climbing. The other advantages of bush pepper are early yielding (within one year) and yielding round the year. The vine pepper may need 3-4 years for bearing. It may also be necessary to climb on tall support trees for harvesting the spikes. These may escalate the cost of production of vine pepper. Besides the support trees may compete with vine pepper for nutrients and water and reduce the yield of black pepper (Sankar *et al.*, 1988).

Bush pepper and vine pepper vary in their morphological and physiological characters and in their response to inputs and environmental stresses. Geetha (1990) observed that response of bush pepper and vine pepper to applied nutrients varied considerably. Bush pepper showed superior growth and yield at 50 per cent shade (Devadas and Chandhini, 1999). Bush pepper may be ideal as an under-storey crop in coconut plantations and agroforestry systems. Since, it can grow in pots, bush pepper is suitable for the terrace gardens in urban as well as rural areas. It can easily find a place in the kitchen gardens and homesteads. Because of these reasons, recently, there has been a lot of interest evinced by traditional pepper growers, both small and marginal farmers, on bush pepper.

India is the world leader in production and trade of black pepper but productivity of the crop is low in India (315 kg ha^{-1}) compared to countries like Thailand (3032 kg ha^{-1}), Malaysia (2600 kg ha^{-1}) and Brazil (1500 kg ha^{-1}). In Kerala, black pepper productivity is particularly low (319 kg ha^{-1}) (Directorate of Economics and Statistics, 1997). The expected global demand for black pepper by 2000 AD is 1,85,000 t which includes 30,000 t for internal consumption (Directorate of Economics and Statistics, 1994). Unless India increases the productivity of this crop at least by three-fold, we may lag behind in tapping the emerging world market for this commodity.

The humid tropical climate of Kerala is congenial for this crop. Inspite of high rainfall (3000 mm per year), the crop is subjected to moisture stress from December to May, because of the uneven distribution of rainfall (an average of 126 rainy days per year). Periodic water stress during the above period is regarded as the major constraint in increasing the productivity of black pepper in the State (Vasantha *et al.*, 1989). A two-pronged approach *viz.* growing drought tolerant varieties and/or providing supplementary irrigation is necessary to overcome this problem (Levitt, 1980). Productivity of both bush and vine pepper may be considerably improved by growing drought tolerant, high yielding varieties, especially in areas where water resources are scarce, or by providing supplementary irrigation, wherever feasible. Drip irrigation is one of the efficient methods of irrigation suggested for perennial crops (Khader, 1982, Dhanapal *et al.*, 1995, Raghuramulu *et al.,* 1996 and Sivanappan, 1998). Increasing the crop area under irrigation has several limitations, the major one being the availability of water resources. The next option is to identify varieties, which will withstand soil moisture stress. Although such considerations led to systematic investigations on drought tolerance in many crop plants (Jones and Turner 1979; Venkataramanan and Ramaiah 1987; Rao *et al.*, 1988; Balasimha *et al.*, 1988 and Rajagopal *et al.*, 1990), such efforts are little in black pepper, except a few isolated reports (IISR, 1996 and Vasantha, 1996).

The survival and success of drought tolerant varieties/cultivars depend on its morphological, physiological, biochemical and anatomical adaptations. Relative water content, membrane stability, epicuticular wax, cuticle thickness, solute accumulations, production of stress proteins, changes in enzyme activities like, catalase, superoxide dismutase, peroxidase etc., are often related to water stress tolerance in many species (Chempakam *et al.*, 1993 and Tong *et al.,* 1991). However, the morphological, physiological, biochemical and anatomical adaptations of black pepper varieties for water stress tolerance were not investigated.

Soil moisture stress affects the translocation of photosynthates from source to sink in many species and affects production. In black pepper there are no reports available on the translocation of carbon from source to sink. Bush pepper, because of its compact size and early bearing, provides a unique opportunity to study the translocation of carbon from leaves (source) to berries and other parts (sink) of the plant.

Another approach to overcome the loss in productivity due to periodic drought is scientific water management (Reddy and Reddy, 1998). Enormous quantity of valuable irrigation water is wasted with the present methods of irrigation. With the advent of high yielding varieties, the next major advance in agricultural production is expected to come through efficient soil and water management practices such as adoption of water-saving methods of irrigation like drip irrigation (Sivanappan, 1998). In drip irrigation systems, water is applied at a low rate, for a long period, at frequent intervals, near to the root zone of the plant. The water saving in this method, compared to surface irrigation is 40-70 per cent and increase in yield varies from 10-100 per cent depending on the crop species and the agroclimatic conditions (Sivanappan, 1996).

There are a few studies on the response of vine pepper to irrigation (IISR, 1996), but none on bush pepper. For scheduling of irrigation in bush pepper, information on its root zone and optimum percentage of depletion of available soil moisture are necessary. The root zone of vine pepper was reported to be within 30 cm radius and 60 cm depth from the plant (Sankar *et al.*, 1988). However, there are no reports on the root zone of bush pepper or on the optimum percentage of depletion of soil moisture in bush pepper. The present investigations were planned with the following broad objectives.

1. To identify drought tolerant pepper varieties/cultivars and to characterize their adaptations to water stress tolerance.

2. To understand the source-sink relations of black pepper varieties grown under water stress by studying the translocation of photosynthates from leaf to other parts.

3. To compare the response of bush pepper and vine pepper to water stress.

4. To study the root distribution pattern and the effective foraging zone of field planted bush pepper, for scheduling irrigation.

5. To estimate the optimum percentage of soil moisture depletion for scheduling irrigation in bush pepper.

6. To fix drip irrigation schedule for field grown bush pepper.

Review of Literature

REVIEW OF LITERATURE

Bush pepper and vine pepper are two morphological types of black pepper. Seasonal water stress is one of the factors, which limits the productivity of black pepper and other plantation crops and spices even in humid regions. To sustain the productivity in such regions, the options are growing water stress tolerant types/varieties and/or supplementary irrigation during the period of water stress. There are only a few studies conducted in this direction on black pepper.

2.1 Effect of water stress on growth

Moisture stress is the major factor, which decides the distribution of plants and their productivity (Fisher and Turner, 1978). Reduction in plant size is the general effect of water stress (Kramer, 1983). Moisture stress reduced height of tea (Duan, 1992) and cashew seedlings (Latha, 1998). Leaf growth is generally more sensitive to water stress compared to other growth parameters. Reduction in rate of leaf expansion due to water stress was reported in several species (Randall and Sinclair, 1989; Kallarackal *et al.*, 1990). Water stress also reduces leaf area index by leaf senescence and early abscission (Ludlow and Muchow, 1990; Duan, 1992). Moisture stress reduced leaf area in chickpea (Yadav *et al.*, 1996) and cashew (Latha, 1998)

Water stressed tea plants grow slowly and the number of leaves were less compared to daily irrigated plants (Chenkuorenn *et al.*, 1992). Water stress reduced number of leaves in cashew also (Latha, 1998).

In sorghum, moisture stress reduced root length by 30 per cent in susceptable varieties (Salih *et al.*, 1999). Drought tolerant tobacco plants had a higher root/shoot ratio (200 per cent of control) (Riga and Vartanian, 1999). Increased root/shoot ratio may result from relatively greater loss of shoot than root dry weight in water stressed plants (Jones *et al.*, 1981).

Decrease in total dry matter production was another consequence of water stress in many crops (Duan, 1992; Yadav *et al.*, 1996; Latha, 1998; Gowda and Krishnamurthy, 1998). Various techniques have indicated that drought response of seedlings was reasonably well correlated with drought response of mature plants (Sammons *et al.*, 1978).

2.2 Influence of water stress on physiological characters

2.2.1 Relative water content

Relative water content (RWC), which is directly related to leaf water potential is an alternative measure of plant water status (Roberts and Knoerr, 1977) (Sinclair and Ludlow, 1985). Cultivars with higher RWC are more drought resistant in soybean (Carter and Patterson, 1985) and wheat (Schonfeld *et al.*, 1988). A high RWC was maintained by stress tolerant hybrids of coconut, like Laccadive Ordinary × Gangabondom and Laccadive Ordinary × Chowghat Dwarf Orange and local varieties like West Coast Tall, under simulated water stress (Voleti *et al.*, 1990). Similarly East Cost Tall (ECT) and Andaman Ordinary (AO) and Veppankulam hybrid 2 (VHC 2) showed higher RWC than dwarfs (Malayan Yellow Dwarf, Malayan Red Dwarf, Gangabondom, Chowghat Dwarf Green and Ayiramkachi (Jayakumar and Giridharan, 1996). The relative water content in drought tolerant and susceptable genotypes of coconut were 82 and 79 per cent respectively in plants grown under water stress (Rajagopal and Balasimha, 1994). Similarly the drought tolerant accessions of cacao (Balasimha and Daniel, 1988) and tea (Rajasekar *et al.*, 1988) had higher RWC compared to susceptable ones. Latha (1998) also observed high RWC (49 per cent) in regularly irrigated cashew seedlings and low in plants under life saving irrigation (33 per cent). In black pepper, RWC decreased with increase in water stress (Krishnamurthy *et al.*, 1998) and it ranged from 82 to 95 per cent in accession ACC 1622 and from 64 to 91 per cent in accession ACC 891, after 8 days of water stress. However, there are a few reports which indicate that RWC is not a good measure to relate tissue water status and metabolic activities. RWC was not found as a good index for screening coffee cultivars to drought tolerance (Venkataramanan, 1985).

2.2.2 Membrane stability

The membrane damage and solute leakage under stress are measures of cell membrane stability (Blum and Ebercon, 1981). Clarke and Mc Craig (1982) used membrane stability to evaluate drought tolerance in wheat. Decrease in cell membrane stability with increasing water deficit was reported in wheat (Blum and Ebercon, 1981) and maize (Premachandra *et al.*, 1991). Effect of water stress on stomatal conductance and leaf water relation of leaves along current year branches of peach was studied by Steinberg *et al.* (1989). Stomatal conductance was lower in immature leaves than in fully mature leaves and conductance of mature leaves declined to a level near that of immature leaves with the onset of water stress. Kasturibai *et al.* (1988) studied membrane damage in coconut by measuring the leakage of electrolytes from leaf discs of water stressed plants and found that it was less in two hybrids and more in the two dwarfs, the highest being in Malayan Yellow Dwarf. Rajagopal and Balasimha (1994) observed that the electrolyte leakage of drought tolerant coconut genotypes was lower than in the susceptable ones, due to water stress. Membrane damage increased significantly with increase in water stress. The drought tolerant cacao accessions had lower electrolytic leakage as compared to susceptable accessions due to increased wax and lipid fractions in the leaves (Bhat *et.al.*, 1990). In tolerant accessions of black pepper (ACC 1622) membrane leakage ranged from 4.6 to 6.3 per cent while in susceptable accessions it ranged from 6.5 to 11 per cent (Krishnamurthy *et al.*, 1998). Riga and Vartanian (1999) reported that water stress induced membrane damage was earlier and more severe in drought sensitive tobacco genotypes than in tolerant ones.

2.2.3 Stomatal conductance

The stomatal frequency and its behaviour play a major role in water conservation in many plants. Begg and Turner (1976) reported that stomata do not close until a threshhold value of leaf water potential is reached. Hourly determination of relative stomatal opening and stomatal conductance of coconut leaves showed that maximum stomatal opening was between 0800 and 1600 h. After this period, stomata closed rapidly as solar radiation decreased (Rajagopal *et al.*, 1988). They also reported that stomatal regulations depend mainly on solar radiation and the stomata do not control water loss efficiently under conditions of water stress. They also observed relative stomatal opening being the greatest at mid day when the leaf water potential was at its lowest value.

High diffusive resistance (low stomatal conductance) was observed in drought tolerant coconut, varieties as compared to the susceptable varieties. Chowghat Orange Dwarf under water stress. (Kasturibai *et al.*, 1988; Rajagopal *et al.*, 1990; Jayakumar and Giridharan, 1996). Similarly drought tolerant varieties of rubber GL-1 and RRII-105 exhibited high stomatal resistance and a low transpiration rate (Vijayakumar *et al.*, 1988). The response of para rubber to water stress was studied by Devakumar *et al.* (1988). They reported that the higher water status observed in rubber clone RRII 105 was associated with higher stomatal resistance and faster flow of xylem sap. Balasimha *et al.* (1988) observed effective stomatal regulation in cacao clones NC-23, NC-29 and NC-31 resulting in decreased transpirational water loss.

Studies on water relations of banana revealed that ten days of rapid stress caused closing of stomata whereas slow stress delayed the closure till 30 days of water stress (Kallarackal *et al.*, 1990). The soil moisture stress reduced stomatal conductance in sorghum, maize and pearl millet (Singh and Singh, 1994). Latha (1998) reported a decrease in stomatal conductance with increase in duration of water stress in cashew seedlings and the values being 183 m mol m^{-2} s^{-1} when water stressed for 2 days, 61 m mol m^{-2} s^{-1} when water stressed for five days and 18 m mol m^{-2} s^{-1} when water stressed for ten days.

Turner *et al.* (1985) reported that a change in stomatal conductance can occur without a change in leaf water status. In maize and sunflower, Gollan *et al.* (1986) observed that the stomatal conductance was not related to turgor potential. Winter *et al.* (1988) and Matin *et al.* (1989) opined that leaf diffusive resistance is not a good screening tool for drought resistance. Rao and Hebbar (1996) reported that stomatal conductance is not directly related to either water potential or relative water content of the leaf.

2.2.4 Transpiration rate

Water stress in general reduced transpiration rate of plants. Drought tolerant rubber clone RRII 105 (Rao *et al.*, 1988) and GL-I, RRII 105 (Vijayakumar *et al.*, 1988) maintained lower transpiration rate under stress. In coconut also, drought tolerant hybrid Laccadive Ordinary × Chowghat Dwarf Orange had lower transpiration rate compared to the sensitive hybrid, Chowghat Orange Dwarf × West Coast Tall and the values reduced from 3.45 to 1.89 μ mol cm^{-2} s^{-1} and 4.58 to 3.30 μ mol cm^{-2} s^{-1} respectively during water stress (Rajagopal and Balasimha, 1994). Similarly drought tolerant dwarfs had lower transpiration rate (Jayakumar and Giridharan, 1996). In cashew, transpiration rate decreased with increase in duration of stress. The transpiration was the highest (4.75 m mol m^{-2} s^{-1}) in seedlings stressed for two days and it declined to 2.11 m mol m^{-2} s^{-1} in plants stressed for five days (Latha, 1998).

Decreased transpiration was observed in drought tolerant black pepper accessions as compared to the control, (Krishnamurthy *et al.*, 1998).

2.2.5 Leaf temperature

Moisture stress increased leaf temperature in plants (Epstein, 1978). Idso *et al.* (1978) observed a declining trend in transpiration and increase in leaf temperature during moisture deficit situation. Plants subjected to water stress are comparatively warmer than well watered plants because of reduced transpiration (Begg, 1980). Bucks *et al.* (1984) reported that difference in temperature of well watered plants and water stressed plants are to the tune 2-4°C but it may go up to 10-15°C. In water stressed coconut trees, increased leaf temperature was observed between 10 and 12 hrs (Kasturibai *et al.*, 1988) and the leaf temperature varied with durations of the stress. The leaf temperature of cashew seedlings was 35.41°C two days after withholding irrigation and it increased to 36.35°C, five days after withholding irrigation and then decreased to 34.98°C, 10 days after withholding irrigation (Latha, 1998).

Water-stress susceptable wheat variety MACs-2496 had lower leaf temperature than in tolerant lines, NI 5439 (Ravichandran and Mungse, 1998).

2.2.6 Leaf water potential

Leaf water potential is an important quantitative character used to assess water status of plants. Leaf water potential varies greatly depending upon the species, types/varieties of the plant and the environmental conditions. Cell growth, photosynthesis and enzyme activities are affected when leaf water potential goes below 1.5 MPa in most of the mesophytes (Hsiao *et al.*, 1976). Kaufman (1976) reported that water potential ranges from nearly 0.001 MPa for well watered plants of low transpiration rates to -3 MPa or lower when desiccated nearly to the point of death.

. Drought tolerant rubber clone, RRII 105 maintained higher leaf water potential and high yield (Rao *et al.*, 1988). Similar observations were made in drought tolerant tea cultivars, TV 1, TV 17, TV 18, TV 19, TV 20. (Handique and Manivel, 1986) and in cacao (Balasimha *et al.*, 1988) grown under moisture stress. Cashew maintained relatively high leaf water potential even during dry periods (Kallarackal and Soman, 1992). The leaf water potential of West Coast Tall and Gangabondum cultivars of coconut was -1.48 MPa and -1.45 MPa respectively during March at Kasargod and their hybrids had a water potential of -1.15 MPa (Rajagopal and Balasimha, 1994). Latha (1998) observed a decrease in water potential of cashew seedlings with increase in duration of stress and it was the highest 2 days after stress (-2.62 MPa) and it decreased to –3.08 MPa at five days after the stress and further decreased to –3.42 MPa, 10 days after stress.

2.3 Biochemical characters

2.3.1 Chlorophyll

Water stress in general decreases the chlorophyll content of leaves (Hsiao, 1973). The leaf chlorophyll contents of cacao accessions were low in plants under water stress compared to irrigated plants (Balasimha, 1988). A reduction in chlorophyll and carotenoid pigments was observed in black pepper due to higher temperature also (Vasantha *et al.*, 1989). Water stress led to a decline in total chlorophyll content in drought tolerant tea clones (Rajasekar *et* al., 1988). The chlorophyll a, b and total chlorophyll content were high in regularly irrigated cashew seedlings than under life saving irrigation (Latha, 1998). Drought induced oxidation stress in rubber leaves led to senescence as indicated by loss of chlorophyll (Jacob *et al.*, 1999).

2.3.2 Epicuticular wax

Layer of epicuticular wax on the surface of higher plants reduces cuticular permeability and thereby helps to protect the plants from excess water loss through transpiration (Schonherr, 1976). Water stress induced enhanced deposition of epicuticular wax in soybean (Vanvolkenburgh and Davies, 1977) and in Cotton (Weete *et al.*, 1978). The leaf surface wax of plants growing wild under arid conditions was greater than under naturally irrigated conditions (Baker and Procopiou, 1980). Higher deposition of epicuticular wax in drought tolerant varieties of cacao (Balasimha, 1982a), rubber (Rao *et al.*, 1988) and tea (Rajasekar *et al.*, 1988) were reported. The drought tolerant cacao accessions had lower electrolytic leaking as compared to susceptable ones under water stress which was associated with higher sterol/phospholipid ratio (Bhat *et al.*, 1990) and the changes in wax and lipid fractions increased membrane stability in cacao leaves. Epicuticular wax in coconut leaves was more in water stressed plants (Rajagopal *et al.*, 1990; Voleti and Rajgopal, 1991) and in drought tolerant coconut varieties (Jayakumar and Giridharan, 1996).

2.3.3 Proline

Increases in free proline content of the leaf tissues were observed in many mesophytic plants during moisture stress. Significant accumulation of proline occured under stress conditions in wheat (Tyankova, 1967) and in barley (Hanson *et al.*, 1977). The content of free proline in plants with an optimum supply of water is usually very low (0.2-0.69 mg g^{-1} dry matter) (Palfi *et al.*, 1973). Proline accumulation begins only when water stress becomes severe to prevent growth and stomatal closure (Michael and Elmore, 1977). In water stressed sunflower, several amino acids increased initially and proline accumulated only at severe stress (Lawlor and Fock, 1977). Water stress not only inhibited proline oxidation, but also induced a reconversion of oxidation products of proline back to proline in leaves (Stewart and Boggess, 1978). Proline accumulation during water stress is due to its synthesis from glutamase as well as due to decreased rate of proline oxidation (Kramer, 1983). Among plantation crops, proline accumulation in response to water stress has been reported in coffee (Vasudeva *et al.*, 1981), cacao (Balasimha, 1982a), coconut (Voleti *et al.*, 1990) and tea (Rajasekar *et al.*, 1991).

In water stressed black pepper, proline content was the highest in stressed Karimunda followed by Kalluvally-4 (Vasantha *et al.*, 1991). The reports indicate that water stress in all the species at all the levels may not lead to proline accumulation.

2.3.4 Total sugar

Plant water stress influences the sugar content and translocation in many plants. Woodhams and Kozlowski (1954) observed the rapid conversion of starch to sugar in tomato and bean plants during water stress. Adjahossou and Silva (1978) reported that soluble sugars and starch content varied in oil palm varieties and starch content was more in drought susceptible varieties. Increased accumulation of soluble sugars due to water stress were reported in sorghum and black pepper (Cortes and Sinclair 1987; Krishnamurthy *et al.*, 1998). Although soluble sugars accumulated with decrease in osmotic potential in cacao, no relationship with drought tolerance could be established (Balasimha *et al.*, 1988). Increased content of soluble sugars was observed in drought tolerant cacao accessions during stress (Balasimha, 1999).

2.3.5 Solute accumulation

A range of solutes accumulate during osmotic adjustment in both fully expanded and growing tissues subjected to water stress. The solutes include inorganic ions, organic anions, soluble sugars, amino acids and quarternary ammonium compounds (Munns *et al.*, 1979; Jones *et al.*, 1980). Yadav *et al.* (1996) reported that water stress reduced total soluble sugars and starch in drought tolerant (RSG 143-1) and drought susceptible (C-235) chickpea cultivars but to a greater extent in susceptible cultivar C-235 than RSG 143-1. They also noted that amino acids contents positively associated with drought tolerance in chickpea. In rubber, the drought tolerant clone RRII-105 is characterized by high solute potential (Deva Kumar *et al.*, 1988). Venkataramanan *et al.* (1989) found that drought resistant coffee cultivar possessed higher osmo-regulation during moisture stress.

2.3.5.1 Mineral elements

In annual crops like maize, the turgor maintenance by active accumulation of solute has been reported (Acevedo *et al.*, 1971). Ameliorative effect of potassium reported under water stress may be due to the solute potential of K^+. Accumulation of nutrients such as N, P, K and Ca was reported in drought tolerant coffee cultivars (Naidu and Srinivasan, 1982; Venkataramanan, 1985; Rahman, 1988; Venkataramanan *et al.*, 1989; Saraswathy *et al.*, 1992 and Saraswathy *et al.*, 1996). Potassium concentration in tissue has physiological relevance as it helps in osmotic adjustment (Umar and Bansal, 1995).

Edwards (1982) and Nelson (1982) reported that with adequate potassium, stomata close rapidly under drought conditions and minimize the transpiration rate. Application of potassium in sugarcane significantly increased the stomatal diffusive resistance and decreased transpiration rate and increased leaf water potential (Singh *et al.*, 1998).

2.3.6 Activities of peroxidase, catalase, SOD and lipid peroxidation

At cellular level, moisture stress affects the enzyme activities as well as the structures, as water forms the site for enzyme functions. In general, water stress reduced enzyme activities. Peroxidase was the most common oxido-reductase that gets affected due to water stress. Increased peroxidase activity was reported in wheat due to water stress (Li and Liang, 1981). The responses of SOD, peroxidase and catalase under stress conditions were studied in 102 tea cultivars (Tong *et al.*, 1991). They observed that SOD, stress induced activity of catalase were significantly correlated with relative permeability of plasma membrane. Activities of SOD, peroxidase and catalase increased at the beginning of water stress in tea seedlings but decreased when water stress was prolonged (Duan, 1992). Tea cultivars with high drought tolerance possessed high catalase activity (Tong *et al.*, 1992). Drought tolerant coconut cultivars showed lower levels of lipid peroxidation and higher activities of SOD, catalase and peroxidase (Chempakam *et al.*, 1993). Shivashankar and Nagaraja (1996) observed that superoxide dismutase and peroxidase activities increased more rapidly in the drought tolerant coconut variety than the susceptible variety, during stress.

2.3.7 Protein

The quality and quantity of protein in many plants were altered by water stress. The normal protein metabolism was adversely affected and special type of proteins called stress proteins accumulated. The enzymes associated with solute accumulation during osmotic adjustment are known as drought stress proteins (Newton *et al.*, 1991). Water stress reduced protein in drought tolerant chickpea cultivars (Yadav *et al.*, 1996). Water stress leads to degradation of many tissue proteins and a new set of proteins known as stress shock proteins are shown to be produced in some plant species (Shinozaki and Yamaguchi Shinozaki, 1997).

Synthesis of heat shock proteins in the leaves of a drought and heat resistant line (ZPBL 1304) and a drought and heat sensitive line (ZPL 389) of maize was studied under two environmental stress treatments *viz.* soil drying and high temperature and high temperature alone (Ristic *et al.*, 1991). Plants of drought and heat resistant line synthesized a band of heat shock proteins of approximately 45 KD which was not found in stressed plants of drought and heat sensitive line.

Studies on *in vivo* synthesis of early heat shock proteins in young leaves of barley and sorghum showed a greater number and diversity of heat shock proteins in C_4 (sorghum) species compared to temperate C_3 (barley) species (Adrian and Critchley, 1990). The same study also revealed that majority of heat shock proteins were being associated with soluble fraction in both sorghum and barley.

Krishnamurthy *et al.* (1998) reported that proteins decreased with water stress intensity in black pepper.

2.4 Anatomical variations

Leaf cuticle thickness, epicuticular wax, thickness of sclerenchyma, number of xylem vessels are a few of the leaf anatomical characters which helps to conserve water in plants.

Thicker cuticle was observed in a drought tolerant cashew seedling, as compared to a drought susceptible variety (Latha, 1998). Salih *et al.* (1999) studied anatomical difference between drought tolerant (Gadambalia) and drought susceptible (Tabat) sorghum cultivars in the development of sclerenchyma, during water stress. The stem of 'Gadambalia' has a 1 to 3 cell thick layer of sclerenchyma beneath the epidermis. The vascular bundles were surrounded by a wide sclerenchyma sheath, three cell thick, in the stem periphery. Stems of 'Tabat' were much less sclerified, and no sclerenchyma was detected under the epidermis. Further more, the sclerenchyma protecting the vascular bundles was much less developed.

According to Nareshkumar *et al.* (1999) coconut genotypes like West Coast Tall, Federal Malayan State, Philippines Ordinary and West Coast Tall × Chowghat Orange Dwarf hybrid were relatively tolerant to soil moisture stress, based on characters such as thicker leaflets, thick cuticle on both sides, larger palisade and spongy parenchyma cells, larger hypodermal cells and sub-stomatal cavity.

2.5 Methods of screening for drought tolerance

High leaf water potential, stomatal resistance and tolerance to heat (Singh *et al.*, 1973), proline content (Sullivan and Rose, 1979) and osmotic adjustment (Venkataramanan *et al.*, 1989) etc. are important characteristics to judge drought tolerance of crops.

Leaf water potential, especially at predawn hours were good indicators of plant moisture status and severity of stress conditions in rubber (Chandrasekhar, 1977). Chlorophyll stability index was used for *in vitro* screening for drought tolerance in cacao (Ravindran and Menon, 1981). Pomir and de Taffin (1982) reported that leaf characters and nut yield were used to screen five coconut hybrids and a West African Tall for drought tolerance. In tea, shoot water potential was used for screening drought tolerance varieties (Handique and Manivel, 1986). Similarly, in cacao, leaf water potentials of excised leaves were used for rapid drought tolerance screening (Balasimha and Daniel, 1988). Balasimha (1999) reported that chlorophyll fluorescence can be used for screening coca against drought tolerance.

Leaf diffusive resistance, leaf water potential and epicuticular wax content were employed to screen for drought tolerance in 23 types of coconut, comprising ten tall, six dwarfs and 7 hybrids (Rajagopal *et al.*, 1990). Parameters such as leaf water status RWC (Voleti *et al.*, 1990) and (Repellin *et al.*, 1994) can also be used for screening drought tolerance in coconut. Venkataramanan *et al.* (1996) reported that RWC was not a good measure for screening of coffee cultivars to drought tolerance. They emphasised on osmoregulation to screen the coffee cultivars for drought tolerance. Enzymes such as SOD and catalase were suggested as important indices for screening drought resistance in tea (Tong, *et al.*, 1991). The characters such as chlorophyll-carotenoid ratio, stomatal resistance, leaf water potential, transpiration rate, relative water content, specific leaf weight, proline content, sugars and nitrate reductase activity were suggested for screening drought tolerance in black pepper varieties (Vasantha *et al.*, 1989; Vasantha, 1996). Reduction in leaf area, RWC, dry weight of shoot and roots were used to screen genotypes for drought tolerance in cardamon at seedling stage (Gowda and Krishnamurthy, 1998).

The morphological, physiological, biochemical and anatomical response to water stress in plants vary. It may not be dependable to base the screening only on a few characters. The review also indicated that studies on black pepper, in these lines are only a few and in bush pepper, there are no such studies.

The available reports on plant characters used as index of drought tolerance are summerised.

Crops	Methods tried	References
Black pepper	Stomatal resistance, Transpiration rate, Leaf water potential, Relative water content, Specific leaf weight, Proline, Sugars, Nitrate reductase and Chlorophyll- carotenoid ratio	Vasantha (1996)
Black pepper	Stomatal diffusive resistance, Reducing sugar, Total proteins, Relative water content	Krishnamurthy *et al.* (1998)
Cardamom	Sullivans Dessication tolerance test and Relative water content	Gurumurthy *et al*, (1996)
Cardamom	Reduction in leaf area, Relative water content, Shoot and root dry weight	Gowda and Krishnamurthy (1998)

Cashew	Diffusive resistance, Transpiration rate, Leaf water potential, Chlorophyll stability index, Proline content and Nitrate reductase activity	Latha (1998)
Cacao	Chlorophyll stability index Nitrate reductase activity Leaf water potential	Ravindran and Menon (1981) Balasimha (1982b) Balasimha and Daniel (1988)
Coconut	Leaf characters and nut yield	Pomir and de Taffin (1982)
Coconut	Leaf water potential and phosphatase enzyme activity	Rajagopal, *et al.* (1988)
Coconut	Polyphenol isozymes, Nitrate reductase	Shivasankar (1988), Shivasankar (1992)
Coconut	Leaf diffusive resistance and Epicuticular wax content	Rajagopal *et al.* (1990)
Coconut	Relative water content	Voleti *et al.* (1990)
Coconut	Lipid peroxidation, Peroxidase, Catalase and SOD activity	Chembakam *et al.* (1993)
Coconut	Relative water content and Epicuticular wax	Jayakumar *et al.* (1996)
Coconut	Relative water content, Diffusive, resistance, transpiration rate and epicuticular wax	Jayakumar and Giridharan (1996)
Coffee	Solute accumulation - Proline, Nitrogen, Phosphorous, Potassium and Calcium	Venkataramanan *et al.* (1996)
Rubber	Leaf water potential Epicuticular wax	Chandrasekhar (1977) Rao *et al.* (1988)
Tea	Shoot water potential Superoxide dismutase and catalase Epicuticular wax content	Handique and Manivel, (1986) Tong *et al.* (1991) Rajasekar *et al.* (1988)

2.6 Translocation of photosynthates and dry matter production

Water stress influences the translocation of photosynthates and other biochemicals in the plants. In tomato, grown under low soil moisture stress, partitioning of dry matter to the stem was maximum, while leaf and roots got lesser photosynthates (Gates, 1957). In sunflower, a mild water deficit during reproductive development resulted in an increased partitioning of assimilates to reproductive organs and reduced partitioning to the stem (Sobrado and Turner, 1983).

Dry matter partitioning of young tea clones was studied in Southern Tanzania (Burgess and Carr, 1996). They observed more translocation to roots and less to shoots during cool season, while in dry season dry matter partitioning declined to leaves, stems and harvested shoots by 80 to 95 per cent.

Poor partitioning of the dry matter has been reported for moisture stressed coconut palm (Rajagopal *et al.*, 1988). Dry matter partitioning towards stem was lower and high towards leaf in drought tolerant palms (Kasturibai, 1993).

In water stressed cacao ^{14}C distribution measured after 24 and 72 h showed that the ^{14}C content was lower in new flush of leaves, than in stems and roots (Deng *et al.*, 1990a). Storage of new assimilates were observed in source leaves and in stems during periods of water stress. The net assimilation rate and translocation of ^{14}C labelled assimilates in cacao seedlings showed a reduction when plant water potential (ψ) decreased to –1.0 and –1.5 MPa (Deng *et al.*, 1990b).

Kasturibai *et al.* (1996) carried out a detailed evaluation of coconut cultivars and hybrids for dry matter production under water stress. The tall cultivars excelled in vegetative dry matter while the hybrids were superior in the reproductive dry matter and nut yield.

2.7 Root distribution pattern

The root distribution patterns of crops vary and fertilizer application and irrigation should be streamlined according to root distribution. The root distribution of plants are studied by ^{32}P plant or soil injection technique or physical methods like soil escavation techniques. Studies on root distribution pattern of plantation crops and spices are limited. In coconut, studies by ^{32}P soil injection technique revealed that 80 per cent of roots were confined to an area of 2 m radius and 60 cm depth (Anil Kumar and Wahid, 1988). In cashew, about 50 per cent of the root activity was confined to top 15 cm of soil layer and about 72 per cent of the root activity was within a radial distance of 2 m from the tree (Wahid *et al.*, 1989). Investigation on root distribution pattern of colocasia studied by ^{32}P plant injection technique revealed that active root zone of colocasia was within 20 cm lateral distance and 40 cm deep, around the plant (Eapen *et al.*, 1995). Active roots of rubber are concentrated in radial distance of 50, 100 and 150 cm from the plant during 1st, 2nd and 3rd year of growth respectively. Majority of roots are below soil surface to a range of 20-30 cm during the initial 3 years (Joseph, 1999).

Root activity pattern of black pepper vines trailed on live (*Erythrina*) and dead (teak poles) standards were compared employing ^{32}P soil injection technique (Sankar *et al.*, 1988). In both cases, over 90 per cent root activity was within 30 cm radius around the vine. This finding was supported by Geetha (1990) from the experiments on pepper vines trailed on teak pole. All the above reports are on vine pepper and there are no information available on the root distribution pattern or root activities of bush pepper.

2.8 Optimum percentage of allowable depletion

In annual crops viz. pearl millet, finger millet and barley irrigation at 50 per cent depletion of available soil moisture is recommended (Reddy and Reddy, 1998).

There are no reports available on the optimum percentage or allowable depletion of available soil moisture, both in vine as well as bush pepper.

2.9 Drip irrigation

Drip irrigation is based on the concept to maintain near optimum moisture levels in the root zone of crops by applying irrigation water in drops, as required, through a net work of tubes. In many crops this method of irrigation improved productivity, reduced the quantity of irrigation water and increased water use efficiency. Drip irrigation increased yield of arecanut (Khader, 1982), coconut (Dhanapal *et al.*, 1995), cassava (Ponnuswamy *et al.*, 1996), coffee (Raghuramulu *et al.*, 1996), grapes (Narayanamurthy and Deshpande, 1998), pepper and cardamom (Sivanappan, 1998),

Water relations of papaya under drip and sub surface drip irrigation showed that increasing the evaporation replenishment rates from 12 to 20 per cent increased RWC by 13.2 per cent, transpiration by 18.8 per cent, plant height by 21.9 per cent, stem girth by 12.5 per cent, fruits per plant by 88.3 per cent and yield by 34.6 per cent (Srinivas, 1996).

In cashew, drip irrigation at the rate of 43 mm per week during April to October increased nut yield by 20 per cent in Australia (Scharper and Chacko, 1992). Drip irrigation at the rate of 80 litres per tree per day was suggested for the state of Kerala for obtaining the highest productivity from cashew (Latha, 1998).

Effect of drip irrigation of coffee variety 'cauvery' was investigated using double drippers 30 cm apart from the trunk, one dripper on each side of trunk delivering 8 L day^{-1}. Plant height was 30 and 35 per cent, more with single and double dripper respectively as compared to unirrigated control (Mirazizudin *et al.*, 1994). However, no significant differences were observed in plant height, crown diameter and stem diameter, 8, 12 and 16 months after providing drip irrigation.

Irrigation requirement of coconut under drip method was 30 litres per day palm^{-1} (Varadan and Madhavachandran, 1991). Coconut hybrids responded well to drip irrigation and the yield increased by 43 nuts per palm per year compared to basin irrigated trees (Dhanapal *et al.*, 1995) and saving of water was 45.50 per cent (Kapadiyal *et al.*, 1996).

Irrigation requirement under conventional method of basin irrigation was 100 L for Coconut, 40 L for Arecanut, 20 L for Rubber, 100 L for Oil Palm, 4 L for Tea, 15 L for Coffee and 20 L for Cardamom, whereas irrigation requirement under drip method of irrigation were 30, 15, 10, 30, 1, 5, 8 L respectively for these crops and a water economy of 70, 62, 50, 70 75, 66 and 60 per cent respectively were achieved by adopting drip method (Satheesan *et al.*, 1994).

Irrigation of black pepper at the rate of 7 L per day per vine through drip during October to May, resulted in maximum yield (IISR, 1998).

2.10 Incidence of disease and pests

Among the diseases of black pepper, Phytophythora, foot root and slow decline cause severe economic losses (Sarma *et al.*, 1992). The causal organism of foot root is *Phytophthora capsici* which is a soil borne fungus and infects leaves, stems and roots of pepper plants. Water plays an important role in the perpetuation of inoculam in the soil. Griffin (1972) reported that passive movement of zoospores in moving water is required for dispersal of phytophthora. If the soil is allowed to dry out to 2% moisture, viability of chlamydospores and oospores will be lost (Nesbitt *et al.*, 1979). Irrigation increased the disease incidence in some of the genotypes of phytophthora and had no effect on others. Satheesan *et al.* (1998) reported increased incidence of foot rot in black pepper, due to irrigation.

Though a number of insect pests have been recorded on black pepper, 'pollu' beetle, top shot borer, leaf gall thrips and scale insects are major pests. Irrigation at IW/CPE ratio of 0.25 recorded higher percentage (1.00) of fungal 'pollu' as compared to IW/CPE ratio of 0.125 (Satheesan *et al.*, 1998). The review indicate that the method and quantity of irrigation influence the incidence of pest and diseases in many crops including black pepper.

2.11 Quality

The two major constituents of pepper berries that determine the quality are pepper oil (Mathew and Sankarikutty, 1977) and oleoresin. These constituents vary with varieties. Pepper oil contains chiefly turpenes and sesquiterpenes, whereas major constituent of oleoresin is piperine. The oleoresin of pepper is heterogenous, partly liquid with an upper oily layer and lower crystalline layer of piperine, which account for about half the weight (Mathew and Sankarikutty, 1977). Irrigation at IW/CPE ratio of 0.25 recorded the highest oleoresin yield of 136 g per vine (Satheesan *et al.*, 1998). They also reported increased oleoresin content in Karimunda than in Panniyur-1.

Essential oil, piperin and oleoresin content in black pepper were investigated during berry development (Chempakam *et al.*, 1998). The maximum oil was in berries at 4.5 months after flowering, piperine and oleoresin were high at 7-8 months after flowering.

Reports on the response of black pepper to drip irrigation are limited and there are no information available on the response of field planted bush pepper to drip irrigation.

2.12 Soil moisture distribution

Vertical and horizontal movement of water and volume of active root zone wetted were directly related to quantity of water applied through emitters under drip irrigation in coconut (Dhanapal *et al.*, 1995). Similar findings were reported by Mahaswarappa *et al.* (1997) while studying the moisture movement in active root zone of coconut planted in sandy soil, under drip irrigation. Increased trickle discharge rate resulted in a decrease in horizontal component and increase in the vertical component of wetted soil profile in field crops (Moustaghimi *et al.*, 1981) while lower discharges made greater radial spread of moisture in vertisol (Phadtore *et al.*, 1992).

Instantaneous application of water from emitter kept in clay soil increased the width and uniformity of wetting, but it caused high lateral dispersion of soil and reduced the depth of soil irrigated (Amir and Dag, 1993).

Three dimensional movement of water from a point source within the root zone of coconut in sandy loam soil was studied at two discharge rates of 2 and 4 litres per hour (LPH), by applying eight litres of water per dripper per day (Mathew *et al.*, 1999). The horizontal movement of water was greater than the vertical movement in the case of 4 LPH, whereas it was the reverse for 2 LPH.

Drip irrigation in arabica coffee cv. Cauvery showed that irrigations with single emitter per plant (4 LPD) and two emitters per plant (8 LPD) maintained the available soil moisture at 64-66 per cent at 30 cm depth as against 24 per cent in unirrigated control (Raghuramulu *et al.*, 1996).

Obviously, the distribution of soil moisture within in the root zone a crop depends on the discharge rate of the emitter and the number of drippers installed around the plant.

There are a number of studies reported on water stress tolerance in relation, to the morphological, physiological, biochemical characters in both annual and perennial crops. However, such studies are only a few in black pepper and are confined to the vine type. There are no reports on the water stress response of common cultivars of black pepper in the Kerala. The efforts to characterize the varieties based on their water stress response are also lacking. Experiments to screen out drought tolerant varieties/cultivars of black pepper and to characterize them are needed. The bush pepper, having great potential for expansion are not investigated for its water stress tolerance. Bush pepper is usually grown under irrigation. But there are no knowledge about its root zone and optimum percentage of allowable depletion of soil moisture, the information of which are essential for scheduling irrigation. Also there are no scientific reports on the quantity of drip irrigation required for field grown bush pepper and its influence on quality, pest and disease susceptablity of these varieties.

Materials and Methods

MATERIALS AND METHODS

The research project on the influence of soil moisture regimes on growth and yield of bush pepper was carried out in five experiments, three pot culture and two field trials, during 1997 to 2000. In the first pot culture experiment, black pepper varieties were screened and characterized for drought tolerance. In second pot culture experiment, response of bush pepper to soil moisture stress was studied. The optimum percentage of allowable depletion of soil moisture for bush pepper was estimated in the third pot culture experiment. The root-distribution pattern of field planted bush-pepper was studied by ^{32}P plant injection technique, in experiment IV. The fifth was a field experiment to fix drip irrigation schedule for bush pepper.

Experiments I to III were conducted during January 1997 – May 1998 at the Kerala Agricultural University Campus, Vellanikkara, Thrissur. Experiments IV and V were conducted at Peruvannamuzhi farm of IISR, Kozhikode, during October 1998 - January 2000.

Experimental Site

3.1 Climate

The experimental site has a typical tropical humid climate with bimodal monsoon rains, aggregating to 3000 mm per year. The climatic data for the period of investigations, for the two experimental locations are shown in Appendix 1 and 2.

3.2 Soil

Experiments I to III were conducted with pepper vine cuttings raised in polythene bags (size 40 × 20 cm) and bush pepper raised in pots of size (60 × 40 cm)

Table 1: Physio-chemical properties of the potting mixture used for the experiment

	Particulars	Value	Procedure adopted
A.	Physical composition		
	Particulars	Value	Procedure adopted
	Field capacity (0.3 bars) moisture content	12.9 %	Pressure plate apparatus (Richard, 1947)
	Permanent wilting point (15 bars)	6.4 %	Pressure plate apparatus (Richard, 1947)
B.	Chemical composition		
	Organic C	2.9 %	Walkley and Black method (Soil Survey staff, 1992)
	Available N	200 ppm	Alkaline permanganate method (Subbiah and Asija,1956)
	Available P	21 ppm	Bray I extractant Ascorbic acid reductant method (Soil Survey Staff, 1992)
	Available K	712 ppm	Neutral normal ammonium acetate extract, Flame photometry (Jackson, 1973)
	Calcium	3123 ppm	Atomic Absorption Spectrophotometer (AAS)
	Magnesium	607 ppm	AAS
	Iron	55 ppm	AAS
	Mn	18 ppm	AAS
	Zinc	2.2 ppm	AAS
	Copper	1.5 ppm	AAS
	pH	6.7	1:2.5 soil water suspension (Jackson, 1973)

Table 2: Physio-chemical properties of soil in the Peruvannamuzhi farm

A.	Physical composition of the soil		
	Particulars	Value	Method employed
	Coarse sand	20.0 %	Robinson's International Pipette method (Piper, 1966)
	Fine sand	7.0 %	
	Silt	15.0 %	
	Clay	58.0 %	
	Textural class	Clay	
	Field capacity (0.3 bars) soil moisture	20 %	Pressure plate apparatus (Richard, 1947)
	Permanent wilting (15 bars)	16 %	Pressure plate apparatus (Richard, 1947)
B.	Chemical composition		
	Particulars	Value	Method employed
	Organic C	2.2 %	Walkeley and Black Method (Soil Survey Staff, 1992)
	Available N	400 $kg.ha^{-1}$	Alkaline permanganate method (Jackson, 1973)
	Available P	24 $kg.ha^{-1}$	Bray I extractant Ascorbic acid reductant method (Jackson, 1973)
	Available K	72 $kg.ha^{-1}$	In neutral ammonium acetate extractant. Flame photometry (Jackson, 1973)
	PH	5.2	1:2.5 soil Water suspension using pH meter (Jackson, 1973)

respectively, using a potting medium consisting of garden soil, sand and cow dung in 1:1:1 proportion. The physical and chemical properties of the potting medium are given in Table 1.

Experiments IV and V were conducted in the field with laterite soil. The physical and chemical properties of this soil are given in Table 2.

Methods

Experiment 1

3.3 Screening and characterization of black pepper varieties for water stress tolerance

Forty four black pepper varieties/types from the germplasm collections maintained at pepper garden of the Department of Plantation Crops, College of Horticulture, Vellanikkara, were screened in a pot culture experiment (Table 3). Two nodded vine cuttings of these varieties/types were planted in polythene bags of size 40 × 20 cm, filled with potting mixture made of soil, sand and farmyard manure (FYM) in 1:1:1 proportion. The cuttings were grown for eight months with daily irrigation with measured quantity of water to bring moisture in the bag to field capacity. After eight months, irrigation was withheld till the plants showed symptoms of permanent wilting. Relative water content (RWC) and cell membrane stability (MS) were determined on each day after withholding irrigation. Based on the above parameters and the number of days taken for wilting, six apparently drought tolerant and one sensitive variety was selected for further study.

Detailed studies on the physiological, morphological, anatomical and biochemical characters of the selected varieties were conducted in the next stage of the study. For this, nine months old plants of the selected varieties, maintained in

Table 3: Details of the varieties used for the experiment

Name of variety	Status (Local / improved/ Hybrid)	Popular * area
Arassanimortta	Local	Mysore
Arivalli	Local	Central Kerala
Arikottanadan	Local	North Kerala
Balankotta-4	Local	North Kerala
Balankotta-2	Local	North Kerala
Ceylon	Local	Ceylon
Cheriyakaniyakadan	Local	Central Kerala
Cholamunda	Local	-
Chumala	Local	-
Kalluvally-4	Local	Certain pockets of Wynad district and North Kerala
Kalluvally-2	Local	Certain pockets of Wynad district and North Kerala
Kalluvally-4	Local	Certain pockets of Wynad district and North Kerala
Kalluvally-7	Local	Certain pockets of Wynad district and North Kerala
Karimunda	Local	Central Kerala
Karimunda-2	Local	Central Kerala
Karimkotta	Local	North Kerala
Kumbakodi	Local	North Kerala
Kottanadan-1	Local	South Kerala
Kottanadan-2	Local	Nedumangad taluk, Thiruvananthapuram
Malligesara	Local	Uttarakannada
Narayakkodi	Local	Central Kerala
Neriyamundi	Local	-
Nilamundi-2	Local	Idukki district
Nilamundi-1	Local	-
Nilagiri-1	.Local	-
Nilagiri-4	Local	Tamil Nadu
Padarpan	Local	South Kerala

Contd...

Table 3 Contd...

Name of variety	Status (Local / improved/ Hybrid)	Popular * area
P_1 (Uthirankotta-2 × Cheriya Kaniyakadan)	Hybrid	North Kerala
P_2 (open pollinated progeny of Balankotta)	Hybrid	North Kerala
P_3 (Uthirankotta-2 × Cheriya Kaniyakadan)	Hybrid	North Kerala
P_4 (clonal selection from Kuthiravally)	Hybrid	North Kerala
P_5 (open pollinated progeny of Perumkodi)	Hybrid	North Kerala
Perumunda	Local	South Kerala
Perumkodi	Local	Central Kerala
Poonjarmunda	Local	Central Kerala
Sreekara (clonal selection from Karimunda)	Improved	North Kerala
Sulliya	Local	Karnataka
Thevarmundi	Local	Iduki
Thulakodi	Local	North Kerala
TMB 1	Local	Thaliparamba
TMB 6	Local	Thaliparamba
Uthirankotta 1	Local	North Kerala
Uthirankotta-2	Local	North Kerala
Veluthanamben	Local	Iduki

* Source:- Ravindran, P.N. (1990)

Fig. 1. A Vine Pepper

Fig. 2. Potted bush pepper

Fig. 3. Field planted bush pepper

polythene bags of 40 × 20 cm in 5 kg 1:1:1 soil, sand and FYM mixture were subjected to water stress as given below.

0. No water stress (Daily irrigation to field capacity)
1. Mild water stress (irrigating every alternate day to field capacity).
2. Moderate water stress (irrigating once in two days to field capacity).
3. Severe water stress (irrigating once in three days to field capacity).

Factorial combinations of the six water–stress tolerant varieties (Poonjarmunda, Uthirankotta–2, Kumbakodi, Panniyur–5, Kalluvally-4 and Padarpan) and one water–stress sensitive variety (Panniyur-1) and the four water stress levels formed the treatments for this experiment. After each stress period the plants were irrigated to field capacity by slowly and steadily applying water till the water just drained out through the drainage hole. The water stress-cycles were continued during summer months (March-May). This experiment was laid out in completely randomized design and replicated four times. Biometric and physiological observations were recorded at monthly intervals. Leaf thickness was measured using a screw gauge at the end of the experiment. Biochemical estimations were done twenty days after imposing water stress. Nutrient analysis was done at the end of the experiment.

Observations

3.3.1 Membrane stability

The cell membrane stability was studied by observing the leakage to the membrane under water stress. For this ten leaf discs (0.1 g) were floated in 15 ml distilled water for 3 hours. The leaf discs were removed and the electrical conductivity (E.C) of the solution was measured. After the initial measurements, leaf discs were returned to original solution and boiled in distilled water for ten minutes. Leaf discs were removed and the solution was cooled. The electrical conductivity of the solution was determined again.

$$\text{Membrane stability} = \frac{\text{Initial Electrical Conductivity}}{\text{Final Electrical Conductivity}}$$

3.3.2 Stomatal conductance

A steady state porometer (Model L1-1600, L1-COR, Nebraska, USA) was used to measure the leaf diffusive resistance. Measurements were taken at 0800 hrs and 1400 hrs, on the abaxial surface of physiologically mature leaves of three plants from each treatment. The mean diffusive resistance was converted to conductance and expressed in m mol m^{-2} s^{-1}.

3.3.3 Transpiration rate

Transpiration rates were recorded at 0800 hrs and 1400 hrs using the steady state porometer. Observations were made on three plants each and the mean expressed in μ g cm^{-2} s^{-1}.

3.3.4 Leaf temperature

Leaf temperatures were recorded from the same leaf while recording the stomatal conductance at 0800 hrs and 14 hrs using the steady state porometer.

3.3.5 Leaf water potential

A Scholander - pressure chamber (Soil Moisture Equipment Corporation, Ohio, USA) was used for finding out the leaf water potential. The leaf water potential was measured one month after imposing water stress cycle, at 0800 hrs. Measurements were also taken from 0800 hrs to 1600 hrs at 2 hours interval from seven year old vines growing in the field.

3.3.6 Chlorophyll

Chlorophyll of the leaves was extracted by acetone and estimated spectrophotometerically, following the method of Starner and Hardley (1967). The chlorophyll a, chlorophyll b and total chlorophyll of each sample were calculated using the following formulae.

$$\text{Chlorophyll a (mg g}^{-1}\text{of tissue)} = 12.7\text{ (OD at 633 nm)}\frac{2.69\text{ (OD at 645 nm)} \times V}{1000 \times W}$$

$$\text{Chlorophyll b (mg g}^{-1}\text{of tissue)} = 22.9\text{ (OD at 645 nm)}\frac{4.68\text{ (OD at 663 nm)} \times V}{1000 \times W}$$

$$\text{Total Chlorophyll (mg g}^{-1}\text{ of tissue)} = 20.2\text{ (OD at 645 nm)}\frac{8.02\text{ (OD at 663 nm)} \times V}{1000 \times W}$$

OD = Optical density

V = Final volume of 100 per cent acetone extract

W = Fresh weight of tissue in gram

3.3.7 Epicuticular Wax

The epicuticular wax was determined by following the method of Ebercon *et al.* (1977). One gram fresh leaf samples were immersed in 15 ml redistilled chloroform for 2 minutes. The extract was filtered and evaporated on a boiling water bath until the smell of chloroform could not be detected. After adding 5 ml of $K_2C_2O_7$, the samples were placed in boiling water bath for 30 minutes. After cooling, 12 ml of de-ionized water was added. Several minutes were allowed for cooling and colour development. The optical density (OD) of the samples were read at 590 nm. Standard wax solutions were prepared from carbo-wax 3000 (polyethelene glycol-3000). The wax was dissolved in chloroform and 15 ml aliquots containing a range of concentrations were prepared and colour developed as described above and the OD determined. The epicuticular wax content was determined from standard graph and expressed in mg dm^{-2}.

3.3.8 Solutes and enzymes

Solutes like proline, amino acids, sugars, plant nutrient elements like N, P, K, Ca, Mg, Fe, Mn, Zn and Cu and the enzymes were estimated at the time of destructive sampling. The youngest fully matured three leaves from each variety were used for these estimations.

3.3.9 Proline

The proline content of the leaves were estimated by following the method of Bates *et al.* (1973). Fresh leaves (500 mg) from the plants in each treatment were homogenised with 10 ml of 3 per cent aqueous sulfosalicilic acid, centrifuged at 3000 rpm for ten minutes. Two millilitre of the supernatent liquid was taken and 2 ml of glacial acetic acid, 2 ml of acid ninhydrin mixture and 2 ml of 6 N orthophosphoric acid were added. The contents were allowed to react at 100°C for 1 hour and the reaction was terminated in an ice bath for ten minutes. The reaction mixture was mixed vigorously with 4 ml of toluene using a mixer for 10-20 seconds. The upper chromophore containing toluene was aspirated from the aqueous phase and warmed at room temperature and the OD was read at 520 nm in a spectrophotometer. The proline content was determined from a standard curve of pure proline and expressed µg g^{-1} fresh weight.

3.3.10 Total Sugars

Total sugars of the dried leaves were estimated by the method of Dubois *et al.* (1951). For this 100 mg of dried and powdered samples were hydrolyzed in 5 ml of 2.5 N HCl in a boiling water bath for three hours. The cooled samples were neutralized using solid Na_2CO_3 and made up to 100 ml. To one milliliter of the aliquot 1 ml of 5 per cent redistilled phenol and 5 ml, 96 per cent sulphuric acid were added. The mixture was kept at room temperature for 20 minutes and the colour were read in a spectrophotometer at 490 nm against a glucose standard (40-200 µg). The results were expressed as mg glucose 100 mg^{-1} sample.

3.3.11 Amino acids

Aminoacids were extracted from 500 mg fresh leaf samples using 80 per cent ethanol. The amino acid contents of the samples were estimated spectrophotometrically by using ninhydrin and reading the colour intensity at 570 nanometer (Sadasivam and Manickam, 1992).

3.3.12 Plant nutrient elements

The leaf sample wiped with tissue paper was kept in a hot air oven at 70 ± 5°C for 48 hours. The dried leaves were ground to a fine powder and passed through 72 mesh sieve. For the estimation of plant nutrient elements, 0.5 g samples were digested by nitric acid - perchloric acid mixture (2:1). Phosphorous was determined by vanadomolybdo-phosphoric-yellow colour method in nitric acid medium. Potassium was determined by flame photometer (Jackson, 1973). The micro nutrient elements in the acid digest were estimated in an Atomic Absorption Spectrometer.

3.3.13 Superoxide dismutase (SOD), catalase and peroxidase

These three enzymes were extracted by following a common procedure given below.

One gram of the chopped leaf sample was ground under ice-cold conditions using 0.1 m Na phosphate buffer, pH 7.6, containing 0.5% β-mercaptoethanol and 5% polyvinyl pyrrolidone. The homogenate was squeezed through two layers of muslin cloth and centrifuged at 10,000 rpm for 20 minutes, at 5°C. The enzymes were partially purified from the supernatent by ammonium sulphate precipitation and subsequent dialysis. The clear pale yellow dialysate, after centrifuging was used for all the enzyme assays.

Superoxide dismutase activity was determined by using its ability to initiate photochemical reduction of Nitro Blue Tetrazolium (NBT) according to the method of Beauchamp and Fridovich (1971). Catalase was assayed titrimetrically using $KMNO_4$ (Kar and Mishra,1976). The activity of the enzyme was expressed in "units" where one unit is defined as the amount of enzyme which consumes one mole of H_2O_2 per minute under the conditions of the assay. Activities of the peroxidase was also determined by the method of Kar and Mishra (1976). For this the absorbance of the above mentioned reaction product was read at 420 nm. The enzyme activity was expressed as changes in absorbance (ΔA min^{-1}mg $protein^{-1}$).

3.3.14 Electrophoretic pattern of protein

The electrophoretic pattern of water stressed and daily irrigated (control) plants were studied by sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS PAGE). The youngest fully matured leaves were used for the estimation of proteins. The leaves were chopped and one gram tissue was homogenized using Tris HCl buffer of pH 7.4 containing 17.5 per cent sucrose. The extract was centrifuged at 8000 rpm. The clear supernatent was used for electrophoresis. Protein was also estimated in the supernatent using Lowry's method (Lowery *et al.*, 1951). Twenty micro litres each of the protein extract were subjected to SDS PAGE. (Hoofer Analytical Equipment, USA). The bands were visualized by staining with Coommassie blue R-250. Rf values of the bands were documented using the "gel documentation system", Amsterdam, Sweden.

3.3.15 Lipid peroxidation

The youngest fully matured leaf was used for the estimation of lipid peroxidation. One gram chopped leaf sample was homogenised with 2 ml 0.1% trichloro acetic acid (TCA). Aliquots were allowed to react with 4 ml of 20% trichloro acetic acid containing 0.5% trichloro butyric acid by boiling in a water bath for 30 minutes and then quickly cooling in an ice bath. The absorbance at 532 nm was read and the non specific absorption at 600 nm was subtracted (Heath and Packer, 1968).

3.3.16 Anatomical characters

The anatomical characters of the varieties under investigation were done in field grown rainfed plants of eight years age.

The youngest fully matured leaves were collected from orthotropic shoots of drought tolerant as well as drought susceptible varieties. Leaf sections were prepared with a razor and stained by dilute toludine blue 'O' solution. The sections were kept in the stain for 20 minutes and mounted on a slide with glycerol. The measurements on cuticle thickness were made with calibrated eye piece micrometer, in the region of stained cuticle overlying the epidermal cell wall. Similarly stem sections were also prepared and cuticle thickness measured using an eyepiece micrometer. Ten measurements were taken from different spots of every section on upper surfaces and means worked out. Photomicrographs were also taken with Olympus automatic photo micrographic camera (PM 30).

Experiment II

3.4 Response of bush pepper and vine pepper to soil moisture stress

One apparently water stress tolerant (Panniyur-5) and one sensitive variety (Panniyur-1) were used for this study. The bush pepper of these varieties were made by planting cuttings of laterals and vine pepper by planting runner vines in 40 × 20 cm sized polythene bags filled with 5 kg potting mixture of soil, sand and farm yard manure in 1:1:1 proportion. These plants were grown in the green house for nine months by providing daily irrigation and then subjected to water stress levels as in the experiment II.

Biometric observations such as height, girth, number of leaves, internodal length and leaf area were recorded one month and two months after imposing the water stress cycles. Destructive sampling was done at the end of the experiment and the root weight, shoot weight, root/shoot ratio and the total dry weight of each plant were recorded.

Physiological parameters like leaf temperature, stomatal conductance, transpiration rate and leaf water potential were measured in the water stressed bush and vine pepper.

3.4.1 Translocation of photosynthate in bush pepper

Translocation of photosynthate in water stress tolerant and susceptable varieties of bush pepper were studied using ^{14}C. This study was done at two stages of growth of the plant viz. at berry setting and berry maturing stage. One year old bush pepper plants of varieties Panniyur-5 (drought tolerant) and Panniyur-1 (drought susceptible) were exposed to water stress cycles for 1 or 2 or 3 days respectively for one month. Daily irrigated plants were used as control. After one month growth under stress cycles one fully matured leaf of each variety was allowed to fix ^{14}C in a custom made chamber (IAEA, 1975) which had a closed air circulation system. ^{14}C labelled sodium carbonate ($Na_2\ ^{14}CO_3$) kept inside the chamber in a petridish was allowed to react with dilute hydrochloric acid to release $^{14}CO_2$, which in turn was fixed by the leaf in the chamber. After inserting the leaf into the leaf chamber through the rubber beading between the lower and upper portions, the chamber was firmly clipped to make it air tight. There were two exhaust rubber tubes for purging the radioactive gases at the end of the feeding. Before commencing the experiment the tubes were closed by a clip. After loading the leaf and setting the chamber air tight, HCl was rundown to the petridish containing $Na_2\ ^{14}CO_3$ through a burette. HCl was added sufficiently in excess to ensure complete reaction. The leaf chamber was provided with a built-in fan to facilitate circulation of the liberated gas inside the chamber. The leaves were allowed to fix $^{14}CO_2$ for 10 minutes. After feeding the leaves, the unused mixture of gases were purged through the exhaust tubes into 10% KOH absorbant

Fig. 4. Air circulated chamber used for ^{14}C-leaf feeding

solution. The chamber was opened and the plants were taken out and kept inside a green house. The water stress treatments as described earlier were continued. On 14th day, these plants were cut at the basal portion and separated into stem, leaves and berries and dried in an oven at 70 ± 5°C. The samples were ground separately in a Cyclotec mill. The samples (0.1 g) were oxidised in a biological oxidiser using methanol, ethanol amine and cocktail solution (10:10:50). ^{14}C counts were taken in a liquid scintillation system. The experiment was repeated at berry maturity stage also. However, at berry maturity stage instead of ^{14}C counting, autoradiography of the samples were done.

For autoradiography, the plants were cut basally and wiped dry using cotton. The specimens were pressed for five days in a herbarium press and dried at 70 ± 5 °C in an oven for about 30 minutes. The dried specimens were kept in contact with X-ray film in the dark for one month. The X-ray films were developed using the commercial X-ray film developer solution (Agfa-beevaert India Ltd). The developed films were photographed by placing it on a X-ray viewer.

Experiment III

3.5 Allowable depletion of soil moisture in bush pepper

Two year old bush pepper, variety Karimunda, grown in pots of size 60×40 cm, filled with 10 kg sieved potting mixture was used for this experiment. Field capacity and wilting point of the potting mixture were determined and the available water content of the medium calculated prior to the experiment. The available soil moisture in pots were allowed to deplete by 25, 50 and 75 per cent before giving irrigation, based on soil moisture estimated by gravimetric method. After irrigation, the surface of the pots were covered with black polythene sheets to prevent evaporation from the soil surface. Every day, soil moisture of the pots were determined gravimetrically. The moisture determinations were continued until the plants began to wilt. After each soil sampling, the holes left were filled with the potting mixture. The number of days taken to deplete the available soil moisture to 25, 50 and 75 per cent respectively were calculated and irrigation scheduled accordingly. In order to ensure the correct soil moisture status before irrigation under each depletion levels, the soil moisture was estimated a day prior to the proposed date of irrigation. Depending on the moisture content in the pots, schedulings of irrigation were adjusted. All the plants were kept in a green house with 50 per cent shade. In control-plants irrigation was given daily. The optimum allowable depletion of soil moisture was determined by observing the growth and development of the plants in daily-irrigated plants and in the plants irrigated at 25, 50 and 75 per cent depletion, for three months. This experiment was laid out in completely randomized block design and replicated six times.

Observations

3.5.1 Number of leaves

Number of leaves on main, secondary and tertiary branches were counted at monthly intervals.

3.5.2 Leaf area

Total leaf area on main, secondary and tertiary branches were estimated using the emphirical relation, LA=0.6 l × w (Ibrahim *et al.*, 1985) and by summing the areas of individual leaves; where LA = leaf area, l = length of leaf and w = width of leaves.

3.5.3 Number of branches

Branches on each plant was catagorised into main, secondary and tertiary based on the position of the branches in the main shoot and number of each type of branches were recorded at monthly intervals.

3.5.4 Length of branch

Length of each type of branch was measured using a meter scale, from base of the branch to tip of the last leaf on that branch, at beginning and at end of the experiment.

3.5.5 Number of spike

The number of spike on main, secondary and tertiary branches were counted and the total number of spikes were worked out.

3.5.6 Length of spike

After the harvest, five spikes were randomly selected from each plant and the lengths were measured and the mean length worked out.

3.5.7 Number of berries on spike

Number of berries on the spike were counted from five randomly selected spikes and the average worked out.

3.5.8 Hundred-berry weight

Five spikes were selected randomly and the berries separated. From this hundred berries were counted at random and the weight recorded using an electronic balance.

3.5.9 Hundred berry volume

A fixed quantity of water is taken in a measuring cylinder and 100 berries were immersed in water for one minute and 100 berry volume was determined by observing water displacement.

3.5.10 Compaction of spike

This was calculated using a formula, $\dfrac{\text{No. of berries}}{\text{Total length of spike}}$

3.5.11 Yield of green pepper

The green berries harvested from individual plants were weighed and expressed as g plant^{-1}.

3.5.12 Yield of dry pepper

The dry pepper yield was worked out by drying the green berries harvested from individual plants in sunlight until it attain a constant weight.

3.5.13 Dry matter content

At the end of the experimental period, in experiment I and II destructive sampling was done and plant parts were separated into leaves, stem and roots. They were dried in a hot air oven for 48 hours at 70°C ± 5°C. The dry weight of stem, leaves and roots were recorded separately.

3.5.14 Oleoresin

The oleoresin content of the berries was estimated by cold percolation of berry powder with acetone and the percentage was calculated gravimetrically (American Spice Trade Association, 1968). Transferred one gram of dry powdered berry samples to chromatographic column with stop cock and added 80 ml of acetone. Allowed the extraction to proceed for 24 hrs, thereafter the extract was drained to a beaker. This extract was kept in an oven and evaporated to dryness. The oleoresin content was calculated as percentage of dry berry weight.

3.5.15 Piperine

Piperine was extracted from 500 mg dry berry samples by refluxing for 3 hours in 96 per cent (v/v) ethyl alcohol excluding light. The piperine content in the extract was estimated using a Shimadzu Reversed phased high performance liquid chromatography (RPHPLC) (Wood *et al.*, 1988).

3.5.16 Incidence of pests and diseases

Damage caused by leaf eating catterpiller, thrips, pollu bettle and incidence of foot root disease were observed at monthly intervals, for the experiments III and V.

Experiment IV

3.6 Root distribution pattern of field planted bush pepper

Four years old bush pepper, variety Karimunda grown at a spacing of 2 m × 2 m in Peruvannamuzhi farm of IISR, Kozhikode and maintained under uniform fertilizer and cultural management were made use for this experiment. Five plants each were selected at random from the bulk planting and ^{32}P was smeared on two fully mature leaves of these plants. Similarly ^{32}P was fed to the root by exposing a single root by excavation. In both methods of ^{32}P application, the dosage per plant was 7400 Bq plant^{-1}. After 7 days core samples of the soil were taken from around the plant at following distances and depth

10 × 20 cm, 10 × 40 cm, 10 × 60 cm

20 × 20 cm, 20 × 40 cm, 20 × 60 cm

30 × 20 cm, 30 × 40 cm, 30 × 60 cm

40 × 20 cm, 40 × 40 cm, 40 × 60 cm

There were border plants on both sides of the experimental plants. The soil samples were analysed for ^{32}P by Cerenkov counting technique (Wahid *et al.*, 1989). The root distribution pattern was deduced from the ^{32}P count of the soil at different lateral distances and depths. The percentage of root activity at different lateral distances and depths of the soil were calculated as follows.

Percentage root activity at a particular radial distance and depth =

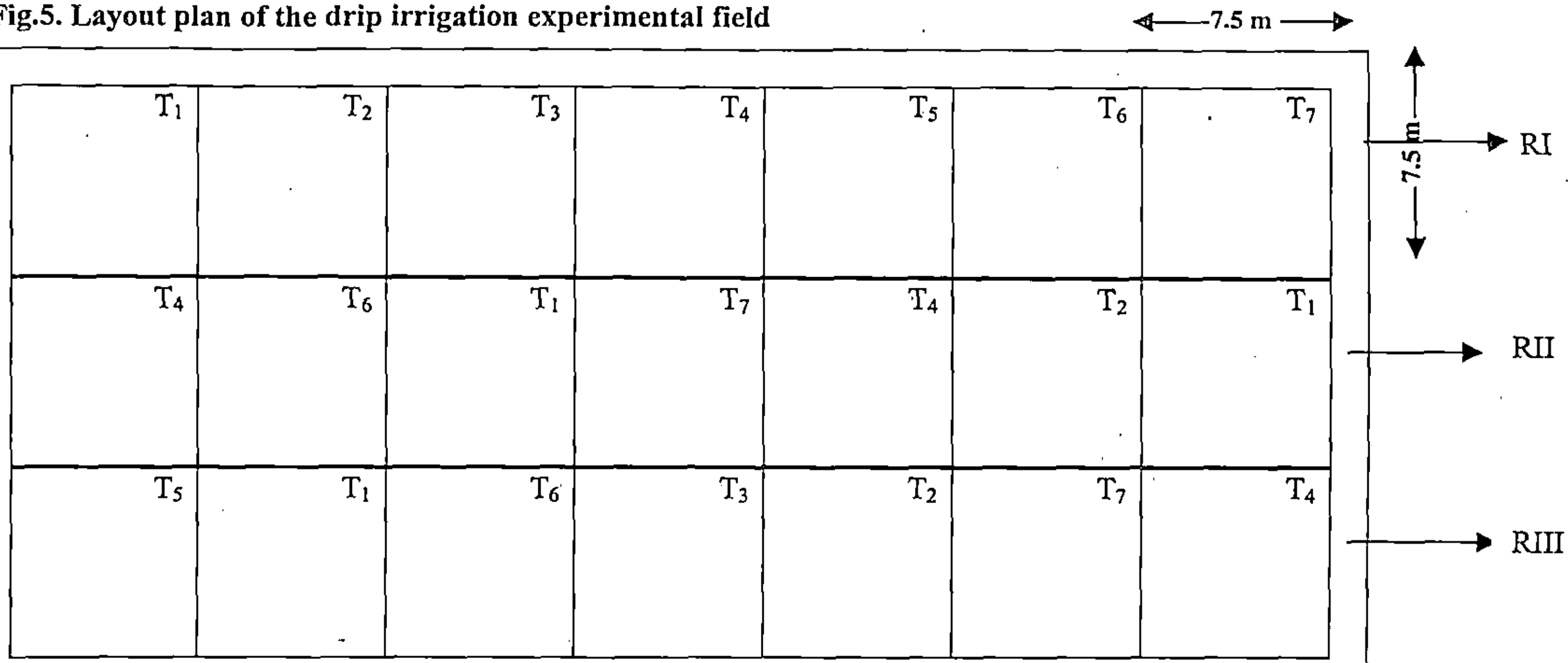
$$\frac{\text{Count rate (cpm) for that particular lateral distance and depth}}{\text{Total cpm for all the lateral distances and depths for a plant}} \times 100$$

Experiment V

3.7 Scheduling of drip irrigation in bush pepper

Six months old bush pepper was planted in the mature coconut garden, at a spacing of 2 m × 1.85 m, during June 1997. The plants were maintained by providing

Fig.5. Layout plan of the drip irrigation experimental field



TREATMENTS

T_1	DRIP 2 L	October-May
T_2	DRIP 4 L	October-May
T_3	DRIP 8 L	October-May
T_4	DRIP 12 L	October-May
T_5	DRIP 16 L	October-May
T_7	POT WATERING	October-May
T_6	DRIP 16 L	October-March

supplementary irrigation under drip system. NPK fertilizer were applied at the rate of 10:5:20 gm plant^{-1} at bimonthly intervals. The experiment was laid out in RBD with seven treatments and three replications. Each net plot had three bush pepper plants. One border row was provided around each net plot. The following drip irrigation rates were scheduled and compared with daily pot irrigation at the rate of 10 L per plant.

1. Drip irrigation 2 litres per day (Oct - May)
2. Drip irrigation 4 litres per day (Oct - May)
3. Drip irrigation, 8 litres per day (Oct – May)
4. Drip irrigation, 12 litres per day (Oct – May)
5. Drip irrigation, 16 litres per day (Oct - May)
6. Drip irrigation, 16 litres per day (Oct - Mar)
7. 10 litres per day, Daily pot irrigation (control) (Oct – May)

To provide drip irrigation, emitters were placed 10 cm away from the planting point. In the case of 2 L drip per day, single emitter of 2 L capacity was used, 10 cm away from the planting point in western direction. For 4 L drip per day, single emitter of 4 L capacity was placed in western direction. For 8 L drip, two 4 L emitters were placed at eastern as well as western direction. For 12 L drip per day, one emitter of 8 L capacity was placed on western direction and 4 L capacity emitter on eastern direction. For 16 L drip per day, two emitters of 8 L capacity each were placed on both sides of the plant. In control, pot watering at the rate of 10 L per plant was given daily.

3.7.1 Observations

All the biometric and biochemical observations stated under experiment No. II were recorded. The soil moisture depletion at different depths and lateral distances were also estimated by gravimetric method.

3.7.2 Soil moisture

Soil samples were collected at 15 days interval using a soil auger, from 2 distances and 2 depths viz. 0-20 and 20-40 cm beginning from position of drippers respectively on each side of the plant in East-West direction. Soil moisture was determined by gravimetric method.

3.7.3 Statistical Analysis

For experiments No. 1, 2 and 4, data were subjected to analysis of variance for completely randomized design. For other two experiments, data were subjected to analysis of covariance by taking the pre-treatment values as the co-variate (Panse and Sukhatme, 1989). The means were ranked by DMRT. LSD was used for ranking the means where the number of treatments were less than four.

Results

RESULTS

Experiment I

4.1 Screening and characterisation of black pepper varieties for water stress tolerance

Preliminary Screening

The water stress tolerance of 44 black pepper varieties/cultivars varied and the relative water content (RWC) and membrane stability of these varieties showed significant difference due to water-stress.

4.1.1 Relative water content

Relative water content of forty four varieties/cultivars grown under no water stress (daily irrigation), two days water stress cycle and four days water stress cycle are shown in Table 4. In all the varieties maximum relative water content was observed in plants subjected to no water stress. The varieties showed considerable variation in their RWC both in water stressed as well as in daily irrigated plants. The daily irrigated plants of varieties Kalluvally–1, Kalluvally–2, Panniyur-1 and Panniyur-4 recorded RWC above 90 per cent. The varieties Ceylon, Cheriyakaniyakaden, Kumbakodi, Kottanadan–1, Nilagiri–4, Panniyur-3 Poonjarmunda and Uthirankotta–2 showed RWC ranging from 80-90 per cent.

The varieties Arivalli, Arikottanadan, Cheriyakaniyakadan, Cholamunda, Chumala, Karimunda, Karimkotta, Kottanadan–2, Neriyamundi, Nilamundi–2, Nilagiri–1 and Nilagiri–4, Perumunda, Sulliya, Thulakodi dried of within two days of water stress.

Table 4: Effect of water - stress on relative water content (RWC) of black pepper varieties / cultivars

Varieties	Water stress levels		
	0	2	4
	RWC (%)		
Arassanimortta	59.2^{o}	28.2^{q}	-
Arivalli	69.5^{kl}	-	-
Arikottanadan	71.4^{p}	-	-
Balankotta-4	57.3^{p}	27.3^{q}	-
Balankotta-2	62.3^{n}	21.0^{r}	-
Ceylon	87.4^{de}	50.0^{g}	-
Cheriyakaniyakadan	85.4^{f}	-	-
Cholamunda	65.2^{m}	-	-
Chumala	54.1^{q}	-	-
Kalluvally-1	92.0^{b}	67.3^{d}	-
Kalluvally-2	95.1^{a}	63.3^{e}	-
Kalluvally-4	77.4^{g}	76.3^{b}	68.1^{d}
Kalluvally-7	70.1^{k}	60.3^{f}	-
Karimunda	77.3^{gh}	-	-
Karimunda-2	69.5^{k}	33.1^{o}	-
Karimkotta	68.2^{l}	-	-
Kumbakodi	87.1^{de}	82.3^{a}	73.3^{a}
Kottanadan-1	82.3^{f}	30.4^{p}	-
Kottanadan-2	52.2^{r}	-	-
Malligesara	75.4^{i}	37.3^{m}	-
Narayakkodi	74.2^{ij}	42.3^{i}	-
Neriyamundi	60.2^{o}	-	-
Nilamundi-2	74.4^{i}	-	-
Nilamundi-2	55.0^{pq}	47.3^{h}	-
Nilagiri-1	74.4^{i}	-	-
Nilagiri-4	84.4^{f}	-	-
Padarpan	74.2^{i}	67.4^{d}	62.0^{f}
Panniyur-1	94.2^{a}	40.6^{j}	-
Panniyur-2	56.4^{p}	30.5^{p}	-
Panniyur-3	86.4^{e}	32.3^{o}	-
Panniyur-4	90.2^{c}	38.3^{l}	-
Panniyur-5	76.3^{h}	72.1^{c}	67.8^{e}
Perumunda	67.0^{lm}	-	-
Perumkodi	74.0^{i}	20.2^{r}	-
Poonjarmunda	80.2^{fg}	76.1^{b}	70.8^{c}
Sreekara	79.8^{fg}	35.0^{n}	-
Sulliya	79.5^{g}	-	-
Thevarmundi	73.4^{j}	32.1^{o}	-
Thulakodi	78.5^{g}	-	-
TMBI	75.3^{i}	35.2^{n}	-
TMB 6	72.3^{k}	39.3^{k}	-
Uthirankotta-1	62.0^{n}	33.3^{o}	-
Uthirankotta-2	81.5^{f}	76.1^{b}	72.8^{b}
Veluthanamben	65.0^{m}	20.0^{r}	-

The interaction means followed by a common letter are not significantly different at 5% level by DMRT

A significant decrease in RWC was observed in plants subjected to two days of water stress and only 29 varieties survived. In plants subjected to two days of water stress maximum RWC was observed in Kumbakodi and least in Veluthanamben.

Relative water content further decreased when plants were exposed to four days water stress and only six varieties viz. Kalluvally-4, Kumbakodi, Padarpan, Panniyur-5, Poonjarmunda and Uthirankotta-2 survived. These varieties showed RWC values of 62 to 73 per cent even after four days of water stress. The lowest RWC among the survived plants was in the variety Padarpan and the highest in Kumbakodi.

4.1.2 Membrane stability

Water stress significantly influenced the membrane stability of the varieties (Table 5). The membrane stability decreased significantly when the plants were subjected to water stress for two days; highest membrane leakage was observed in TMBI and lowest in Kottanadan. Only six varieties survived water stress for four days and the membrane leakage was maximum in Uthirankotta-2 and least in Poonjarmunda.

4.1.3 Water stress tolerance of selected varieties

The six varieties which survived four days of water stress in the preliminary screening showed considerable variation in their biometric, physiological, biochemical and anatomical characters in response to water stress levels (Table 6 to 31).

Table 5: Effect of water - stress on membrane stability (MS) of black pepper varieties / cultivars

Varieties	Water stress levels		
	0	2	4
	MS (%)		
Arassanimortta	39.1^{d}	75.4^{c}	-
Arivalli	25.0^{no}	-	-
Arikottanadan	28.2^{l}	-	-
Balankotta-4	44.3^{c}	91.3^{b}	-
Balankotta-2	44.4^{c}	96.1^{a}	-
Ceylon	32.4^{hi}	74.4^{d}	-
Cheriyakaniyakadan	26.4^{m}	-	-
Cholamunda	34.1^{g}	-	-
Chumala	31.4^{i}	-	-
Kalluvally-1	21.2^{q}	32.3^{t}	-
Kalluvally-2	73.3^{a}	32.0^{t}	-
Kalluvally-4	23.3^{p}	28.3^{v}	40.5^{c}
Kalluvally-7	24.1^{op}	-	-
Karimunda	27.4^{l}	-	-
Karimunda-2	26.3^{m}	59.1^{i}	-
Karimkotta	27.3^{lm}	-	-
Kumbakodi	32.3^{hi}	38.5^{o}	41.8^{b}
Kottanadan-1	17.4^{r}	21.4^{w}	-
Kottanadan-2	26.5^{m}	35.0^{q}	-
Malligesara	25.3^{n}	33.3^{s}	-
Narayakkodi	20.8^{q}	30.0^{u}	-
Neriyamundi	27.4^{l}	-	-
Nilamundi-2	28.3^{kl}	-	-
Nilamundi-1	25.3^{n}	66.4^{f}	-
Nilagiri-1	28.4^{kl}	-	-
Nilagiri-4	24.3^{o}	-	-
Padarpan	30.8^{j}	36.5^{p}	40.8^{c}
Panniyur-1	29.0^{kl}	40.0^{n}	-
Panniyur-2	32.0^{i}	42.3^{m}	-
Panniyur-3	24.2^{o}	49.0^{k}	-
Panniyur-4	36.5^{e}	50.8^{j}	-
Panniyur-5	27.3^{lm}	34.3^{r}	39.3^{d}
Perumunda	16.3^{r}	-	-
Perumkodi	25.2^{n}	-	-
Poonjarmunda	24.2^{o}	26.3^{w}	30.8^{e}
Sreekara	29.2^{k}	60.0^{h}	-
Sulliya	33.1^{h}	-	-
Thevarmundi	56.3^{b}	63.3^{g}	-
Thulakodi	28.1^{l}	67.3^{e}	-
TMBI	16.4^{s}	96.3^{a}	-
TMB 6	26.3^{m}	43.3^{l}	-
Uthirankotta-1	35.3^{f}	-	-
Uthirankotta-2	31.2^{i}	43.3^{l}	47.3^{a}
Veluthanamben	22.4^{p}	26.3^{w}	-

The interaction means followed by a common letter are not significantly different at 5% level by DMRT

Biometric characters

4.1.4 Height

There were significant reduction in height of vines in all the varieties due to waterstress (Table 6). In all the varieties, except Uthirankotta-2 and Panniyur-5 increasing water stress levels decreased the height of the plant. In Uthirankotta-2 and Panniyur-5 mild water stress increased the height, but moderate and severe water stress decreased the height. The maximum rate of decrease in height with water stress was observed in Kumbakodi, followed by Kalluvally-4. The height of Panniyur-5 was relatively less influenced by water stress levels. The height of the variety Padarpan was also not much influenced by moderate water stress. However, severe water stress decreased the height in this variety, sharply.

At 30 DAT and 60 DAT the height of the plants showed more or less similar trend in response to water stress.

4.1.5 Number of leaves

In general the number of leaves per plant decreased due to water stress (Table 7), though significant differences were observed only at 60 DAT. The number of leaves on the variety Poonjarmunda was relatively higher than other varieties. Maximum decrease in number of leaves was observed in Panniyur-5 and Padarpan. In all the varieties severe water stress resulted in considerable decrease in number of leaves per plant at 60 DAT.

Table 6: Effect of water stress on height of black pepper varieties

Varieties	Height (30 DAT) (cm)				Height (60 DAT) (cm)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	28.9^{ab}	21.3^{bc}	23.6^{b}	21.5^{b}	35.3^{bc}	31.3^{bc}	33.0^{bc}	22.4^{cd}
Uthirankotta-2	29.4^{ab}	37.5^{a}	24.3^{ab}	28.0^{ab}	36.3^{b}	44.8^{a}	28.5^{bc}	32.8^{bc}
Kumbakodi	18.3^{bc}	10.3^{bc}	9.3^{c}	9.8^{bc}	20.5^{cd}	13.5^{cd}	10.9^{cd}	13.5^{cd}
Panniyur-5	21.1^{bc}	22.0^{b}	18.5^{bc}	19.0^{bc}	27.5^{bc}	24.5^{bc}	23.5^{bc}	21.0^{cd}
Kalluvally-4	18.1^{bc}	15.0^{bc}	15.9^{bc}	9.6^{bc}	18.8^{cd}	18.3^{cd}	17.8^{cd}	9.5^{d}
Padarpan	31.1^{ab}	28.0^{ab}	25.9^{ab}	11.3^{bc}	33.0^{bc}	30.3^{bc}	30.8^{bc}	12.4^{cd}
Mean	24.5^{a}	22.4^{a}	19.6^{a}	16.1^{b}	28.6^{a}	27.1^{a}	24.1^{a}	18.6^{b}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 7: Effect of water stress on number of leaves of black pepper varieties

Varieties	Number of leaves (30 DAT)				Number of leaves (60 DAT)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	6.0^{a}	3.0^{bcd}	3.5^{abcd}	6.0^{a}	8.5	5.8	4.5	5.0
Uthirankotta-2	3.5^{abcd}	5.8^{ab}	2.3^{cd}	4.0^{abcd}	4.0	3.5	2.3	1.5
Kumbakodi	4.0^{abcd}	3.3^{abcd}	2.3^{cd}	3.0^{bcd}	5.0	2.8	0.5	1.5
Panniyur-5	3.5^{abcd}	3.8^{abcd}	4.8^{abcd}	1.8^{d}	3.5	2.4	2.0	2.3
Kalluvally-4	3.5^{abcd}	2.5^{cd}	2.5^{cd}	3.5^{abcd}	4.5	1.5	1.5	1.5
Padarpan	3.3^{abcd}	4.5^{abcd}	5.0^{abc}	1.8^{d}	4.5	5.4	4.0	1.5
Mean	3.9	3.8	3.4	3.4	5.0^{a}	3.6^{b}	2.5^{c}	2.2^{c}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT
The marginal means of water stress levels of number of leaves at 30 DAT are not significantly different at 5% levels by DMRT
The interaction means of number of leaves at 60 DAT are not significantly different at 5% levels by DMRT

4.1.6 Leaf area

The leaf area of the plants at 60 DAT was significantly influenced by water stress levels (Table 8). The leaf area at 30 DAT showed no significant difference due to water stress. At 60 DAT leaf area decreased with increasing levels of water stress, except in the variety Kalluvally-4, where the decrease in leaf area was observed only with severe water stress.

4.1.7 Internode length

The influence of water stress levels on internodal length were not significant (Table 9) at 30 DAT. At 60 DAT also, the internodal length was not significantly influenced by mild water stress. However, moderate water stress increased the internode length and severe stress decreased it. The interaction between water stress levels and varieties showed significant difference at 30 DAT. But there were no perceivable trends in response to water stress.

4.1.8 Girth of vine

The girth of the vines, 30 days after the start of the stress cycle (DAT) increased due to water stress. Whereas it showed a decrease due to severe water stress at 60 DAT (Table 10). The interactions between the varieties and water stress were not significantly different.

4.1.9 Leaf thickness

The leaf thickness was reduced in varieties, Panniyur-1 and Panniyur-5 due to severe water stress whereas in the other varieties it increased except Kumbkodi and Kalluvally-4 (Table 11). With mild and moderate water stress the responses were

Table 8: Effect of water stress on leaf area of black pepper varieties

Varieties	Leaf area (30 DAT) (cm^2 $Plant^{-1}$)				Leaf area (60 DAT) (cm^2 $Plant^{-1}$)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	146.5	82.5	133.6	133.9	281.3^{a}	184.5^{b}	129.8^{bc}	123.0^{bc}
Uthirankotta-2	109.7	129.3	86.8	109.7	140.0^{bc}	91.7^{cd}	48.8^{cd}	53.0^{cd}
Kumbakodi	97.9	33.2	27.0	56.9	128.3^{bc}	44.6^{d}	10.7^{d}	10.9^{d}
Panniyur-5	56.3	124.0	110.6	110.6	114.3^{c}	69.4^{cd}	65.9^{cd}	47.9^{cd}
Kalluvally-4	65.9	47.0	54.2	56.5	82.8^{cd}	114.6^{c}	92.0^{cd}	40.8^{d}
Padarpan	90.9	105.1	121.0	40.3	54.5^{cd}	38.6^{d}	45.5^{d}	27.4^{d}
Mean	94.5	86.0	88.9	84.7	133.5^{a}	90.6^{b}	65.5^{b}	50.5^{b}

Leaf area recorded at 30 DAT are not significantly different at 5 % levels by DMRT.
The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 9: Effect of water stress on internodal length of black pepper varieties

Varieties	Internode length (30 DAT) (cm)				Internode length (60 DAT) (cm)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	2.8^{cdef}	3.4^{bcd}	3.1^{bcdef}	4.3^{ab}	2.9	2.8	2.9	3.8
Uthirankotta-2	4.5^{ab}	4.1^{ab}	4.3^{ab}	3.7^{bcd}	4.8	3.5	3.7	3.0
Kumbakodi	1.8^{fg}	1.3^{g}	1.3^{g}	1.3^{g}	2.2	2.1	2.1	1.5
Panniyur 5	4.3^{ab}	3.5^{bcd}	3.4^{bcd}	5.4^{a}	3.9	3.4	3.3	3.1
Kalluvally-4	2.0^{efg}	1.8^{fg}	2.3^{defg}	1.9^{efg}	2.3	2.1	2.5	1.5
Padarpan	2.8^{cdef}	2.5^{defg}	3.2^{bcdef}	2.0^{fg}	2.7	2.8	3.2	2.0
Mean	3.0	2.8	2.9	3.1	3.1^{b}	2.8^{bc}	3.8^{a}	2.5^{c}

At 30 DAT the marginal means are not significantly different at 5 % levels by DMRT
The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT
The marginal means at 30 DAT and interaction means of inter nodal length at 60 DAT are not significantly different at 5% levels by DMRT

Table 10: Effect of water stress on girth of black pepper varieties

Varieties	Girth (30 DAT) (mm)				Girth (60 DAT) (mm)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	0.31	0.48	0.47	0.46	0.41	0.38	0.38	0.33
Uthirankotta-2	0.31	0.43	0.46	0.44	0.45	0.31	0.39	0.26
Kumbakodi	0.40	0.34	0.35	0.39	0.43	0.36	0.35	0.38
Panniyur-5	0.24	0.39	0.34	0.45	0.45	0.36	0.40	0.27
Kalluvally-4	0.43	0.40	0.38	0.41	0.40	0.43	0.43	0.38
Padarpan	0.41	0.50	0.37	0.43	0.38	0.46	0.33	0.33
Mean	0.35^{c}	0.42^{b}	0.46^{b}	0.50^{a}	0.42^{a}	0.38^{b}	0.38^{b}	0.33^{b}

The interaction means are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 11: Effect of water stress on leaf thickness and root length of black pepper varieties

Varieties	Leaf thickness (30 DAT) (mm)				Root length (60 DAT) (cm)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	28.3^{abc}	28.5^{abc}	28.0^{abc}	30.3^{d}	15.8	15.3	14.5	12.3
Uthirankotta-2	25.5^{def}	28.5^{abc}	28.3^{abc}	28.0^{bc}	7.3	19.5	19.8	14.3
Kumbakodi	25.5^{def}	20.0^{j}	23.0^{fgh}	25.8^{de}	8.3	3.1	4.3	7.8
Panniyur-1	28.5^{abc}	20.8^{ij}	25.8^{de}	25.3^{def}	--	--	--	--
Panniyur-5	25.8^{de}	24.3^{efg}	22.5^{ghi}	24.5^{ef}	9.8	6.5	20.0	18.0
Kalluvally-4	28.3^{abc}	28.3^{abc}	22.0^{hc}	28.3^{abc}	6.3	4.8	5.6	4.5
Padarpan	26.8^{cd}	26.0^{de}	28.3^{abc}	29.5^{ab}	12.3	11.3	14.3	13.1
Mean	27.0^{b}	25.2^{c}	25.4^{c}	27.4^{a}	10.0	10.1	11.4	10.4

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT
The observations on root length was not significantly different at 5 % levels by DMRT

highly variable but no definite trend could be discerned. Conspicuous increases in leaf thickness due to severe water stress were observed in varieties Padarpan, Poonjarmunda and Uthirankotta-2.

4.1.10 Root length

The root length was not significantly influenced due to water stress or interactions between water stress and varieties (Table 11).

4.1.11 Root dry weight

The root dry weight decreased, sharply, due to mild water stress in varieties Uthirankotta-2, Kalluvally-4 and Padarpan (Table 12). The root dry weight did not vary in Panniyur-5 due to water stress. In Uthirankotta-2 water stress decreased the root dry weight.

Kumbakodi, Poonjarmunda and Kalluvally-4 showed significant decrease in root dry weight with higher levels of water-stress. At severe water stress the varieties Kalluvally-4, Padarpan, Kumbakodi and Poonjarmunda showed very low root dry weight.

4.1.12 Shoot dry weight

The shoot dry weight decreased significantly in the variety, Padarpan with higher water–stress levels (Table 12). In Kalluvally-4 and Panniyur-5 mild water stress increased the shoot dry weight. However, moderate and severe water stress decreased the shoot dry weight considerably. The shoot dry weight of Kumbakodi was not significantly influenced by water stress.

Table 12: Effect of water stress on root dry weight and shoot dry weight of black pepper varieties

Varieties	Root dry weight (60 DAT) (g)				Shoot dry weight (60 DAT) (g)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	0.19^{ab}	0.19^{ab}	0.15^{b}	0.15^{b}	0.42^{b}	0.30^{bc}	0.39^{bc}	0.42^{b}
Uthirankotta- 2	0.24^{a}	0.12^{b}	0.19^{ab}	0.19^{ab}	0.49^{ab}	0.25^{c}	0.57^{a}	0.45^{ab}
Kumbakodi	0.17^{ab}	0.18^{ab}	0.14^{b}	0.14^{b}	0.50^{ab}	0.50^{ab}	0.40^{b}	0.42^{b}
Panniyur-5	0.21^{ab}	0.21^{ab}	0.20^{ab}	0.24^{a}	0.21^{c}	0.31^{bc}	0.24^{c}	0.24^{c}
Kalluvally- 4	0.25^{a}	0.21^{ab}	0.15^{b}	0.10^{b}	0.20^{c}	0.40^{b}	0.22^{c}	0.16^{c}
Padarpan	0.20^{ab}	0.13^{b}	0.15^{b}	0.13^{b}	0.40^{b}	0.31^{bc}	0.28^{b}	0.24^{c}
Mean	0.21^{a}	0.17^{b}	0.16^{b}	0.16^{b}	0.37	0.35	0.35	0.32

The marginal means of shoot dry weight are not significantly different at 5 % levels by DMRT.
The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 13: Effect of water stress on total dry matter production and root:shoot ratio of black pepper varieties

Varieties	Total dry matter (60 DAT) (g)				Root:shoot ratio (60 DAT)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	0.63^{ab}	0.50^{b}	0.55^{ab}	0.58^{ab}	0.50^{bc}	0.65^{b}	0.35^{c}	0.44^{bc}
Uthirankotta-2	0.73^{a}	0.40^{bc}	0.68^{ab}	0.70^{ab}	0.55^{bc}	0.53^{bc}	0.35^{c}	0.35^{c}
Kumbakodi	0.63^{ab}	0.60^{ab}	0.54^{ab}	0.45^{bc}	0.34^{c}	0.36^{c}	0.35^{c}	0.33^{c}
Panniyur-5	0.34^{bc}	0.60^{ab}	0.48^{b}	0.48^{bc}	1.1^{a}	0.88^{ab}	0.83^{b}	1.00^{a}
Kalluvally-4	0.40^{bc}	0.60^{ab}	0.35^{bc}	0.25^{c}	1.1^{a}	0.50^{bc}	0.70^{b}	0.50^{bc}
Padarpan	0.58^{ab}	0.55^{ab}	0.75^{a}	0.38^{bc}	0.60^{b}	0.43^{bc}	0.53^{bc}	0.53^{bc}
Mean	0.55^{a}	0.54^{a}	0.56^{a}	0.47^{b}	0.70^{a}	0.56^{b}	0.52^{b}	0.53^{b}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

4.1.13 Total dry matter

Severe water stress decreased the total dry matter in all the varieties except Panniyur-5. The total dry matter increased in varieties Panniyur-5 and Kalluvally-4 due to mild water stress (Table 13). In Uthirankotta-2 mild water stress decreased the dry matter production whereas at moderate and severe water stress the decrease was not significant.

4.1.14 Root/shoot ratio

Water stress decreased the root/shoot ratio. The root/shoot ratio decreased in all the varieties except in Kumbakodi and Padarpan (Table 13).

The decrease in root/shoot ratio with water stress was sharp in Kalluvally-4 and Uthirankotta-2. In varieties Padarpan, Panniyur-5, Poonjarmunda and Kumbakodi the influence of water stress on root/shoot ratio was relatively less conspicuous. Panniyur-5 and Kalluvally-4 recorded high root/shoot ratio as compared to other varieties.

Physiological characters

4.1.15 Stomatal conductance

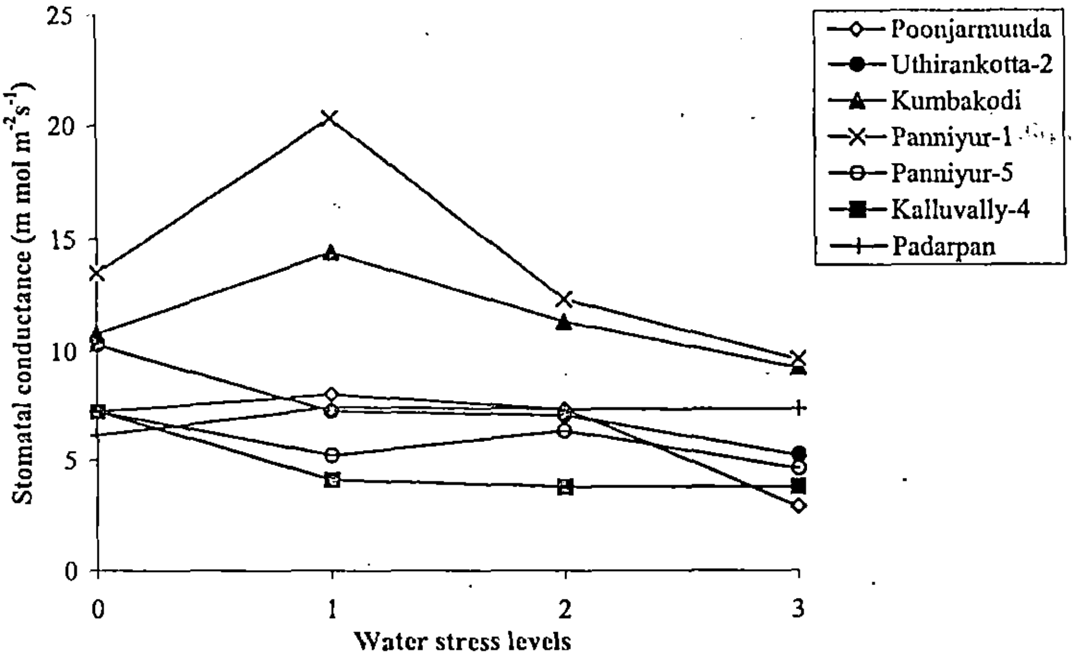
The stomatal conductance of black pepper varieties decreased in general due to water stress (Table 14). The stomatal conductance decreased with increase in the levels of water stress.

Daily irrigated plants of the variety Panniyur-1 recorded more stomatal conductance than all other varieties. The least conductance was observed in Kalluvally-4 when exposed to moderate and severe water stress. The varieties

Table 14: Stomatal conductance, transpiration rate and leaf temperature of black pepper varieties at 0800 hrs.

Varieties	Stomatal conductance (m mol $m^{-2}s^{-1}$)				Transpiration rate (µg cm^{-2} s^{-1})				Leaf temperature (°C)			
	Water stress levels				Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3	0	1	2	3
Poonjarmunda	7.2^{i}	8.0^{h}	7.3^{i}	2.9^{n}	1.2^{def}	0.95^{f}	1.5^{def}	1.2^{def}	29.2^{f}	30.1^{cde}	29.3^{f}	29.3^{def}
Uthirankotta-2	10.3^{f}	7.2^{i}	7.0^{i}	5.2^{k}	2.3^{c}	1.50^{de}	1.3^{def}	1.1^{ef}	30.3^{c}	33.5^{b}	29.4^{def}	34.1^{ab}
Kumbakodi	10.8^{ef}	14.4^{b}	11.3^{e}	9.2^{g}	3.2^{b}	2.4^{c}	1.2^{def}	3.1^{b}	29.3^{f}	29.5^{def}	29.4^{def}	29.6^{cdef}
Panniyur-1	13.5^{c}	20.3^{a}	12.3^{d}	9.6^{g}	4.0^{a}	4.5^{a}	4.2^{a}	1.5^{de}	29.3^{ef}	29.5^{def}	29.5^{def}	29.4^{def}
Panniyur-5	7.2^{i}	5.2^{k}	6.3^{j}	4.6^{l}	2.5^{c}	1.6^{d}	1.5^{def}	2.2^{c}	29.3^{ef}	29.2^{f}	29.4^{def}	29.4^{def}
Kalluvally-4	7.2^{i}	4.1^{lm}	3.8^{m}	3.8^{m}	1.5^{de}	1.3^{def}	1.3^{def}	1.5^{def}	29.5^{def}	34.5^{a}	29.1^{f}	30.3^{c}
Padarpan	6.1^{j}	7.4^{i}	7.3^{i}	7.3^{i}	2.3^{c}	3.4^{a}	3.4^{b}	4.0^{a}	29.5^{def}	30.3^{c}	29.1^{f}	30.2^{cd}
Mean	9.5^{a}	7.9^{c}	6.1^{d}	8.9^{b}	2.3^{a}	2.0^{b}	2.1^{b}	2.3^{a}	29.5^{c}	30.9^{a}	29.3^{c}	30.3^{b}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT



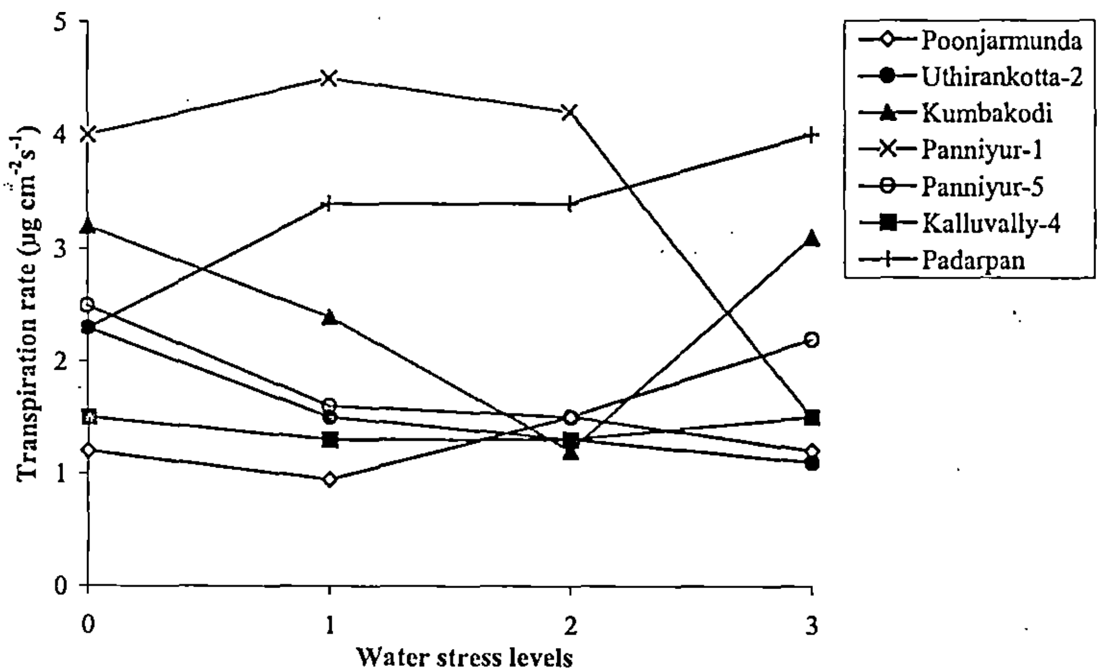


Fig. 6. Stomatal conductance and transpiration rate of black pepper varieties at 0800hrs

Panniyur-1 and Kumbakodi showed the highest stomatal conductance even when exposed to severe water stress.

There was a conspicuous increase in stomatal conductance due to mild water stress in Panniyur-1. In severely stressed plants the lowest stomatal conductance was observed in Poonjarmunda and the highest in Panniyur-1.

In the afternoon also (Table 15) the stomatal conductance varied significantly due to the influence of water stress and interaction of varieties and water stress. A decrease in the conductance was observed in all the varieties during the afternoon as compared to the morning hours. The varieties Uthirankotta-2, Panniyur-1, Kumbakodi and Panniyur-5 showed relatively higher stomatal conductance in unstressed plants. When exposed to mild water stress the stomatal conductance increased in Kumbakodi, Poonjarmunda, Uthirankotta-2 and Padarpan. Severe water stress resulted in a decrease in stomatal conductance in all the varieties except to Padarpan. Severely stressed plants of Uthirankotta-2, Panniyur-5 and Panniyur-1 recorded relatively higher stomatal conductance, as compared to other varieties. The variety Panniyur-5 showed most steady values of stomatal conductance when exposed to water stress.

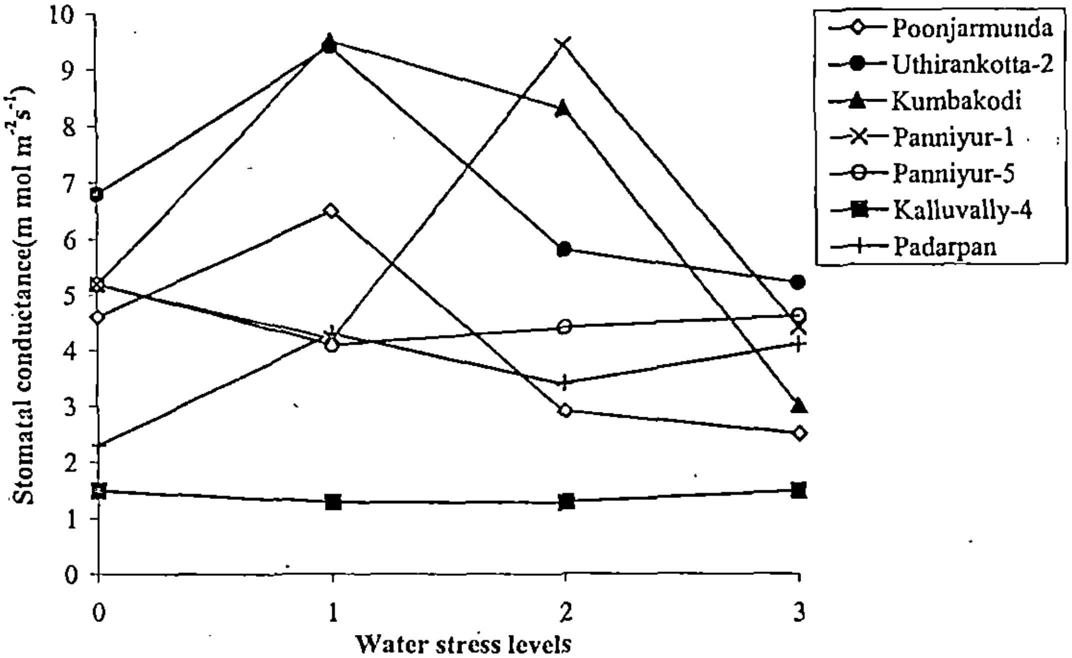
4.1.16 Transpiration rate

The rate of transpiration (TR) recorded at 8 A.M. (Table 14) showed significant decrease due to mild and moderate water stress while no significant influence was observed due to severe water stress. The transpiration rate showed variation depending on varieties due to the interactions between the varieties and water stress. In plants with out water stress, high rates of transpiration were observed in varieties Panniyur-1 followed by Kumbakodi.

Table 15: Stomatal conductance, transpiration rate and leaf temperature of black pepper varieties at 1400 hrs

Varieties	Stomatal conductance (m mol $m^{-2}s^{-1}$)				Transpiration rate (μg $cm^{-2}s^{-1}$)				Leaf temperature (°C)			
	Water stress levels				Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3	0	1	2	3
Poonjarmunda	4.6^{f}	6.5^{c}	2.9^{i}	2.5^{j}	1.2^{ef}	1.3^{def}	1.3^{de}	1.1^{ef}	30.8	32.3	29.8	32.0
Uthirankotta-2	6.8^{c}	9.4^{a}	5.8^{d}	5.2^{e}	3.0^{a}	1.2^{ef}	1.3^{def}	1.2^{ef}	31.0	33.5	28.6	32.5
Kumbakodi	5.2^{e}	9.5^{a}	8.3^{b}	3.0^{i}	3.3^{a}	1.4^{de}	3.1^{a}	2.2^{bc}	31.7	34.1	28.9	34.3
Panniyur-1	5.2^{e}	4.2^{g}	9.4^{a}	4.4^{fg}	3.2^{a}	3.4^{a}	1.2^{ef}	0.71^{f}	31.7	33.5	29.4	33.6
Panniyur-5	5.2^{h}	4.1^{g}	4.4^{fg}	4.6^{i}	1.8^{cd}	1.5^{de}	2.1^{bc}	1.3^{de}	32.3	33.9	28.8	33.8
Kalluvally-4	1.5^{k}	1.3^{k}	1.3^{k}	1.5^{k}	2.2^{bc}	2.4^{b}	2.5^{b}	1.3^{de}	31.2	32.3	29.1	32.9
Padarpan	2.3^{j}	4.3^{fg}	3.4^{h}	4.1^{g}	2.1^{bc}	2.2^{bc}	1.3^{de}	1.4^{de}	30.0	33.3	29.1	33.2
Mean	9.5^{a}	7.9^{c}	6.1^{d}	8.8^{b}	1.9^{b}	1.8^{b}	1.3^{c}	2.4^{a}	31.7^{b}	33.3^{a}	29.5^{c}	33.3^{a}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT
The interaction means of leaf temperature are not significantly different at 5% levels by DMRT



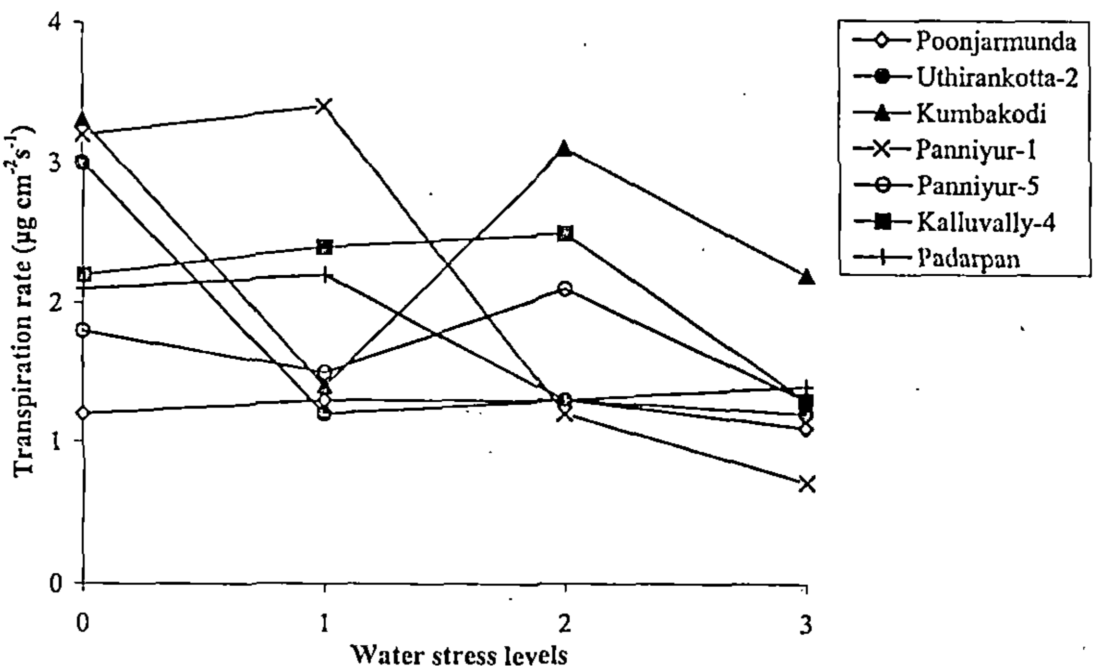


Fig.7. Stomatal conductance and transpiration rate of black pepper varieties at 1400hrs.

In mildly water stressed plants maximum transpiration rate was observed in Panniyur-1, followed by Padarpan and Kumbakodi. In moderate water stress also Panniyur-1 and Padarpan showed higher rate of transpiration. When the water stress were increased to highest level, Panniyur-1 showed a dip in TR.

In severely stressed plants maximum transpiration was observed in Padarpan followed by Kumbakodi at 2 P.M. (Table 15). The varieties Kumbakodi, Panniyur-1 and Uthirankotta-2 recorded higher TR in unstressed plants. Mild water stress resulted in maximum TR in Panniyur-1 which showed a dip with higher levels of water stress. Among the severely stressed plants, Kumbakodi showed maximum and Panniyur-1 minimum TR.

4.1.17 Leaf temperature

The leaf temperature of pepper varieties subjected to different water stress levels are given in (Table 15). Leaf temperature showed a marginal increase in all the varieties except Panniyur-5 due to mild water stress in comparison with control. Significantly high leaf temperature was observed in Kalluvally-4 followed by Uthirankotta-2 and least in Panniyur-5 when exposed to mild water stress. In severely and moderately stressed plants the leaf temperature did not show any definite pattern even though it varied significantly.

In the after noon (Table 15) there were no significant difference in leaf temperatures due to the interactions of water stress and varieties. The water stress increased the leaf temperature except in moderate water stress.

4.1.18 *Biochemical characters*

4.1.18.1 Chlorophyll

Water stress significantly influenced the chlorophyll a content of black pepper varieties (Table 16). Mild water stress decreased chlorophyll a content in Poonjarmunda and Kalluvally-4 whereas in other varieties an increase was noticed. In moderate stress chlorophyll a content was decreased in all the varieties except Poonjarmunda and Uthirankotta-2. Severe stress decreased chlorophyll content in all the varieties.

Mild water stress increased chlorophyll b content in Poonjarmunda, Kalluvally-4 and Padarpan. Decreased chlorophyll b content was observed in Uthirankotta-2, due to moderate water stress. Chlorophyll b content was reduced in Poonjarmunda and Uthirankotta-2 due to severe stress.

Total chlorophyll content was not significantly influenced by water stress levels or interactions between varieties and water stress levels.

4.1.18.2 Epicuticular wax

The epicuticular wax content varied with water stress and their interactions (Table 17). The wax content increased in general with water stress and maximum wax content was in plants exposed to severe water stress. The wax content was relatively high in varieties Padarpan and Panniyur-5 followed by Kalluvally-4, Kumbakodi and Poonjarmunda. Panniyur-1 showed very low epicuticular wax. The percentage increase in epicuticular wax, over control was maximum in Kalluvally-4 followed by Panniyur-1 and the minimum increase was in Panniyur-5.

Table 16: Effect of water stress on chlorophyll content of black pepper varieties

Varieties	Chlorophyll a (mg g pl^{-1})				Chlorophyll b (mg g pl^{-1})				Total chlorophyll (mg g pl^{-1})			
	Water stress levels				Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3	0	1	2	3
Poonjarmunda	0.83^{a}	0.60^{c}	1.60^{g}	0.70^{ab}	0.60^{c}	0.84^{a}	0.75^{a}	0.45^{ef}	1.70	1.50	1.70	1.15
Uthirankotta-2	0.87^{a}	1.00^{e}	0.90^{a}	0.72^{ab}	0.75^{a}	0.65^{b}	0.40^{ef}	0.55^{d}	1.70	1.40	1.60	1.55
Kumbakodi	0.50^{cd}	1.30^{f}	0.50^{cd}	0.48^{cd}	0.37^{ef}	0.35^{ef}	0.35^{ef}	0.35^{ef}	1.00	1.50	1.10	0.95
Panniyur-5	0.75^{ab}	0.75^{ab}	0.44^{cd}	0.39^{cd}	0.35^{ef}	0.35^{ef}	0.40^{ef}	0.30^{f}	1.40	1.05	0.75	1.01
Kalluvally-4	0.65^{b}	0.62^{c}	0.55^{cd}	0.60^{c}	0.35^{ef}	0.50^{e}	0.30^{f}	0.30^{f}	1.00	1.09	1.00	0.95
Padarpan	0.60^{c}	0.90^{a}	0.35^{d}	0.50^{cd}	0.30^{f}	0.60^{c}	0.30^{f}	0.28^{f}	1.65	1.55	0.60	1.25
Mean	0.70^{c}	0.86^{a}	0.72^{b}	0.57^{d}	0.45^{d}	0.55^{a}	0.42^{b}	0.37^{c}	1.21	1.35	1.13	1.14

The marginal means of total chlorophyll are not significantly different at 5 % levels by DMRT
The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 17: Effect of water stress on epicuticular wax content of black pepper varieties

Varieties	Epicuticular wax (mg 100 mg^{-1}) Water stress levels				% change over control
	0	1	2	3	
Poonjarmunda	2.5^{gh}	1.9^{i}	2.1^{i}	3.7^{c}	+48
Uthirankotta-2	1.5^{j}	1.1^{k}	1.9^{hi}	3.4^{d}	+107
Kumbakodi	2.5^{gh}	1.3^{k}	1.3^{jk}	4.0^{ab}	+60
Panniyur-1	1.0^{k}	1.8^{i}	1.9^{h}	2.4^{h}	+140
Panniyur-5	2.7^{ef}	2.6^{fg}	3.6^{d}	4.1^{ab}	+52
Kalluvally-4	1.6^{j}	2.8^{ef}	2.9^{e}	4.0^{b}	+150
Padarpan	3.5^{d}	3.7^{c}	1.5^{j}	4.3^{a}	+23
Mean	2.1^{b}	2.7^{b}	2.0^{b}	3.6^{a}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 18: Effect of water stress on proline content of black pepper varieties

Varieties	Proline (µg g^{-1}) Water stress levels				% change over control
	0	1	2	3	
Poonjarmunda	0.57^{k}	1.1^{ij}	1.1^{ij}	1.3^{ghi}	+128
Uthirankotta-2	1.4^{gh}	3.8^{a}	2.1^{cd}	2.3^{c}	+64.3
Kumbakodi	1.8^{de}	1.3^{ghi}	2.3^{c}	2.9^{b}	+61.1
Panniyur-1	2.0^{d}	2.1^{cd}	1.9^{d}	2.3^{c}	+15.0
Panniyur-5	0.9^{j}	2.0^{cd}	1.5^{gh}	1.7^{ij}	+80.9
Kalluvally-4	1.1^{ij}	2.0^{d}	0.97^{j}	1.5^{efg}	+36.6
Padarpan	1.5^{fgh}	1.2^{hij}	1.0^{ij}	1.9^{def}	+6.7
Mean	1.3^{c}	1.9^{a}	1.5^{b}	2.0^{a}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

4.1.19 Solutes

4.1.19.1 Proline

Proline content in the fresh leaves of black pepper showed significant variations due to water stress, and their interactions (Table 18). Water stress increased the proline content of the leaves. In mild stress, maximum proline content was observed in Uthirankotta-2 and minimum in Poonjarmunda. Mild water stress decreased the proline content in varieties Kumbakodi and Padarpan. In Poonjarmunda, Uthirankotta-2, Panniyur-5 and Kalluvally-4 showed a sharp increase in proline content. Similar pattern was also observed in Panniyur-5 and Kalluvally-4. In moderately stressed plants maximum proline content was observed in Panniyur-5 followed by Kalluvally-4 and Poonjarmunda; other varieties showed relatively low proline content. The varieties Poonjarmunda, Panniyur-5 and Kalluvally-4 showed relatively low proline content as compared to Uthirankotta-2, Kumbakodi and Panniyur-1 at severe water stress.

4.1.19.2 Total sugar

Total sugar content decreased due to water stress. Total sugar content of the plants varied with varieties, water stress levels and their interactions (Table 19). Among the varieties, Kalluvally-4 showed maximum total sugar, followed by Poonjarmunda and Padarpan at severestress. The minimum total sugar content was observed in the variety Panniyur-5. In varieties Poonjarmunda, Kumbakodi, Kalluvally-4 and Padarpan the sugar content increased due to increasing levels of water stress. There was a decrease in sugar content, due to increase in water stress levels, in varieties like Uthirankotta-2, Panniyur-1 and Panniyur-5. A sharp increase

Table 19: Effect of water stress on total sugar content of black pepper varieties

Varieties	Total sugar (mg 100mg^{-1})			
	Water stress levels			
	0	1	2	3
Poonjarmunda	10.9^{gh}	20.4^{defg}	25.5^{cdef}	40.8^{b}
Uthirankotta-2	35.9^{bl}	13.2^{efgh}	21.5^{defg}	14.7^{efgh}
Kumbakodi	10.8^{gh}	22.8^{defg}	26.0^{cde}	16.8^{defgh}
Panniyur-1	28.8^{bcd}	6.8^{h}	10.5^{gh}	20.8^{defg}
Panniyur-5	26.4^{cde}	13.2^{efgh}	18.0^{defgh}	12.6^{fgh}
Kalluvally-4	13.0^{efgh}	21.5^{defg}	25.5^{cdef}	55.5^{a}
Padarpan	17.0^{defgh}	14.7^{efgh}	19.0^{defgh}	29.3^{bcd}
Mean	23.8^{a}	19.5^{c}	18.1^{b}	22.5^{d}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 20: Effect of water stress on amino acid content of black pepper varieties

Varieties	Total amino acid (mg 100 mg^{-1})			
	Water stress levels			
	0	1	2	3
Poonjarmunda	1.9^{ijkl}	1.6^{l}	2.0^{aijkl}	2.7^{bcd}
Uthirankotta-2	3.2^{a}	1.8^{jkl}	2.2^{fghij}	2.4^{cdefgh}
Kumbakodi	3.1^{ab}	1.7^{kl}	2.0^{hijkl}	2.2^{fghl}
Panniyur-1	2.3^{defghi}	2.0^{hijkl}	2.3^{efghi}	2.7^{bcde}
Panniyur-5	2.0^{ghijk}	2.1^{ghijk}	2.6^{cdef}	2.8^{bc}
Kalluvally-4	2.3^{coefgh}	2.2^{fghij}	1.8^{jkl}	1.9^{ijkl}
Padarpan	1.9^{ijkl}	1.9^{ijkl}	2.5^{cdefg}	2.7^{bc}
Mean	2.4^{a}	1.9^{c}	2.2^{b}	2.5^{a}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

in sugar content was observed in Kalluvally-4, Poonjarmunda and Padarpan subjected to severe water stress.

4.1.19.3 Total Amino acids

The total amino acid content varied with water stress levels and the interactions (Table 20). The amino acid content of the plants decreased due to mild water stress in varieties Uthirankotta-2 and Kumbakodi. In Panniyur–5, Kalluvally-4 and Padarpan mild water stress did not significantly influence the amino acid content. The amino acid content showed an increasing trend due to severe stress in varieties Poonjarmunda, Panniyur-1, Panniyur-5 and Padarpan and a decreasing trend in varieties Kumbakodi, Uthirankotta-2 and Kalluvally-4

4.1.19.4 Mineral nutrients

The concentration of mineral nutrients like N, P, K, Ca, Mg, Fe, Mn, Zn and Cu in the leaves of black pepper varieties varied significantly due to water stress (Table 21-24).

The nitrogen content of the leaves increased with increasing levels of water stress (Table 21). The interactions were not significant. However, maximum nitrogen content was recorded by Panniyur-5 and least by Kumbakodi, when severely stressed.

In unstressed plants phosphorous content was highest in varieties Poonjarmunda and Uthirankotta-2 (Table 22). The P content of other varieties were significantly low. The P content decreased with water stress levels in Uthirankotta-2. In Poonjarmunda P content decreased with increase in water stress levels except when the water stress were severe, where a sharp increase in leaf P content was observed.

Table 21: Effect of water stress on nitrogen content of black pepper varieties

Varieties	Nitrogen (%)			
	Water stress levels			
	0	1	2	3
Poonjarmunda	1.3	1.4	1.5	1.8
Uthirankotta-2	1.9	2.1	2.3	2.3
Kumbakodi	1.2	1.3	1.3	1.6
Panniyur-5	2.1	2.2	2.3	2.4
Kalluvally-4	1.6	1.6	1.8	2.0
Padarpan	1.8	1.9	2.1	2.3
Mean	1.7^{d}	1.8^{c}	1.9^{b}	2.1^{a}

The interaction means are not significantly different at 5 % levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 22: Effect of water stress on phosphorous and potassium content of black pepper varieties

Varieties	Phosphorous (%)				Potassium (%)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	0.26^{a}	0.17^{b}	0.20^{b}	0.38^{a}	2.4^{d}	2.0^{d}	1.9^{d}	3.7^{a}
Uthirankotta-2	0.26^{a}	0.19^{b}	0.14^{c}	0.17^{b}	2.8^{c}	2.9^{c}	2.9^{c}	3.4^{b}
Kumbakodi	0.11^{d}	0.14^{c}	0.16^{c}	0.16^{c}	3.1^{c}	3.0^{c}	3.1^{c}	3.7^{a}
Panniyur-5	0.16^{c}	0.15^{c}	0.25^{a}	0.19^{b}	3.1^{c}	3.4^{b}	3.8^{a}	3.7^{a}
Kalluvally-4	0.11^{d}	0.16^{c}	0.11^{d}	0.16^{c}	3.0^{c}	3.1^{c}	2.9^{c}	3.5^{a}
Padarpan	0.11^{d}	0.19^{b}	0.11^{d}	0.21^{b}	3.2^{b}	3.1^{c}	2.6^{d}	3.6^{a}
Mean	0.17^{b}	0.17^{b}	0.16^{b}	0.21^{a}	2.9^{b}	2.9^{b}	2.9^{b}	3.6^{a}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

The P content showed an increasing trend with higher levels of water stress in all the varieties except Uthirankotta-2.

The potassium content of the varieties Kumbakodi, Panniyur-5, Kalluvally-4 and Padarpan were higher than that in Poonjarmunda and Uthirankotta-2, when the plants were not water stressed (Table 22). In Poonjarmunda mild and moderate water stress decreased the K content, but severe water stress increased it. In Uthirankotta-2, Kumbakodi and Kalluvally-4 mild and moderate water stress did not significantly influence the K content. However, severe water stress increased the K content in these varieties. The variety Padarpan also showed similar trend except the moderately water stressed plants in which a reduction in K content was observed. The K content showed a steady increase with water stress upto moderate levels, in Panniyur-5. Further increase in water stress did not significantly influence the leaf potassium content.

The calcium content of the leaves did not vary among the varieties except in Padarpan which had high level of leaf Ca (Table 23). The Ca content of the leaf in Uthirankotta-2 and Panniyur–5 increased significantly when subjected to severe water stress. Other levels of water stress were not having significant influence on Ca content of leaves.

The magnesium content of leaves did not vary due to water stress (Table 23). Mild water stress showed a decreasing trend in Mg content of the leaves in all the varieties except Padarpan.

The micronutrients (Fe, Mn, Zn, Cu) of the leaves varied with varieties (Table 24). Maximum Fe content was observed in Panniyur-5 and the minimum was

Table 23: Effect of water stress on calcium and magnesium content of black pepper varieties

Varieties	Calcium (%)				Magnesium (%)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Poonjarmunda	2.2^{bc}	2.2^{bc}	2.1^{c}	2.4^{ab}	0.5	0.2	0.4	0.4
Uthirankotta-2	2.0^{c}	2.1^{c}	2.2^{bc}	2.8^{ab}	0.4	0.4	0.4	0.5
Kumbakodi	2.0^{c}	2.0^{c}	2.1^{c}	1.6^{c}	0.2	0.2	0.2	0.4
Panniyur-5	2.0^{c}	1.6^{c}	2.2^{bc}	3.0^{a}	0.3	0.3	0.5	0.4
Kalluvally-4	2.1^{c}	2.3^{b}	2.5^{ab}	2.3^{b}	0.4	0.3	0.3	0.4
Padarpan	2.6^{ab}	2.3^{b}	2.1^{c}	2.0^{c}	0.3	0.4	0.3	0.3
Mean	2.3	2.1	2.2	2.4	0.4	0.3	0.4	0.4

The marginal means of Ca and the marginal means and the interactions of Mg are not significantly different at 5 % levels by DMRT.
The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

in Padarpan when there was no water stress. The Fe content in Panniyur–5 decreased due to water stress whereas in Padarpan the decrease was observed only in response to mild water stress. With moderate and severe stress, the Fe content increased and reached values comparable to the control plants. In general water stress decreased the Fe content in all the varieties except in Kalluvally-4, Kumbakodi and Padarpan where the iron content increased due to severe water stress.

The manganese content of the leaves showed significant variation between varieties and water stress levels (Table 24). In control plants, Mn content was maximum in Poonjarmunda and minimum in Padarpan. The varieties Panniyur–5 and Kalluvally-4 showed low Mn content whereas Poonjarmunda, Uthirankotta-2 and Kumbakodi had relatively higher levels of Mn. The Mn content decreased with mild water stress except in Kalluvally-4 and Padarpan where it increased due to mild and moderate water stress. Severe water stress decreased the Mn content in all the varieties.

The Zn content was maximum in Uthirankotta-2 and minimum in Kumbakodi when the plants were not water stressed. The Zn content of the leaves decreased due to water stress in Poonjarmunda and Uthirankotta-2 and increased in Kumbakodi.

When the plants were not water stressed, maximum Cu content was observed in Panniyur–5 and the minimum in Kumbakodi and Uthirankotta-2. The variety Padarpan showed relatively higher content of Cu than Panniyur–5, Poonjarmunda, Uthirankotta-2 and Kumbakodi under mild stress. In general water stress increased the Cu content of leaves. However, in Panniyur–5 mild and moderate water stress decreased the Cu content. Similarly in Kalluvally-4, mild water stress decreased the

Table 24: Effect of water stress on micronutrient content of black pepper varieties

Variety	Iron (ppm)				Manganese (ppm)				Zinc (ppm)				Copper (ppm)			
	Water stress levels				Water stress levels				Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Poonjarmunda	441.5^{f}	311.0^{k}	321.5^{j}	331.5^{i}	234.0^{b}	211.0^{c}	221.0^{b}	229.0^{b}	117.0^{g}	87.0^{j}	92.0^{i}	94.0^{i}	41.0^{l}	53.0^{i}	48.0^{k}	56.0^{h}
Uthirankotta-2	416.5^{g}	306.5^{l}	301.5^{m}	332.5^{i}	192.5^{d}	121.5^{g}	126.5^{g}	133.0^{g}	202.0^{b}	112.0^{g}	122.0^{f}	130.0^{e}	38.0^{m}	61.0^{g}	71.0^{e}	115.0^{c}
Kumbakodi	161.5^{p}	112.0^{t}	110.5^{u}	177.5^{o}	197.5^{d}	191.5^{d}	291.5^{a}	132.5^{g}	78.0^{j}	82.0^{j}	87.0^{j}	92.0^{i}	37.0^{m}	41.0^{l}	131.0^{b}	67.0^{f}
Panniyur-5	662.0^{a}	524.5^{c}	516.5^{b}	561.5^{d}	105.5^{h}	96.5^{i}	94.5^{i}	80.5^{i}	112.0^{g}	141.0^{d}	158.0^{c}	315.0^{a}	61.0^{g}	53.0^{i}	54.0^{hi}	71.0^{e}
Kalluvally-4	296.5^{n}	291.5^{n}	294.5^{n}	450.5^{e}	91.5^{i}	225.5^{b}	159.0^{e}	88.5^{i}	112.0^{g}	122.0^{f}	102.0^{h}	117.0^{g}	46.0^{k}	36.0^{m}	81.0^{d}	52.0^{ij}
Padarpan	141.5^{s}	101.5^{v}	146.5^{r}	151.5^{q}	71.5^{j}	153.5^{f}	141.5^{g}	65.8^{k}	122.0^{f}	126.0^{f}	82.0^{j}	132.0^{e}	56.0^{h}	134.0^{a}	50.0^{j}	41.0^{l}
Mean	353.3^{a}	274.5^{d}	281.8^{c}	334.0^{b}	148.8^{b}	166.6^{a}	172.3^{a}	121.5^{c}	131.3^{b}	111.7^{c}	107.2^{d}	146.7^{a}	46.5^{d}	63.0^{c}	72.5^{a}	67.0^{b}

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Cu content. Maximum increase in Cu content was observed in Padarpan in response to mild water stress and in Kumbakodi in response to moderate water stress.

4.1.20 Enzymes

4.1.20.1 Peroxidase

The peroxidase content of the pepper varieties varied with water–stress levels (Table 25). In varieties, Uthirankotta-2 and Padarpan, peroxidase activity increased with water stress levels. In Poonjarmunda, Kumbakodi, Panniyur-1, Panniyur-5 and Kalluvally-4 peroxidase activity decreased due to mild water stress whereas moderate and severe water stress increased the peroxidase activity. When severely water stressed, in all the varieties except in Panniyur-1, the peroxidase activity increased and the maximum was observed in Uthirankotta-2 followed by Padarpan and Kalluvally-4. The maximum percentage increase in enzyme activity due to water stress was in Padarpan followed by decreased activity observed in Panniyur-1.

4.1.20.2 Catalase

Water stress significantly influenced the catalase activity of black pepper varieties (Table 26). Mild water stress decreased the catalase activity except Padarpan and Panniyur-5. Higher levels of water stress level increased the catalase activity in all the varieties. The percentage increase in catalase activity over control was maximum in Padarpan followed by Panniyur-5. Contrary to this Panniyur-1 showed a decrease in the activity of the enzyme, in plants exposed to severe water stress. Poonjarmunda, Uthirankotta-2, Kumbakodi and Kalluvally-4 showed relatively small increase in catalase activity due to severe water stress.

Table 25: Effect of water stress on peroxidase content of black pepper varieties

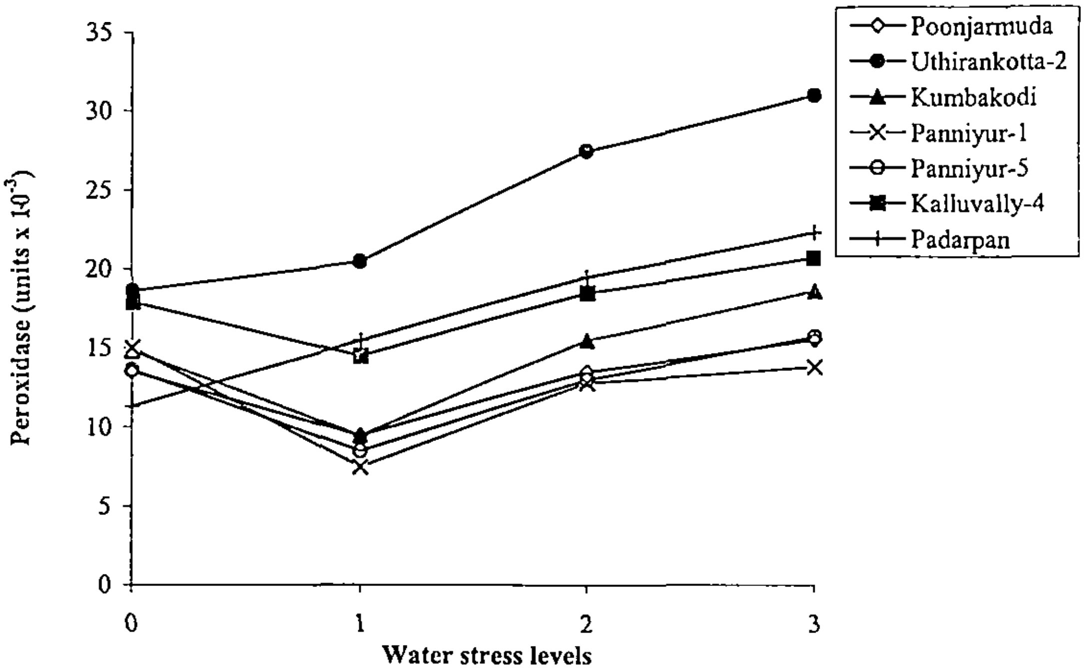
Varieties	Peroxidase (units × 10^{-3}) Water stress levels 0	1	2	3	% change over control
Poonjarmunda	13.5^{hij}	9.5^{l}	13.5^{hij}	15.5^{g}	+14.8
Uthirankotta-2	18.6^{ef}	20.5^{d}	27.5^{b}	31.0^{a}	+66.7
Kumbakodi	14.8^{gh}	9.5^{l}	15.5^{g}	18.6^{ef}	+25.7
Panniyur-1	15.0^{gh}	7.5^{m}	12.8^{j}	13.8^{hij}	-8.0
Panniyur-5	13.6^{hij}	8.5^{lm}	13.0^{ij}	15.7^{g}	+15.9
Kalluvally-4	17.9^{f}	14.5^{ghi}	18.5^{ef}	20.7^{d}	+15.6
Padarpan	11.3^{k}	15.5^{g}	19.5^{de}	22.3^{c}	+97.3
Mean	14.9^{c}	12.2^{d}	17.2^{b}	19.6^{a}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 26: Effect of water stress on catalase content of black pepper varieties

Varieties	Catalase (units × 10^{-3}) Water stress levels 0	1	2	3	% change over control
Poonjarmunda	15.6^{h}	7.8^{l}	16.5^{gh}	20.8^{bcd}	+33.0
Uthirankotta-2	10.7^{jk}	4.8^{m}	9.7^{jkl}	13.6^{i}	+27.2
Kumbakodi	22.0^{bc}	9.3^{kl}	17.3^{fgh}	26.0^{a}	+18.2
Panniyur-1	8.2^{l}	5.0^{m}	6.9^{l}	7.7^{l}	-6.1
Panniyur-5	10.6^{jk}	10.7^{jk}	18.5^{efg}	21.8^{b}	+105.7
Kalluvally-4	18.9^{def}	10.6^{jk}	19.5^{cde}	25.9^{a}	+37.0
Padarpan	8.6^{kl}	11.7^{j}	16.5^{gh}	17.8^{efg}	+107.0
Mean	13.4^{c}	8.2^{d}	15.0^{b}	19.1^{a}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT



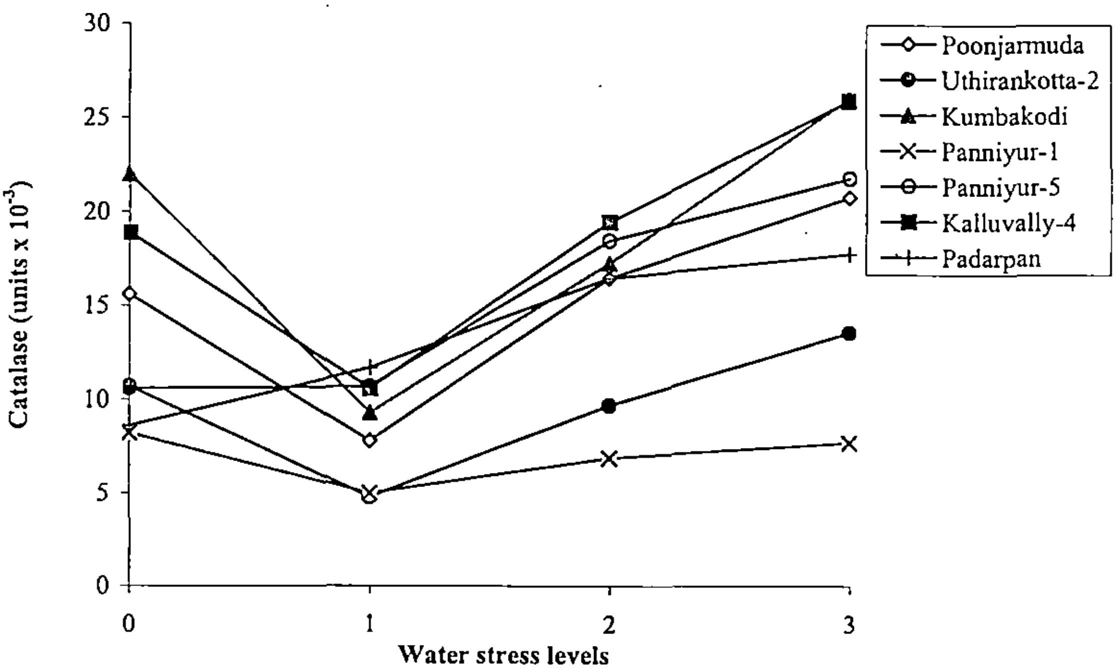


Fig. 8. Effect of water stress on Peroxidase and Catalase in black pepper varieties

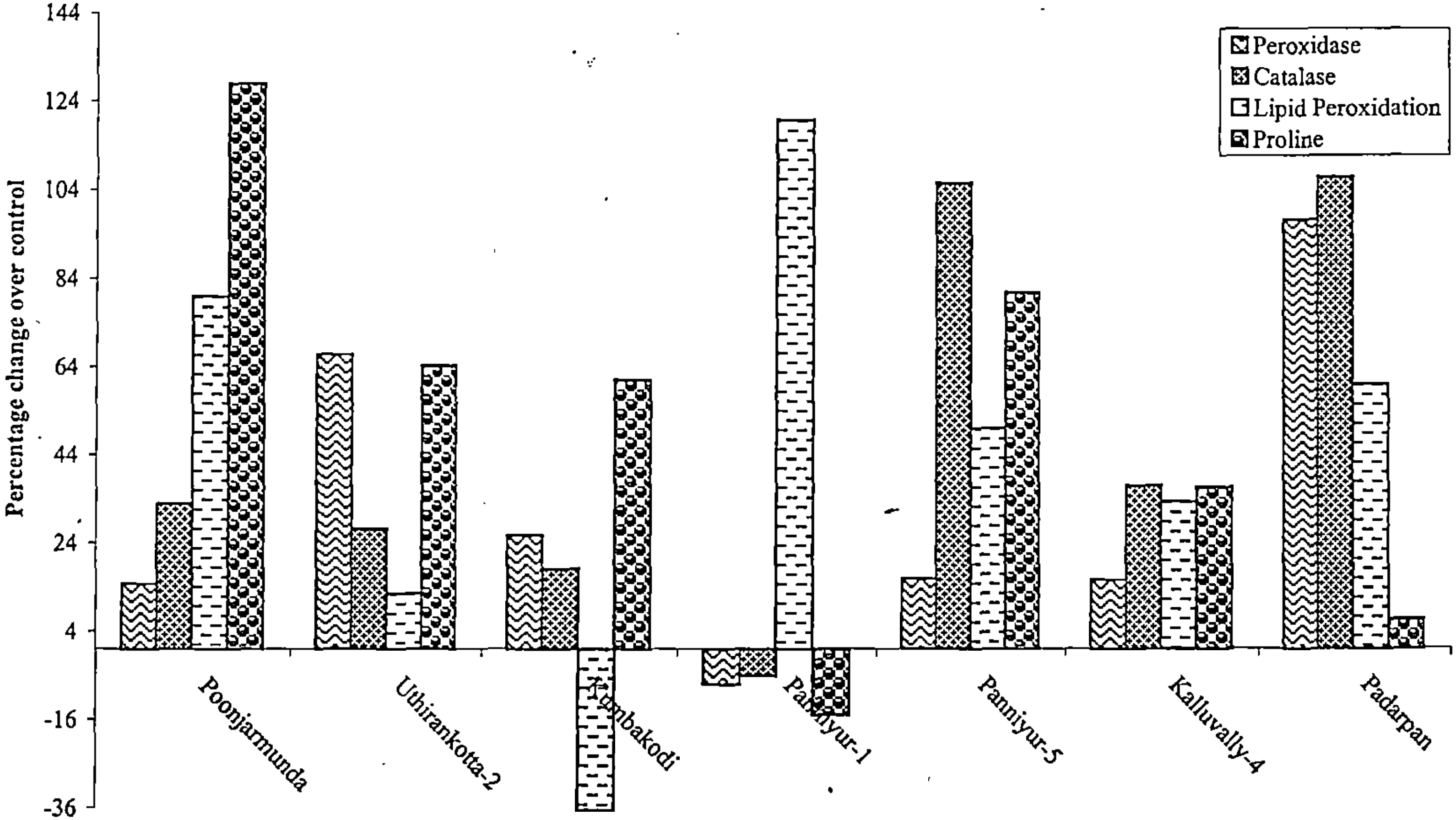


Fig. 9. Percentage change in enzyme activities (peroxidase, catalase), lipid peroxidation and proline content in black pepper varieties in response to water stress

4.1.20.3 Superoxide dismutase

The superoxide dismutase (SOD) activity increased in all the varieties except Panniyur-1, in response to water stress (Table 27). In stressed plants of Panniyur-5, SOD activity increased by about 114 per cent. Maximum increase in SOD activity due to water stress was observed in Panniyur-5, followed by Kumbakodi, Kalluvally-4 and Padarpan. In Panniyur-1 the SOD activity decreased by about 15 per cent in response to water stress.

4.1.20.4 Lipid peroxidation

Lipid peroxidation increased due to mild water stress and it decreased with higher levels of water stress (Table 27). All the varieties, except Panniyur-1 showed a sharp increase in lipid peroxidation due to mild water stress. In Panniyur-1 the lipid peroxidation progressively increased with the level of water stress, whereas in all other varieties it increased due to mild water stress and then decreased with further increase in the stress levels.

4.1.20.5 Protein

The protein content of leaves decreased due to severe water stress in varieties Poonjarmunda and Uthirankotta-2 (Table 28). In the variety Kumbakodi, Kalluvally-4 and Padarpan there was no significant difference in protein content due to water stress. In Panniyur-1 and Panniyur-5 protein content increased due to water stress.

Table 27: Effect of water stress on superoxide dismutase activity and lipid peroxidation of black pepper varieties

Varieties	Superoxide dismutase (units × 10^{-3})		% change over control	Lipid peroxidation (mg 100 mg^{-1})				% change over control
	Water stress levels			Water stress levels				
	0 day	3 days		0 day	1 day	2 days	3 days	
Poonjarmunda	3.8^{c}	4.2^{c}	+10	0.05	0.18	0.04	0.09	+80
Uthirankotta-2	4.1^{c}	4.4^{c}	+7	0.08	0.16	0.07	0.09	+12
Kumbakodi	2.5^{d}	4.8^{b}	+92	0.11	0.15	0.09	0.07	-36
Panniyur-1	4.6^{b}	3.9^{c}	-15	0.05	0.06	0.09	0.11	+120
Panniyur-5	3.5^{c}	7.5^{a}	+114	0.06	0.13	0.14	0.09	+50
Kalluvally-4	3.6^{c}	5.9^{b}	+63	0.03	0.19	0.06	0.04	+33
Padarpan	3.4^{d}	5.5^{b}	+61	0.05	0.16	0.08	0.08	+60
Mean	3.6^{b}	5.2^{a}		0.06^{b}	0.15^{a}	0.08^{b}	0.08^{b}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT
The interaction means of lipid peroxidation are not significantly different at 5% levels by DMRT

Table 28: Effect of water stress on protein content of black pepper varieties

Varieties	Protein (mg g^{-1})	
	Water stress levels	
	0	3
Poonjarmunda	26.7^{a}	26.5^{b}
Uthirankotta-2	26.1^{a}	20.4^{bc}
Kumbakodi	23.5^{a}	29.3^{a}
Panniyur-1	13.8^{c}	22.0^{b}
Panniyur-5	13.2^{d}	22.5^{a}
Kalluvally-4	15.6^{bc}	22.2^{b}
Padarpan	19.2^{bc}	22.0^{b}
Mean	19.7	20.4

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means are not significantly different at 5% levels by DMRT

4.1.20.6 Electrophoretic pattern of proteins

The electrophoretic pattern of the susceptible variety, Panniyur-1 and drought tolerant varieties viz. Panniyur-5, Kumbakodi, Poonjarmunda and Padarpan showed considerable variation in response to water stress (Table 29).

In the water stressed susceptible variety Panniyur–1, only few bands were seen and resolutions were very poor. The control had eight bands with molecular weight ranging from 5.76 to 65.5 whereas the stressed plants had only few bands with molecular weight 5.53 to 22.91. Slow moving bands with molecular weight 35.6, 56.3 and 65.5 respectively are seen additional in control.

In water stressed plants of the variety, Panniyur-5, there were 11 protein bands with molecular weight ranging from 3.96 to 55.5 KD whereas in non-stressed control there were only ten bands, with molecular weight ranging from 3.9 to 43.32 KD. An additional slow moving band with rf value 0.204 and molecular weight 55.5 was observed in water stressed plants of Panniyur-5. There were variations in rf value in the case of one band (0.738), which was absent in control. The varied band with rf 0.276 and molecular weight 44.32 observed in control was absent in water stressed plants.

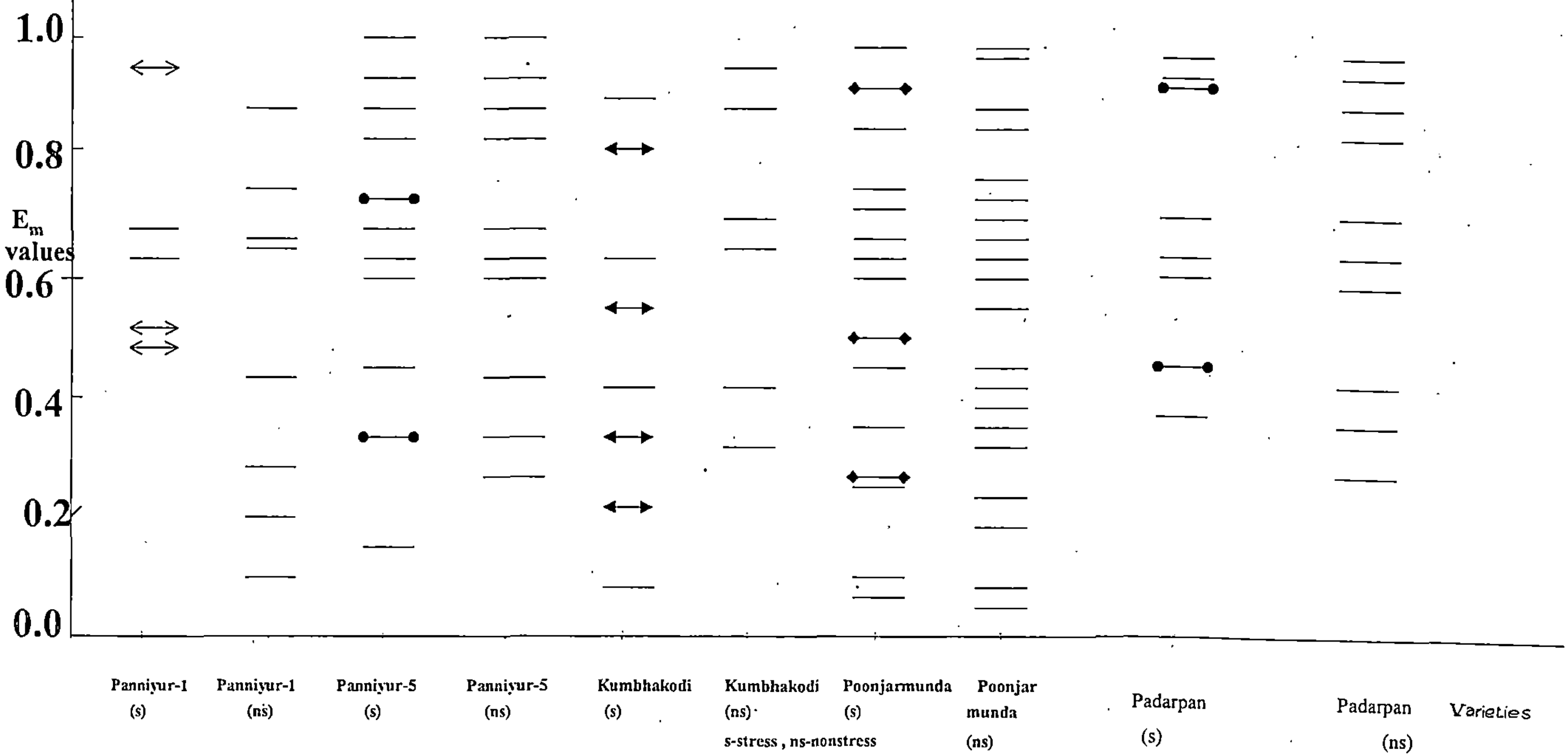
There were eight bands with molecular weight 5.16 KD to 62.89 K.D in the variety Kumbakodi subjected to water stress, while the control, had only 6 bands with molecular weight ranging from 4.63 to 34.32 KD. On comparison of rf values two slow moving bands with rf values 0.244, 0.167 respectively were seen extra in water stressed plants of the variety Kumbakodi. An intermediate band with rf value 0.552 is also seen additional.

Table 29: Electrophoretic patterns of proteins in black pepper varieties under water stress

Panniyur-1				Panniyur-5				Kumbakodi				Poonjarmunda				Padarpan			
Stressed		Non-stressed		Stressed		Non-stressed		Stressed		Non-stressed		Stressed		Non-stressed		Stressed		Non-stressed	
Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)	Rf	MW (KD)
0.878	5.53	0.894	5.76	0.973	3.96	0.977	3.90	0.896	5.16	0.928	4.63	0.977	3.90	0.977	3.90	0.973	3.96	0.977	3.90
0.679	10.91	0.719	10.31	0.932	4.56	0.937	4.49	0.701	10.07	0.882	5.41	0.914	4.85	0.950	4.29	0.928	4.63	0.937	4.49
0.633	12.93	0.645	13.16	0.889	5.33	0.891	5.24	0.629	12.9	0.710	9.76	0.860	5.94	0.887	5.33	0.891	5.24	0.891	5.24
0.534	17.89	0.613	14.65	0.842	6.22	0.842	6.22	0.552	16.8	0.620	13.31	0.747	8.62	0.851	6.03	0.606	9.91	0.842	6.22
0.462	22.91	0.456	24.63	0.738	8.89	0.697	10.22	0.443	24.39	0.448	24.01	0.710	9.76	0.778	7.73	0.629	12.9	0.697	10.22
		0.346	35.55	0.697	10.22	0.643	12.32	0.339	34.86	0.344	34.32	0.679	10.88	0.742	8.75	0.593	14.61	0.643	12.32
		0.207	56.34	0.629	12.9	0.597	14.39	0.244	48.3			0.638	12.51	0.710	9.76	0.448	24.01	0.597	14.39
		0.161	65.53	0.597	14.4	0.443	24.39	0.167	62.89			0.597	14.39	0.674	11.05	0.353	33.27	0.443	24.39
				0.457	23.28	0.357	33.27					0.507	19.62	0.638	12.71			0.357	33.27
				0.353	33.27	0.276	43.32					0.457	23.28	0.597	14.39			0.276	43.32
				0.204	55.54							0.362	32.25	0.572	19.93				
												0.286	42.00	0.457	23.25				
												0.263	46.82	0.421	26.36				
												0.186	59.10	0.389	29.39				
												0.163	63.87	0.353	33.20				
														0.299	40.09				
														0.262	45.29				
														0.213	53.80				
														0.186	59.10				
														0.154	65.88				

Rf - Resolution factor
MW - Molecular weight

Fig. 24 Zymogram showing protein profile of pepper varieties under moisture stress



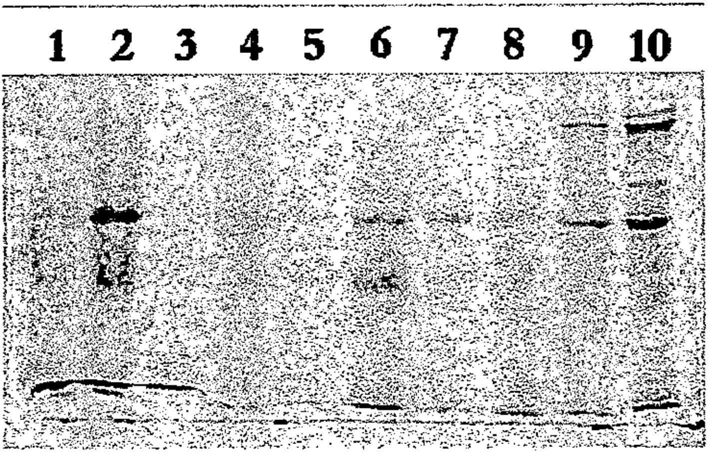


Fig. 25. SDS-Electrophoretic profile of leaf protein from pepper varieties (staining with coomassie blue).

1 & 2- Panniyur-1 (stressed & non-stressed)
3 & 4- Panniyur-5 (stressed & non-stressed)
5 & 6- Kumbakodi (stressed & non-stressed)
7 & 8- Poonjarmunda (stressed & non-stressed)
9 & 10-Padarpan (stressed & non-stressed)

In Poonjarmunda, fifteen bands are seen with molecular weight ranging from 3.9 to 63.87 KD during stress. On the other hand twenty bands having molecular weight ranging from 3.90 to 65.88 were observed in the control. On comparison with rf values, an additional band with rf value of 0.914 was observed in water stressed plants.

In the case of Padarpan 8 bands were seen with molecular weight ranging from 3.96 to 33.27 KD during stress while 10 bands were observed in control with molecular weight ranging from 3.9 to 43.32 KD. One new band was observed under stress condition with rf value 0.928 whereas a slow moving band with rf value 0.276 and a fast moving band with rf 0.842 were seen in control.

4.1.21 Anatomical characters

Anatomical variations in leaf and stem of black pepper varieties are shown in table 30 and 31. The leaf and stem anatomical characters like thickness of epicuticular wax on upper epidermis, starch deposition on epidermal layer, thickness of hypodermis tissue, number of sclerenchyma tissue on hypodermis; thickness of sclerenchyma tissue over vascular bundles showed variation between varieties. The conspicuous result was that in Panniyur-1 most of these characters were rated low whereas in Pannyur-5 these traits were rated as very high. The other varieties were also rated "very high" "high," and medium with respect to these anatomical characters. The thickness of the hypodermis tissue did not vary between varieties. The number of xylem vessels rated as high or very high in all the varieties.

The stem anatomical characters also showed more or less similar pattern.

Table 30: Variations of black pepper varieties in leaf anatomical characters

Sl. No	Leaf anatomical character	Rating of varieties			
		Very high	High	Medium	Low
1.	Thickness of epicuticular wax on upper epidermis	Kumbakodi Panniyur-5 Kalluvalli	-	Poonjarmunda Padarpan	Uthirankotta-2 Panniyur-1
2.	Starch deposition on epidermal layer	Uthirankotta-2 Kumbakodi Panniyur-5	Poonjarmunda Kalluvalli Padarpan	Panniyur-1	-
3.	Thickness of hypodermis tissue (upper hypodermis)	-	-	Poonjarmunda Uthirankotta-2 Kumbakodi Panniyur-5 Kalluvalli Panniyur-1 Padarpan	
4.	Number of sclerenchyma tissue on hypodermis	Panniyur-5	Poonjarmunda Uthirankotta-2 Kalluvally-4 Padarpan	Kumbakodi	Panniyur-1
5.	Thickness of sclerenchyma tissue over vascular bundles	-	Poonjarmunda Uthirankotta-2 Kumbakodi Panniyur-5 Kalluvally-4 Padarpan	-	Panniyur-1
6.	Number of xylem vessels	Uthirankotta-2 Kumbakodi Panniyur-5 Panniyur-1	Poonjarmunda Kalluvally-4 Padarpan		

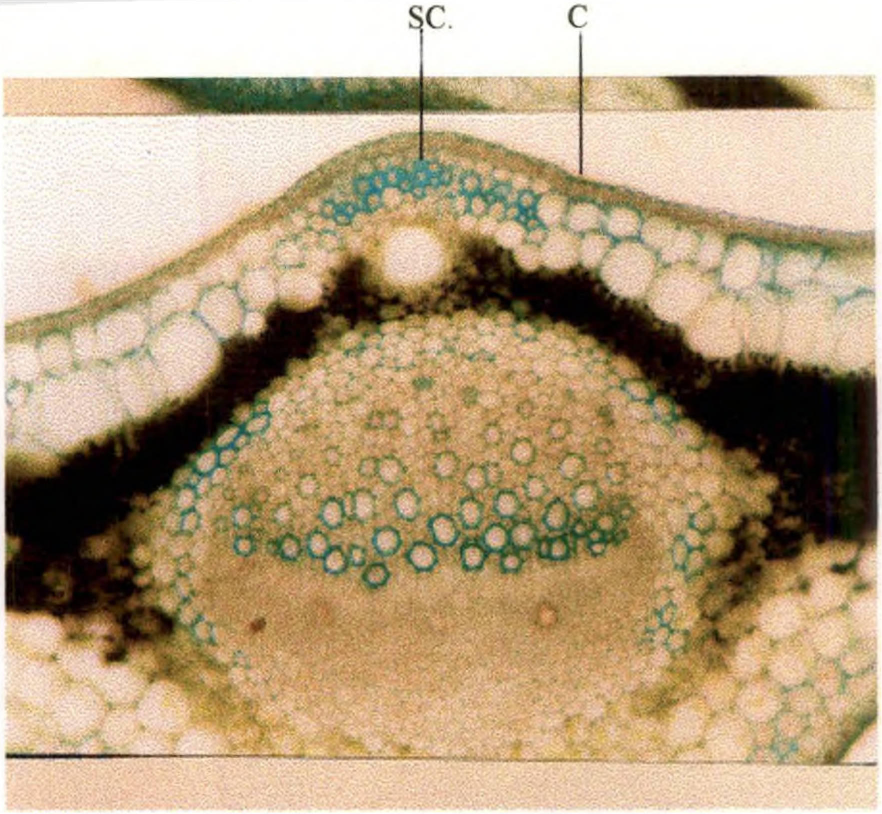


Fig. 10. Leaf c.s. of Panniyur-5
C-Cuticle, SC-Sclerenchyma

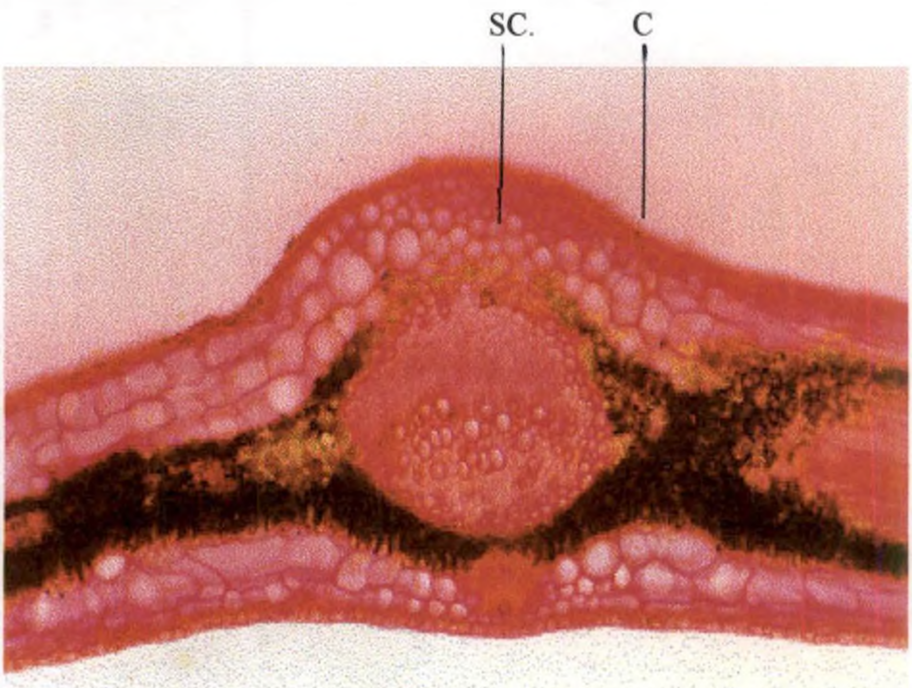


Fig.11. Leaf c.s. of Padarpan
C-Cuticle, SC-Sclerenchyma

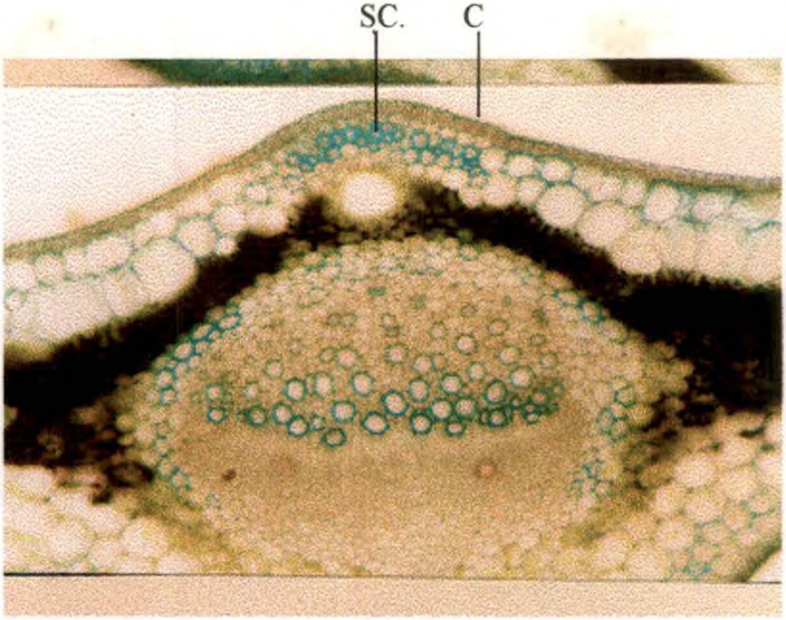


Fig. 12. Leaf c.s of Poonjarmunda
C-Cuticle, SC-Sclerenchyma

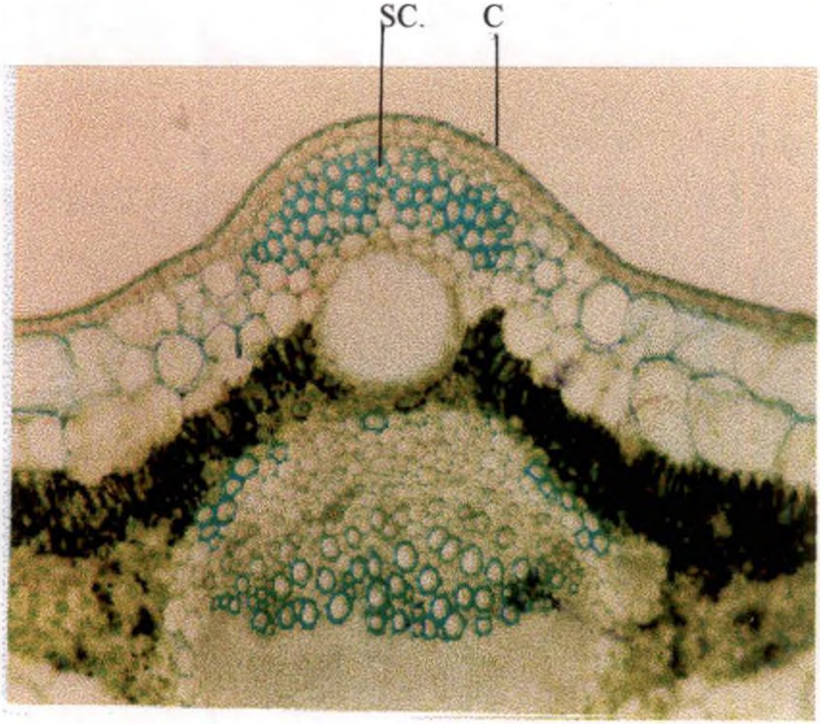


Fig. 13. Leaf c.s of Kalluvally
C-Cuticle, SC-Sclerenchyma

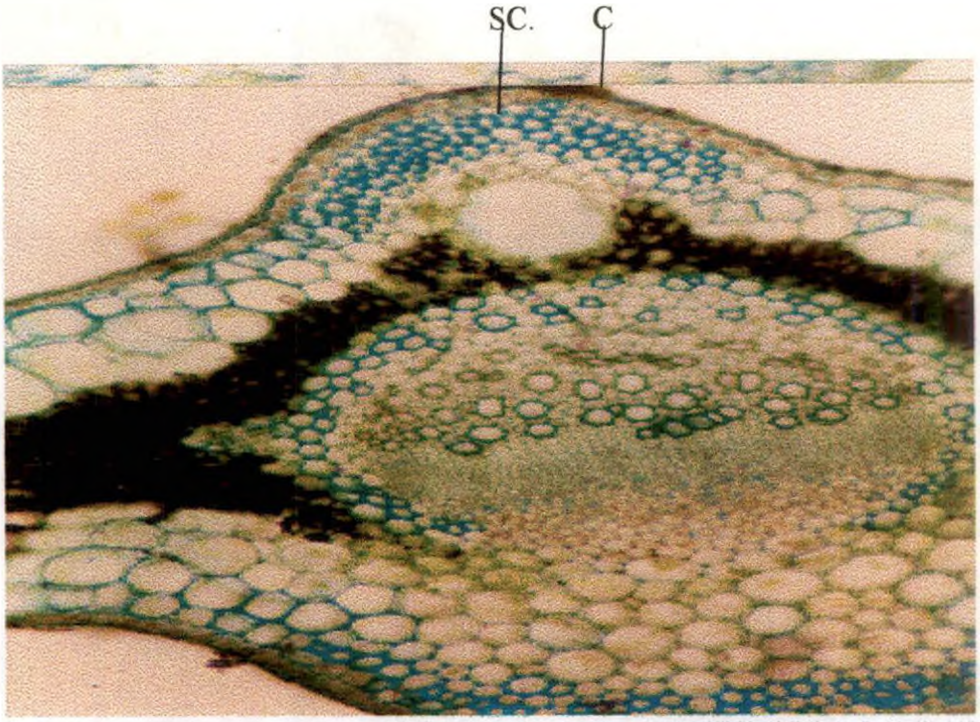


Fig. 14. Leaf c.s. of Kumbakodi
C-Cuticle, SC-Sclerenchyma

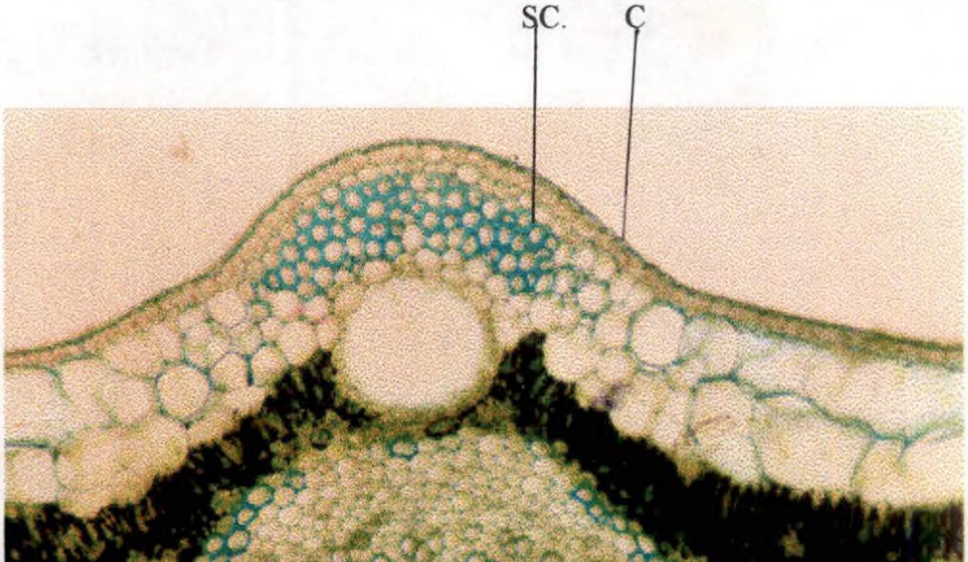


Fig.15. Leaf c.s. of Uthirankotta
C-Cuticle, SC-Sclerenchyma

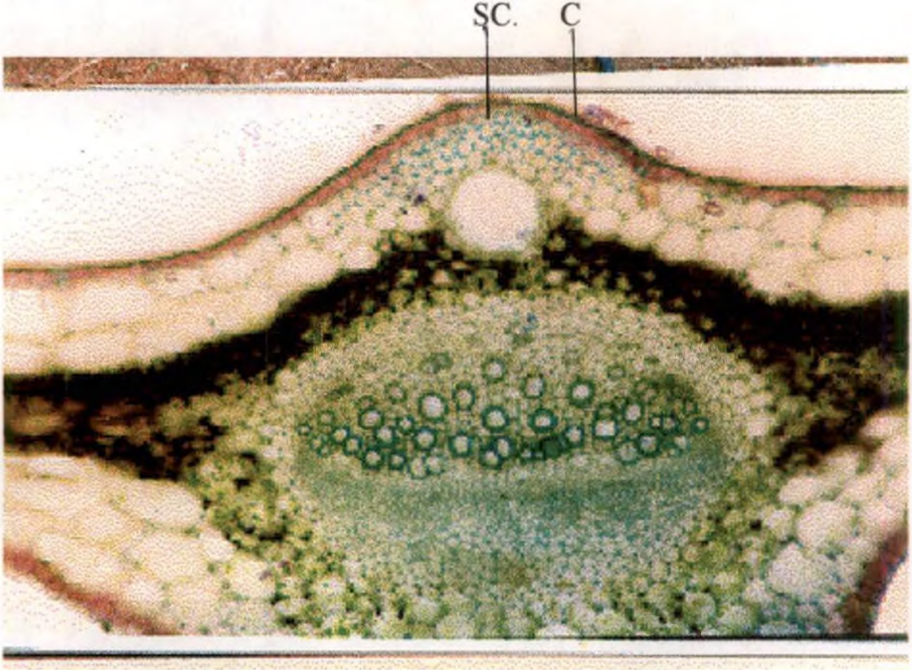


Fig. 16. Leaf c.s. of Panniyur-1
C-Cuticle, SC-Sclerenchyma

Table 31: Variations of black pepper varieties in stem anatomical characters

Sl. No.	Stem anatomical character	Rating of varieties			
		Very high	High	Medium	Low
1.	Thickness of epicuticular wax on upper epidermis	Panniyur-5 Kalluvalli	Uthirankotta-2 Kumbakodi	Poonjarmunda	Padarpan Panniyur-1
2.	Starch deposition on epidermal layer	Poonjarmunda Kalluvalli	-	Uthirankotta-2 Kumbakodi Panniyur-5 Padarpan	Panniyur-1
3.	Thickness of hypodermis tissue (upper hypodermis)	Poonjarmunda Uthirankotta-2 Kumbakodi Panniyur-5 Kalluvalli Panniyur-1	-	Padarpan	-
4.	Number of sclerenchyma tissue on hypodermis	-	Poonjarmunda Uthirankotta-2 Kumbakodi Kalluvally-4 Padarpan	Panniyur-5	Panniyur-1
5.	Thickness of sclerenchyma tissue over vascular bundles	-	Kumbakodi	Poonjarmunda Uthirankotta-2 Panniyur-5 Kalluvally-4 Panniyur-1 Padarpan	-
6.	Xylem numbers	-	Poonjarmunda	Poonjarmunda Kumbakodi Panniyur-5 Kalluvally-4 Panniyur-1 Padarpan	

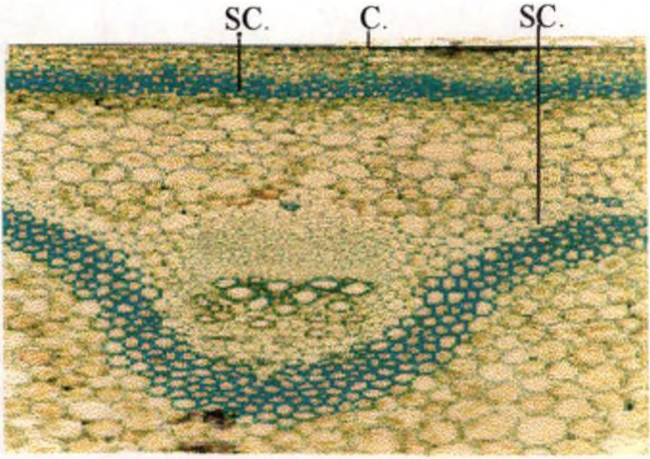


Fig. 17. Stem c.s. of Panniyur-5
C-Cuticle, SC-Sclerenchyma

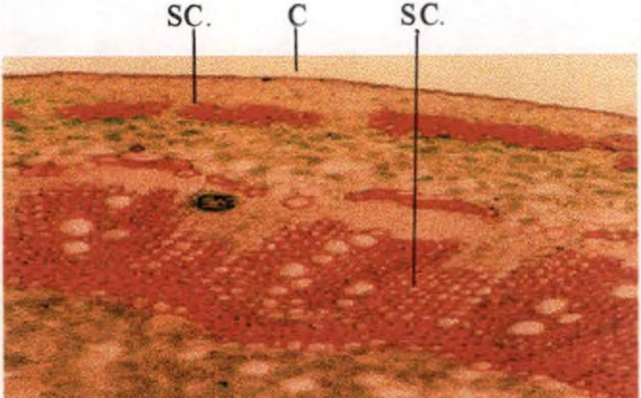


Fig. 18. Stem c.s. of Padarpan
C-Cuticle, SC-Sclerenchyma

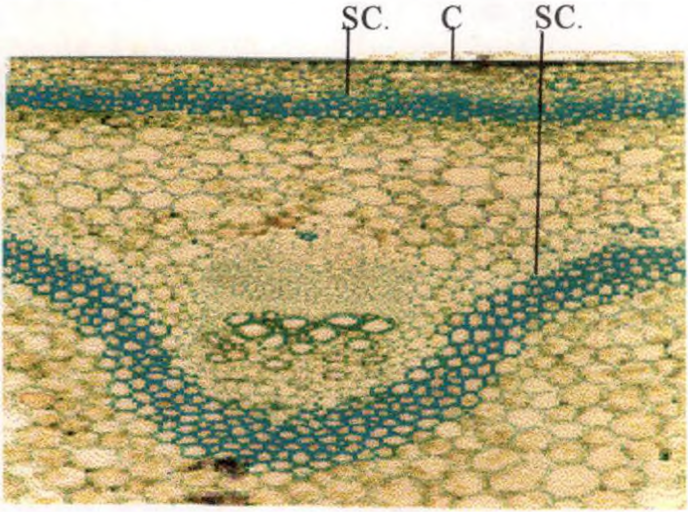


Fig. 19. Stem c.s.of Poonjarmunda
C-Cuticle, SC-Sclerenchyma

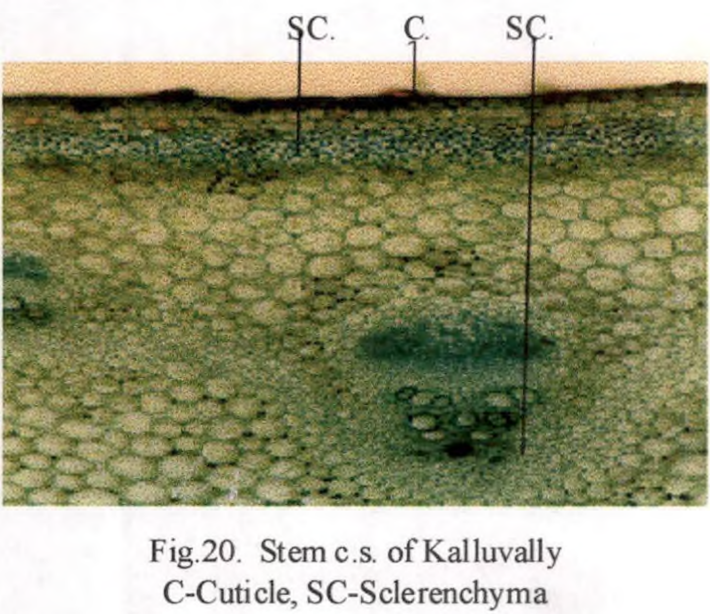


Fig.20. Stem c.s. of Kalluvally
C-Cuticle, SC-Sclerenchyma

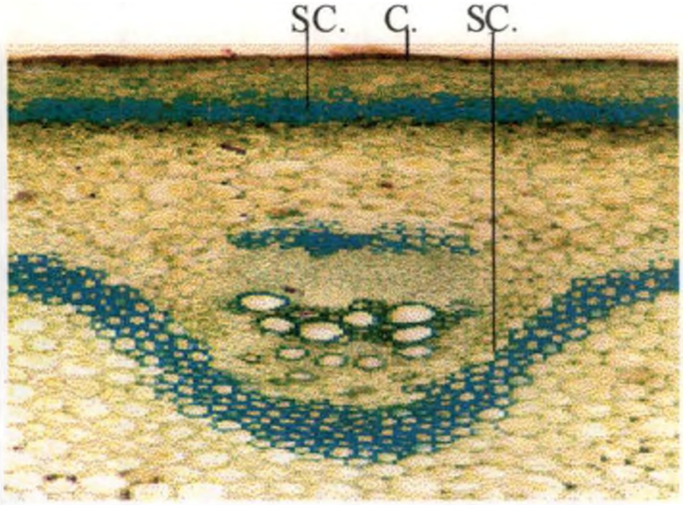


Fig. 21. Stem c.s. of Kumbakodi
C-Cuticle, SC-Sclerenchyma

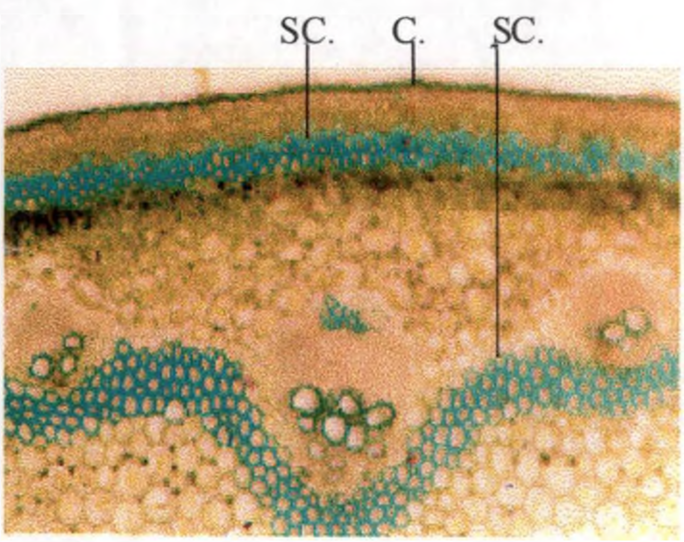


Fig.22. Stem c.s. of Uthirankotta
C-Cuticle, SC-Sclerenchyma

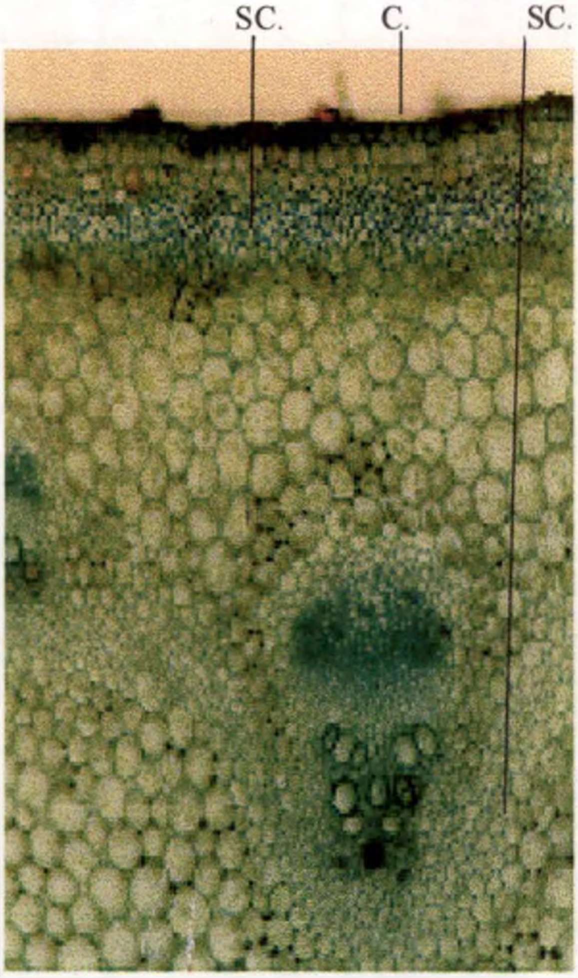


Fig. 23. Stem c.s. of Panniyur-1
C-Cuticle, SC-Sclerenchyma

Experiment II

4.2 Response of bush pepper to soil moisture stress

Bush and vine type of Panniyur-1 did not survive the water stress for more than two weeks. Hence biometric and physiological observations could not be presented for this variety. The biometric and physiological characteristics of the bush and vine type of Panniyur-5 under different water stress levels are given below.

4.2.1 Biometric characters

Height, Number of leaves, Leaf area, Internodal length, Girth and Root length

There was no significant difference in height between vine and bush type of the variety Panniyur-5 even though the height decreased in both the morpho-types (Table 32).

The number of leaves varied only after 60 DAT (Table 33). There were no significant difference in number of leaves, leaf area and internodal length between the bush or vine pepper when exposed to different levels of water stress at 30 DAT (Table 33, 34 and 35).

However, the leaf area (Table 34) at 60 DAT showed steady decrease with higher levels of water stress, both in bush and vine pepper.

The effect of water stress on girth of bush and vine pepper at 30 and 60 DAT was not significant (Table 36).

Root length in bush and vine pepper varied significantly (Table 37) due to water stress levels. Bush type had more root length than vine type. Water stress increased the root length and it was more conspicuous in bush pepper.

Fig. 26. Bush and Vine Pepper (variety Panniyur-1)

Fig. 27. Bush and Vine Pepper(variety Panniyur-5)

Table 32: Effect of water stress on height of bush and vine pepper, variety Panniyur-5

	Height (30 DAT) (cm)					Height (60 DAT) (cm)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	18.4	20.6	22.0	21.5	20.63	22.00	24.00	24.3	24.50	23.7
Vine	21.1	22.0	17.3	18.5	19.73	27.50	24.50	23.50	21.00	24.1
Mean	19.7	21.3	19.7	20.0		24.8	24.3	23.9	22.8	

The marginal means, interaction means and means of black pepper types at 30 and 60 DAT are not significantly different at 5 % levels by DMRT

Table 33: Effect of water stress on number of leaves of bush and vine pepper, variety Panniyur-5

	Number of leaves (30 DAT) (cm)					Number of leaves (60 DAT) (cm)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	1.8	2.5	2.0	2.0	2.06	2.25^{c}	3.3^{a}	1.50^{d}	2.0^{cd}	2.3
Vine	2.5	3.3	3.8	3.0	3.13	3.50^{a}	2.3^{cd}	2.00^{cd}	2.3^{c}	2.5
Mean	2.1	2.9	2.9	2.5		2.9^{a}	2.8^{a}	1.8^{b}	2.1^{a}	

The marginal means, interactions and means of types at 30 DAT are not significantly different at 5% levels by DMRT
The means of types at 60 DAT are not significantly different at 5% levels by DMRT
The interaction means, marginal means of water stress at 60 DAT, followed by a common letter are not significantly different at 5 % levels by DMRT

Table 34: Effect of water stress on leaf area of bush and vine pepper, variety Panniyur-5

	Leaf area (30 DAT) (cm^2 $plant^{-1}$)					Leaf area (60 DAT) (cm^2 $plant^{-1}$)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	86.9	171.2	129.0	80.9	117.0	110.6^{ab}	90.34^{ab}	43.8^{b}	50.6^{b}	73.6
Vine	86.8	68.9	122.0	59.5	84.4	114.3^{a}	69.40^{b}	65.8^{b}	46.8^{b}	74.1
Mean	86.8	120.01	125.7	70.2		112.4^{a}	80.2^{a}	54.8^{b}	48.7^{b}	

The interaction means and marginal means followed by a common letter are not significantly different at 5 % levels by DMRT
The means of types at 60 DAT are not significantly different at 5% levels by DMRT
The observation on leaf are at 30 DAT are not significantly different at 5% levels by DMRT

Table 35: Effect of water stress on internode length of bush and vine pepper, variety Panniyur-5

	Internode length (30 DAT) (cm)					Internode length (60 DAT) (cm)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	3.9	3.9	2.8	2.6	3.3	4.2	3.9	4.1	3.40	3.90
Vine	3.9	3.4	3.4	3.1	3.4	3.9	3.4	3.4	3.1	3.4
Mean	3.9	3.6	3.05	2.83		4.0	3.6	3.7	3.2	

Observations on inter nodal length at 30 and 60 DAT are not significantly different at 5 % levels by DMRT

Table 36: Effect of water stress on girth of bush and vine pepper, variety Panniyur-5

	Girth (30 DAT) (mm)					Girth (60 DAT) (mm)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	0.48	0.48	0.45	0.45	0.46	0.31	0.34	0.26	0.31	0.30^{b}
Vine	0.24	0.43	0.38	0.45	0.37	0.45	0.36	0.40	0.27	0.37^{a}
Mean	0.36	0.45	0.41	0.45		0.38	0.35	0.33	0.29	

The interaction means at 30 and 60 DAT, marginal means are not significantly different at 5% levels by DMRT

Table 37: Effect of water stress on root length of bush and vine pepper, Panniyur-5

	Root length (60 DAT) (cm)				
	Water stress levels				
	0	1	2	3	Mean
Type					
Bush	9.4^{c}	29.5^{a}	22.3^{bc}	19.8^{bc}	20.2^{a}
Vine	9.8^{c}	6.5	20.0^{bc}	18.0^{c}	13.6^{b}
Mean	9.6^{b}	18.0^{a}	21.1^{a}	18.9^{a}	

The interaction means and marginal means followed by a common letter are not significantly different at 5 % levels by DMRT

Table 38: Effect of water stress on shoot dry weight and root dry weight of bush and vine pepper, variety Panniyur-5

	Dry weight of shoot (60 DAT) (g plant^{-1})					Dry weight of root (60 DAT) (g plant^{-1})				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	5.0	3.8	4.4	3.9	4.3^{a}	1.6	1.0	0.85	0.45	0.98^{a}
Vine	0.21	0.31	0.24	0.24	0.25^{b}	0.24	0.28	0.20	0.24	0.24^{b}
Mean	2.6^{a}	2.0^{b}	2.3^{a}	2.1^{b}		0.93^{a}	0.64^{b}	0.52^{b}	0.30^{c}	

The Interaction means of shoot dry weight and root dry weight are not significantly different at 5% levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 39: Effect of water stress on total dry matter production and R/S ratio of bush and vine pepper

	Total dry matter (60 DAT) (g plant^{-1})					Root:Shoot ratio (60 DAT)				
	Water stress levels					Water stress levels				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	6.6^{a}	4.7^{b}	5.3^{ab}	4.3^{b}	5.2^{a}	0.32	0.26	0.19	0.12	0.22
Vine	0.45^{c}	0.59^{c}	0.44^{c}	0.48^{c}	0.5^{b}	1.12	0.90	0.84	1.00	0.91
Mean	3.5^{a}	2.6^{b}	2.9^{a}	2.4^{a}	2.9	0.70	0.60	0.52	0.6	0.61

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

R/S ratio is not significantly different at 5% levels by DMRT

4.2.2 Total dry matter

The dry weight of shoots decreased due to water stress in bush pepper where as in vines there was no significant difference (Table 38). Bush pepper had more shoot and root dry weight.

The total dry matter of the plants decreased due to water stress in bush pepper (Table 39). Bush pepper had more total dry matter than the vine type.

4.2.3 Root/shoot ratio

The root/shoot ratio showed a decreasing trend with water stress both in bush and vine, though it was not significant (Table 39). Vine pepper showed a higher root/shoot ratio than bush pepper.

4.2.4 Stomatal conductance

Stomatal conductance of bush and vine pepper varied at 8 A.M. and 2 P.M. (Table 40 and 41). In unstressed plants there were no significant difference between bush and vine at 8 A.M., however at 2 P.M. bush pepper showed a higher stomatal conductance than vine pepper. During the morning hours the stomatal conductance of bush pepper increased due to water stress whereas in vine type there was no significant difference.

The stomatal conductance in the afternoon decreased with increase in water stress levels in bush pepper whereas in vine pepper there were an increase (Table 41).

Table 40: Effect of water stress on stomatal conductance and transpiration rate of bush and vine pepper, variety Panniyur-5 at 0800 hrs.

	Stomatal conductance (m mol $m^{-2}s^{-1}$)					Transpiration rate (µg cm^{-2} s^{-1})				
	Water stress level					Water stress level				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	5.6^{c}	15.1^{b}	1.2^{c}	43.6^{a}	16.4^{a}	1.8^{c}	3.3^{a}	0.86^{d}	13.0^{cd}	1.8
Vine	5.5^{c}	6.9^{c}	7.0^{c}	7.1^{c}	6.6^{b}	2.0^{b}	2.5^{b}	2.60^{b}	2.4^{b}	2.4
Mean	5.5^{c}	11.0^{b}	4.1^{bc}	25.4^{a}		1.9^{c}	2.9^{b}	1.73^{c}	7.9^{a}	

The interaction means and marginal means followed by a common letter are not significantly different at 5 % levels by DMRT
The mean transpiration rate of types of bush pepper are not significantly different at 5% levels by DMRT

Table 41: Effect of water stress on stomatal conductance and transpiration rate of bush and vine pepper variety, Panniyur-5, at 1400 hrs.

	Stomatal conductance (m mol $m^{-2}s^{-1}$)					Transpiration rate (µg cm^{-2} s^{-1})				
	Water stress level					Water stress level				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	7.5^{a}	4.4^{b}	3.6^{b}	2.7^{b}	4.5	6.0^{a}	6.3^{a}	0.52^{b}	2.8^{ab}	3.9^{a}
Vine	3.7^{b}	5.5^{ab}	6.4^{a}	4.7^{ab}	5.1	1.9^{b}	2.0^{b}	1.80^{b}	2.1^{ab}	1.9^{b}
Mean	5.6	4.9	5.0	3.7		4.0^{a}	4.2^{a}	1.20^{b}	2.5^{a}	

The interaction means and marginal means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means of stomatal conductance are not significantly different at 5% levels by DMRT

4.2.5 Transpiration

The transpiration rate in bush and vine pepper showed significant variations at 8 A.M. (Table 40). The transpiration rate increased in bush pepper exposed to mild water stress and moderate water stress decreased the transpiration rate. In vine pepper, there was no significant difference in transpiration rate due to water stress.

In the afternoon hours also there were no significant difference in transpiration rate of vine pepper at different levels of water stress whereas in bush pepper transpiration rate decreased due to moderate and severe water stress (Table 41). There was no significant difference between unstressed and mildly stressed plants. Transpiration rate was more in bush type than in vine type in the afternoon hours.

4.2.6 Leaf temperature

The leaf temperature in vine pepper did not vary much due to water stress whereas in bush pepper showed wide variation both during morning hours as well as afternoon hours (Table 42). However a perceptible pattern in response to water stress was missing.

4.2.7 Leaf water potential

The vine pepper showed a lower leaf water potential than bush pepper (Table 43). There were no significant difference in leaf water potential due to interaction between type of pepper and water stress levels.

Table 42: **Effect of water stress on leaf temperature of bush and vine pepper, variety Panniyur-5 at 0800 hrs. and 1400 hrs**

	Leaf temperature at 0800 hrs. (°C)					Leaf temperature at 1400 hrs. (°C)				
	Water stress level					Water stress level				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	34.1[b]	38.0[a]	29.4[c]	35.1[b]	34.2[a]	35.8[b]	38.1[a]	29.0[d]	35.5[b]	34.2[a]
Vine	29.5[c]	29.1[c]	29.1[c]	29.3[c]	29.2[b]	32.6[c]	29.3[d]	29.5[d]	29.7[d]	29.3[b]
Mean	31.8[b]	33.6[a]	29.2[c]	32.2[a]		34.2[a]	34.2[a]	29.3[c]	32.6[b]	

Interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
Marginal means followed by a common letter are not significantly different at 5% levels by DMRT

Table 43: Effect of water stress on leaf water potential and chlorophyll a of bush and vine pepper, variety Panniyur-5

	Leaf water potential (MPa)					Chlorophyll a (mg g^{-1})				
	Water stress level					Water stress level				
	0	1	2	3	Mean	0	1	2	3	Mean
Type										
Bush	-0.42	-0.41	-0.39	-0.41	-0.41^{b}	0.75	0.75	0.45	0.40	0.6^{b}
Vine	-0.44	-0.44	-0.43	-0.44	-0.44^{a}	1.2	0.95	0.95	0.65	0.9^{a}
Mean	-0.43^{a}	-0.42^{a}	-0.41^{b}	-0.42^{a}		0.98^{a}	0.85^{a}	0.70^{a}	0.53^{b}	

The interaction means of leaf water potential and chlorophyll a are not significantly different at 5% levels by DMRT
The marginal means followed by a common letter are not significantly different at 5 % levels by DMRT

Table 44: Effect of water stress on chlorophyll b and total chlorophyll content of bush and vine pepper, variety Panniyur-5

	Chlorophyll b (mg g^{-1})					Total chlorophyll (mg g^{-1})				
	Water stress level					Water stress level				
	0	1	2	3	Mean	0.	1	2	3	Mean
Type										
Bush	0.25^{c}	0.35^{bc}	0.40^{bc}	0.25^{c}	0.31^{b}	1.6^{a}	1.2^{b}	0.9^{c}	0.6^{c}	1.0^{b}
Vine	0.70^{a}	0.65^{a}	0.65^{a}	0.25^{c}	0.63^{a}	1.8^{a}	1.5^{a}	1.4^{b}	0.7^{a}	1.3a
Mean	0.48^{a}	0.50^{a}	0.53^{a}	0.25^{b}		1.7^{a}	1.3^{b}	1.1^{b}	0.7^{c}	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT
The marginal means followed by a common letter are not significantly different at 5% levels by DMRT

4.2.8 Chlorophyll

The chlorophyll a content was more in vine pepper than in bush pepper (Table 43). In general, the chlorophyll a content decreased with increasing levels of water stress.

Chlorophyll b and total chlorophyll also showed same trend. The chlorophyll content decreased considerably due to severe water stress.

4.2.9 Translocation of photosynthates in bush-pepper under water stress

There were perceptible difference between translocation of photosynthates in bush pepper of the varieties Panniyur-1 and Panniyur-5 grown under water stress (Table 45).

In Panniyur-5 the ^{14}C fixed in the leaf was traced in the spike on the corresponding node as well as in other spikes on the plant. There were difference between mild and moderate water stress when the translocation to the corresponding nodal spike was considered in Panniyur-5. When the plants were exposed to moderate and severe water stress, most of the ^{14}C was observed in the corresponding nodal spike only and not in other spikes. In the daily irrigated plants of Panniyur-5, ^{14}C count in other spikes were negligible and most of the ^{14}C fixed in leaves were shared by the corresponding nodal spike and the stem. Under mild water stress the ^{14}C fixed by the leaf was traced both in the nodal spike and the spikes on other nodes. There were no translocation to stem, leaves or roots.

In the variety Panniyur-1 all the ^{14}C from the leaf was traced in the corresponding nodal spike and there was no translocation to other spikes, stem or root in water stressed plants (except in moderate stress, where a weak translocation to stem

Table 45: Translocation of photosynthates in bush pepper varieties under water stress

Plant tissue	Panniyur-5				Panniyur-1			
	^{14}C counts (cpm)				^{14}C counts (cpm)			
	Water stress levels				Water stress levels			
	0	1	2	3	0	1	2	3
Spike on the corresponding node	1930 *(46)	1058 (47)	1274 (97)	391 (100)	2776 (100)	247 (100)	2911 (93)	1382 (100)
Other spikes	30.1 (.7)	1197 (53)	0	0	0	0	0	0
Stem	2253 (53)	0	40 (3)	0	0	0	219 (7)	0
Leaf	0	0	0	0	0	0	0	0
Root	0	0	0	0	0	0	0	0

* percentage of total count in each plant

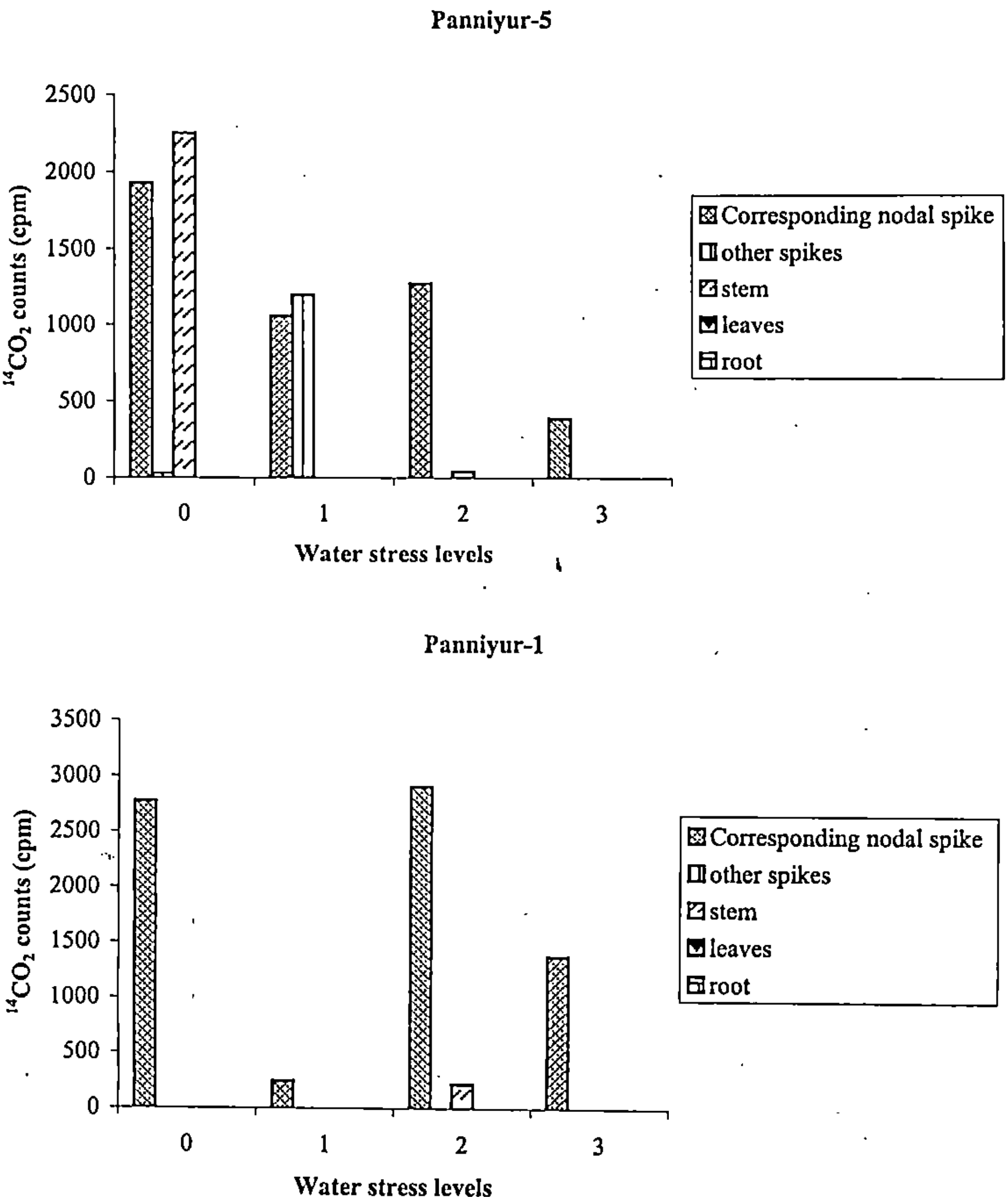


Fig. 28. Influence of water stress on translocation of photosynthates in bush pepper varieties, Panniyur-5 and Panniyur-1

was observed) as well as daily irrigated plants. Severe water stress decreased the translocation of ^{14}C to spikes in both the varieties. The translocation from the leaf to spikes did not vary much between plants subjected to moderate water stress and daily irrigated plants of Panniyur-5.

There were no translocation of ^{14}C to other leaves and roots in both the varieties in water stressed as well as daily irrigated plants.

When the experiment was repeated and autoradiographed, the plants of Panniyur-5 subjected to mild water stress showed more or less translocation of ^{14}C equally towards the spike nearest to the treated leaves and other spikes. When the water stress levels were higher the translocation was restricted to the nearest spike (corresponding nodal spike).

In plants without berries, translocation of ^{14}C varied between Panniyur-5 and Panniyur-1. In water stressed plants of Panniyur-1 ^{14}C was accumulated in the stem and there was no translocation to other leaves. On the other hand in Panniyur-5, translocation of ^{14}C was observed towards the stem and other leaves in water stress plants.

Experiment III

4.3 Optimum percentage of allowable depletion of soil moisture in bush pepper

The growth and development of bush pepper was influenced by progressive depletion of available soil moisture (Table 46). The number of branches, length of branches, number of leaves, leaf area, number of spikes, spike characters and berry yield showed significant response to irrigation scheduled at various soil moisture depletion.

4.3.1 Number of leaves

The number of leaves per plant decreased with progressive depletion of soil moisture (Table 46). Maximum number of leaves were observed at 50 per cent depletion of available soil moisture followed by 25 per cent depletion. Lowest number of leaves were observed, when irrigation was given at 75 per cent depletion of soil moisture. Daily irrigation was on par with irrigation at 25 per cent depletion of soil moisture.

4.3.2 Leaf area

The influence of soil moisture depletion on total leaf area per plant were not significantly different (Table 46) at 30, 60 and 90 DAT. Though statistically not significant, at 90 DAT, maximum leaf area was observed in the daily irrigated plants followed by the plants irrigated at 50 per cent depletion.

4.3.3 Number of branches

The maximum number of branches were observed in plants irrigated when 50 per cent of available water was depleted (Table 46). Irrigating the plants at 25 per cent depletion was on par with irrigation at 50 per cent depletion. However, delaying the irrigation until the soil moisture gets depleted to 75 per cent of the available water resulted in a drastic reduction in number of branches per plant. In control (daily irrigation) < 10 per cent depletion also, the number of branches were considerably less and was on par with 75 per cent depletion.

Table 46: **Effect of irrigation at different levels of soil moisture depletion on number of branches, number of leaves and leaf area of bush pepper**

Soil moisture depletion (per cent of available water)	Number of leaves (DAT)			Number of branches (DAT)			Leaf area (cm^2 plant^{-1}) (DAT)		
	30	60	90	30	60	90	30	60	90
25%	12.3	12.7	10.6^{a}	17.5^{a}	17.0^{a}	17.0^{a}	310.6	279.8	245.5
50%	20.0	16.7	16.3^{a}	18.1^{a}	17.7^{a}	17.6^{a}	463.6	367.1	385.6
75%	14.3	8.5	7.8^{b}	9.6^{b}	9.2^{bc}	8.9^{bc}	338.6	331.7	269.0
~10% (Daily irrigation)	8.0	8.5	10.0^{a}	8.5^{bc}	10.9^{b}	9.4^{b}	355.0	481.6	407.4

Mean values followed by a common letter are not significantly different at 5% levels by DMRT

Mean values of number of leaves at 30, 60 DAT, leaf area at 30, 60 and 90DAT are not significantly different at 5% levels by DMRT

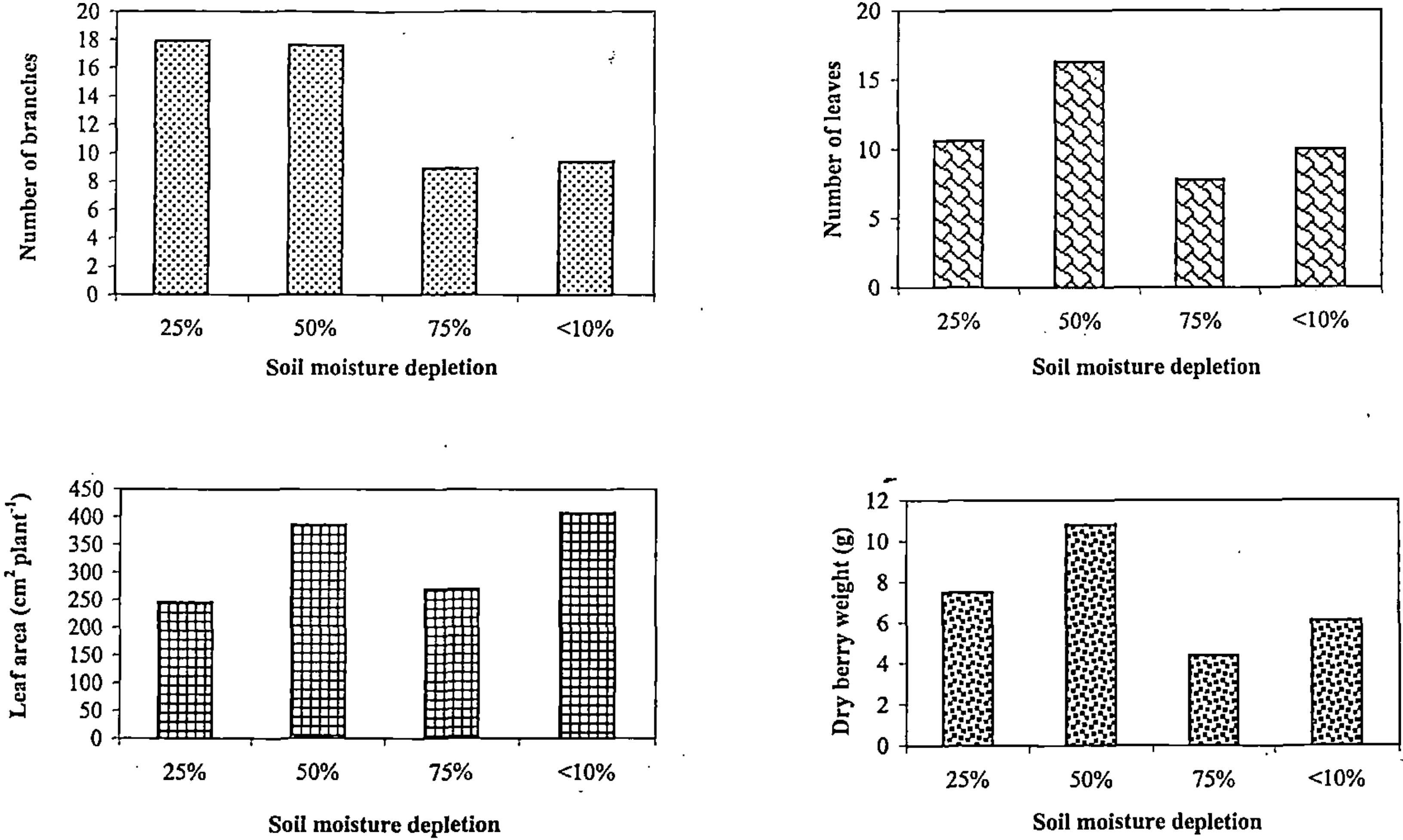


Fig. 35. Effect of irrigation at different soil moisture depletion on number of branches, number of leaves, leaf area and dry berry weight

Table 47: Effect of irrigation at different soil moisture depletion on length of branches in bush pepper

Soil moisture depletion	Length of primary branches (cm) (DAT)			Length of secondary branches (cm) (DAT)			Length of tertiary branches (cm) (DAT)		
	30	60	90	30	60	90	30	60	90
25%	21.3	19.9	16.4	8.5	7.7	8.9	3.9	3.7	2.8
50%	25.1	24.6	26.2	10.3	8.5	8.2	4.2	2.8	1.1
75%	21.2	19.6	19.7	9.5	9.8	7.6	2.4	0.51	1.5
~10% (Daily irrigation)	21.5	21.1	17.5	10.1	10.8	10.8	2.0	0.51	0.67

Length of primary, secondary and teritiary branches at 30, 60 and 90DAT are not significantly different at 5% levels by DMRT

4.3.4 Length of branches

There were no significant difference in the length of branches when the plants were irrigated at 25, 50 or 75 per cent depletion of soil moisture (Table 47). However, longest primary branches were observed in plants irrigated at 50 per cent depletion of available soil moisture and the least number of branches were observed on plants irrigated at 25 per cent depletion.

4.3.5 Root dry weight

The root dry weight of bush pepper was significantly influenced by soil moisture depletions (Table 48). Increase in soil moisture depletion decreased root dry weight and it was lowest in plants irrigated at 75 per cent depletion. Maximum root dry weight was observed in plants irrigated at 50 per cent soil moisture depletion.

4.3.6 Shoot dry weight

The shoot dry weight of bush pepper was not influenced by irrigation at different soil moisture depletion (Table 48).

Highest value of shoot dry weight was observed in plants irrigated at 50 per cent soil moisture depletion. The shoot dry weight was less in plants irrigated daily or at 25 or 75 per cent soil moisture depletion.

4.3.7 Total dry matter

Significantly higher total dry matter was observed in plants irrigated at 50 per cent soil moisture depletion and the least in plants irrigated at 75 per cent depletion (Table 48). However, dry matter production of plants irrigated at 25 and 75 per cent depletion were on par with daily irrigation.

Table 48: Effect of irrigation at different soil moisture depletion on root dry weight, shoot dry weight, root-shoot ratio and total dry matter production in bush pepper

Soil moisture depletion	Root dry weight (g. plant^{-1})	Shoot dry weight (g. plant^{-1})	Total dry matter (g. plant^{-1})	Root- shoot ratio
25%	2.5^{ab}	6.0	12.6^{b}	0.84
50%	8.3^{a}	16.8	35.5^{a}	0.65
75%	1.5^{b}	8.0	12.3^{b}	0.28
<10% (Daily irrigation)	3.3^{ab}	8.3	17.2^{b}	0.63

The means followed by a common letter are not significantly different at 5% levels by DMRT.
Shoot dry weight and root-shoot ratio are not significantly different at 5% levels by DMRT

4.3.8 Root/Shoot ratio

The effect of soil moisture depletion on root/shoot ratio was not significant (Table 48).

4.3.9 Yield characters

4.3.9.1 Number of spikes

Number of spikes on primary branches were not significantly influenced by soil moisture depletion, whereas the number of spikes on secondary branches recorded at one month stage was significantly influenced by soil moisture depletion (Table 49). The number of spikes on tertiary branches were also significantly influenced due to the levels of soil moisture depletion at 30 DAT. At 60 DAT and 90 DAT there were no spikes on tertiary branches. Maximum number of spikes were observed on plants irrigated at 50 per cent depletion of soil moisture, followed by the plants irrigated at 25 per cent depletion of soil moisture. The least number of spikes were in plants irrigated at 75 per cent soil moisture depletion.

The total number of spikes harvested was influenced by different soil moisture depletions (Table 50). Maximum number of spikes were harvested, in plants irrigated at 50 per cent soil moisture depletion followed by daily irrigation and irrigation at 25 and 75 per cent depletion the lowest value being in 25 per cent depletion.

4.3.9.2 Length of spikes

The length of spikes were on par when irrigated at 25, 50 and 75 per cent soil moisture depletion (Table 50). Maximum length of spikes were observed in plants irrigated daily.

Table 49: Effect of irrigation at different soil moisture depletion on production of spikes on primary, secondary and tertiary branches of bush pepper

Soil moisture depletion	Number of spikes on primary branches (DAT)			Number of spikes on secondary branches (DAT)			Number of spikes on tertiary branches (DAT)		
	30	60	90	30	60	90	30	60	90
25%	4.9	1.6	2.3	4.4^{b}	4.4	2.3	1.2^{a}	0.0	0.0
50%	5.6	4.8	1.9	8.7^{a}	5.7	2.6	2.3^{a}	0.0	0.0
75%	3.9	0.8	1.2	3.3^{b}	1.9	2.0	0.8^{bc}	0.0	0.0
<10% (Daily irrigation)	4.1	1.0	1.0	3.0^{b}	1.1	1.2	0.9^{b}	0.0	0.0

Number of spikes on primary branches at 30 DAT, number of spikes on secondary and teritiary branches at 60 and 90 DAT are not significantly different at 5% levels by DMRT.
The means followed by a common letter are not significantly different at 5% levels by DMRT.

4.3.9.3 Compaction of spike

The spikes were more high in plants irrigated at 50 per cent soil moisture depletion (Table 50). This was followed by the plants irrigated at 25 per cent depletion. The least value of spike compaction was observed in plants irrigated at 75 per cent depletion of available water which was on par with daily irrigation.

4.3.9.4 Number of berries

Soil moisture depletion showed significant influence on number of berries on spikes (Table 50). Maximum number of berries were observed in plants irrigated daily followed by irrigation at 50 per cent soil moisture depletion, which was on par with irrigation at 25 per cent depletion. Irrigating the plants at 75 per cent depletion of available soil moisture decreased the number of berries considerably.

4.3.9.5 Volume of berry

Volume of berry differed significantly with soil moisture depletion (Table 50). Maximum volume was observed in plants irrigated daily. Irrigation at 25, 50 and 75 per cent soil moisture depletion showed considerably low volume. Among them the highest value was in plants irrigated at 50 per cent depletion and lowest value in plants irrigated at 75 per cent depletion of soil moisture.

4.3.9.6 Hundred berry weight

Soil moisture depletion did not show any significant influence on hundred berry weight (Table 50).

Table 50: Effect of irrigation at different soil moisture depletion on yield characters and quality of berries in bush pepper

Soil moisture depletion	Total no. of spikes harvested	Length of spikes (cm)	Compaction of spikes (berries cm^{-1})	Number of berries on spike	Volume cc $berry^{-1}$	100 berry weight (g)	Green berry weight (g)	Dry berry weight (g)	Oleoresin (%)	Piperine (%)
25%	9.0^{b}	6.6^{b}	33.2^{b}	35.7^{a}	5.0^{b}	9.7	29.2^{b}	7.5^{a}	10.0^{c}	2.9^{a}
50%	17.8^{a}	5.8^{b}	40.9^{a}	39.2^{a}	7.5^{ab}	9.0	41.2^{a}	10.8^{a}	13.5^{a}	2.5^{ab}
75%	5.5^{bc}	5.6^{b}	25.0^{c}	22.3^{b}	3.7^{b}	9.3	16.5^{c}	4.4^{b}	9.0^{d}	2.0^{bc}
<10% (Daily irrigation)	11.0^{b}	8.9^{a}	26.1^{c}	40.3^{a}	11.7^{a}	10.0	23.6^{c}	6.1^{a}	11.5^{b}	2.2^{b}

The means followed by a common letter are not significantly different at 5% levels by DMRT

The hundred berry weight is not significantly different at 5% levels by DMRT

4.3.9.7 Weight of berries

Soil moisture depletion showed significant effect on green berry weight and the maximum weight was observed in plants irrigated at 50 per cent soil moisture depletion (Table 50). Irrigating at 75 per cent soil moisture depletion resulted in lowest green berry weight.

Similarly maximum dry berry weight was observed in plants irrigated at 50 per cent soil moisture depletion and the minimum in plants irrigated at 75 per cent depletion. Daily irrigation and irrigation at 25 per cent depletion was inferior to irrigation at 50 per cent depletion.

4.3.10 Quality of berries

4.3.10.1 Oleoresin

The oleoresin content of the berries was maximum in plants irrigated at 50 per cent depletion of available moisture and minimum in plants irrigated at 75 per cent depletion (Table 50). Daily irrigation resulted in more oleoresin than irrigation at 25 per cent depletion of available moisture but was inferior to irrigation at 50 per cent depletion of available soil moisture.

4.3.10.2 Piperine

Maximum piperine content was observed when the plants were irrigated at 25 per cent depletion of available soil moisture (Table 50) which was on par with irrigation at 50 per cent depletion of available soil moisture. The minimum piperine content was in the plants irrigated at 75 per cent depletion of available moisture. The piperine content in the berries of daily irrigated plants was inferior to plants irrigated at 25 per cent and 50 per cent depletion of available moisture.

Experiment IV

4.4 Root distribution pattern of bush pepper

The root distribution patterns of bush pepper was evident from the ^{32}P count observed in the soil around the ^{32}P treated bush pepper (Table 51, 52).

The ^{32}P count observed at different depths varied with lateral distances from the plant. At 10-20 cm lateral distance from the plant, the ^{32}P count showed an exponential increase with increase in depth. The ^{32}P showed an exponential decrease with increase in depth, at lateral distances of 20 and 30 cm. At 40-60 cm depth maximum ^{32}P was observed at 10 cm lateral distance. The ^{32}P count at 60 cm depth dropped exponentially with increase in lateral distance from 10-30 cm. The ^{32}P count at a lateral distance of 40 cm was negligible at 20-80 cm depth.

About 40-60 per cent of the total ^{32}P counts detected in the root zone was within 20 cm depth and about 30 per cent of the counts were in 20-40 cm depth. Over all 70-87 per cent of the counts were within 40 cm depth. Only 13-27 per cent counts were observed at 60 cm depth. The ^{32}P counts also varied with lateral distance from the plant. Maximum counts were observed at 20-30 cm lateral distance and minimum at 30-40 lateral distance. About 18-40 per cent of the counts were observed within 10 cm lateral distance and 79-93 per cent of the counts were observed within 30 cm lateral distance from the plant.

Table 51: ^{32}P count in the soil around the plant treated with ^{32}P (leaf smearing) and percentage of root distribution

Depth (cm)	^{32}P counts (cpm)				Total
	Lateral distance (cm)				
	10	20	30	40	
20	70^{b} (7)*	173^{a} (18)	155^{a} (16)	10^{c} (1)	408^{a} (42)
40	185^{a} (19)	38^{bc} (4)	33^{bc} (3)	48^{bc} (5)	304^{b} (31)
60	139^{a} (14)	104^{b} (1)	13^{c} (1)	13^{c} (1)	269^{c} (27)
80	-	-	-	-	
Total	394^{a} (40)	315^{b} (32)	201^{c} (21)	71^{d} (7)	

The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The total counts followed by a common letter are not significantly different at 5% levels by DMRT

(* Values in parenthesis are root distribution percentage)

Table 52: ^{32}P count in the soil around the plant treated with ^{32}P (single root feeding) and percentage of root distribution

Depth (cm)	^{32}P counts (cpm) Lateral distance (cm) 10	20	30	40	Total
20	863^{a} (30)*	517^{b} (18)	169^{e} (6)	86^{fg} (3)	1635^{a} (57)
40	368^{c} (13)	116^{f} (4)	297^{d} (11)	46^{g} (2)	827^{b} (30)
60	251^{d} (9)	48^{g} (2)	47^{g} (2)	31^{g} (1)	377^{c} (14)
Total	1278^{a} (45)	681^{b} (24)	513^{c} (19)	163^{d} (6)	

- The interaction means followed by a common letter are not significantly different at 5 % levels by DMRT

The total counts followed by a common letter are not significantly different at 5% levels by DMRT

(* Values in parentheses are root distribution percentage)

Experiment V

4.5 Scheduling of irrigation in bush pepper

The quantity of drip irrigation influenced the growth and yield of bush pepper grown as an inter crop in twenty five year old coconut plantations (Table 53).

4.5.1 Number of leaves

Maximum number of leaves (Table 53) was observed in plants irrigated with 16 L drip, October-March. Pot watering (10 L per plant) was on par with drip irrigation at the rate of 4, 8, 12 L and significantly superior to drip irrigation at the rate of 2 L per plant.

4.5.2 Leaf area

The total leaf area was the highest in plants irrigated with 16 L drip (October-March) followed by 16 L drip (October-May) and least in.plants irrigated with 2 L drip (Table 53). The leaf area per plant increased with increase in the quantity of drip irrigation. However, with 12 L drip there was a decrease in leaf area. The leaf areas recorded in 8 L drip and pot watering were on par.

4.5.3 Number of branches

The number of branches per plant increased with increasing quantity of drip irrigation except in 12 L drip (Table 53). Maximum number of branches were observed on plants irrigated with 16 L drip (October–Mach), followed by 16 L drip (October–May). The minimum number of branches per plant were observed with 2 L drip. There were no significant differences between pot watering (10 L per plant per day) and drip irrigation at the rate of 4, 8 and 12 L.

Table 53: Effect of drip irrigation on growth parameters of bush pepper inter - cropped in coconut garden

Quantity of drip irrigation L plant^{-1}	Number of leaves	Leaf Area (cm^2)	Number of branches	Length of branches (cm)		
				Primary	Secondary	Tertiary
2	25^{c}	1832^{d}	17.7^{c}	23.7	23.3^{bc}	9.8^{b}
4	69^{b}	2422^{cd}	22.2^{bc}	33.8	22.4^{c}	13.7^{a}
8	72^{b}	3952^{abc}	31.3^{ab}	32.1	27.1^{bc}	12.7^{a}
12	66^{b}	2752^{bcd}	26.3^{bc}	34.2	29.5^{a}	12.2^{a}
16 (Oct.-May)	92^{ab}	4663^{ab}	38.9^{a}	34.8	28.7^{bc}	13.6^{a}
16 (Oct.- March)	102^{a}	5066^{a}	41.2^{a}	38.2	27.4^{bc}	12.0^{a}
Control (Pot watering 10 L plant^{-1})	69^{b}	3545^{abcd}	31.9^{ab}	32.7	23.8^{bc}	12.9^{a}

In a column, means followed by a common letter are not significantly different at 5 % levels by DMRT

The mean values of primary branch length are not significantly different at 5% levels by DMRT

4.5.4 Length of branches

The length of primary branches was not significantly influenced by the quantity of drip irrigation (Table 53). Pot watering was found to be on par with drip irrigation. However, the length of secondary and tertiary branches varied. Maximum number of secondary branches was with 12 L drip and the tertiary branches with 16 L (October- May) drip.

4.5.5 Yield characters

4.5.5.1 Number of spikes

The number of spikes harvested per plant was significantly influenced by drip irrigation (Table 54). During the first year maximum number of spikes were harvested from plants irrigated with 8 L drip (October–March). This was followed by drip irrigation at the rate of 4 L which was on par with 16 L drip irrigation October–March or October-May. The lowest number of spikes per plant were observed in plants irrigated with 2 L drip. During the second year also maximum number of spikes were observed on plants irrigated with 8 L drip and minimum on plants irrigated with 2 L drip (Table 55).

The pooled mean also showed that the number of spikes were maximum with 8 L drip irrigation which was on par with all other irrigation levels except 2 L drip. The lowest number of spikes were observed with 2 L drip.

4.5.5.2 Length of spikes

There were significant differences in length of spikes due to the influence of drip irrigation (Table 54). First year results showed that the length of spike was

Table 54: Effect of drip irrigation on spike characters, yield, quality and incidence of pests in field planted bush pepper in coconut garden (first year)

Quantity of drip L irrigation plant^{-1}	Number of spikes	Length of spikes (cm)	Number of berries	Compaction (berries cm^{-1})	100 berry weight (g)	Volume (cc)	Green berry yield (g plant^{-1})	Dry berry yield (g plant^{-1})	Oleoresin (%)	Piperine (%)	Catterpiller attack (%)	Thrips attack
2	5.3^{c}	5.4^{c}	23.0^{b}	4.2	3^{b}	4.0^{c}	11.9^{d}	2.4^{a}	10.7^{bc}	0.8^{a}	15.2^{c} (22.9)*	17.0^{a} (4.2)*
4	11.3^{ab}	8.3^{ab}	43.7^{a}	5.2	4^{b}	4.7^{c}	24.3^{b}	7.5^{b}	8.3^{d}	1.7^{ab}	24.0^{abc} (29.3)	11.8^{ab} (3.6)
8	16.4^{a}	9.3^{a}	45.6^{a}	5.0	9^{a}	8.3^{a}	37.1^{a}	14.7^{c}	12.3^{a}	3.0^{bc}	30.0^{ab} (33.2)	12.0^{ab} (3.6)
12	5.4^{c}	5.7^{c}	35.0^{ab}	6.2	8^{a}	6.7^{b}	16.9^{c}	5.2^{ab}	8.4^{d}	2.5^{bc}	30.4^{a} (33.4)	7.7^{b} (2.9)
16 (Oct.-May)	7.5^{bc}	7.6^{ab}	43.0^{a}	5.6	8^{a}	7.3^{ab}	21.3^{c}	6.6^{b}	11.8^{ab}	2.3^{bc}	31.2^{ab} (33.0)	1.05^{b} (3.4)
16 (Oct.-March)	11.1^{bc}	8.0^{ab}	45.0^{a}	5.6	8^{a}	8.3^{a}	24.3^{b}	9.0^{b}	11.3^{b}	2.6^{d}	18.8^{bc} (25.3)	6.9^{b} (2.8)
Control Pot watering (10 L plant^{-1})	10.4^{bc}	7.0^{bc}	43.0^{a}	6.2	8^{a}	7.3^{ab}	20.3^{bc}	6.2^{ab}	10.0^{c}	2.7^{bc}	29.1^{ab} (32.6)	7.5^{b} (2.9)

In a column means followed by a common letter are not significantly different at 5% levels by DMRT
The mean values of compaction of berries are not significantly different at 5% levels by DMRT
* Transformed values

Table 55: Effect of drip irrigation on spike characters of bush pepper grown in coconut garden (pooled)

Quantity of drip L irrigation $plant^{-1}$	Number of spikes			Length of spikes (cm)			Number of berries			Compaction (berries cm^{-1})		
	1^{st} year	2^{nd} year	Mean	1^{st} year	2^{nd} year	Mean	1^{st} year	2^{nd} year	Mean	1^{st} year	2^{nd} year	Mean
2	5.0	11.9	8.4^{b}	5.4^{de}	7.0^{bcd}	6.2^{b}	23.0^{b}	22.7^{b}	22.9^{b}	4.2^{bcd}	3.2^{d}	3.7^{c}
4	11.7	40.2	25.9^{ab}	8.3^{ab}	8.4^{ab}	8.4^{a}	43.7^{a}	36.9^{ab}	40.3^{a}	5.2^{bcd}	4.4^{bcd}	4.8^{bc}
8	16.0	57.9	37.0^{a}	9.3^{a}	7.4^{abc}	8.4^{a}	45.7^{a}	41.9a	43.8^{a}	5.0^{bcd}	6.0^{bc}	5.5^{b}
12	5.7	57.9	31.8^{a}	5.7^{cde}	7.4^{abc}	6.6^{b}	35.0^{ab}	32.5^{ab}	23.8^{a}	6.2^{b}	4.2^{bcd}	5.2^{bc}
16	7.7	33.7	20.7^{ab}	7.7^{ab}	4.0^{e}	5.8^{b}	43.0^{a}	34.0^{ab}	38.5^{a}	5.6^{bcd}	8.5^{a}	7.1^{a}
16 (Oct.-March)	11.0	37.8	24.4^{ab}	8.0^{ab}	8.3^{ab}	8.2^{a}	45.0^{a}	29.2^{ab}	37.1^{a}	5.6^{bcd}	3.5^{cd}	4.6^{bc}
Control Pot watering (10 L $plant^{-1}$)	18.3	25.3	21.8^{ab}	7.0^{bcd}	7.1^{bcd}	7.1^{ab}	42.7^{a}	29.9^{ab}	36.3^{a}	6.2^{b}	4.1^{bcd}	5.2^{bc}

In a column means followed by a common letter are not significantly different at 5% levels by DMRT
The mean values of number of spikes are not significantly different at 5% levels by DMRT

significantly superior in 8 L drip which was on par with 4 L and 16 L drip. The lowest spike length was observed in plants with 2 L drip irrigation.

In the second year the difference between irrigation levels were not conspicuous except 16 L (October-March) where an inferior value was recorded (Table 55). The pooled mean indicated the superiority of 4 and 8 L drip which were on par with 16 L drip (October-March). Two litre drip and 16 L (October-May) drip were inferior to 4 and 8 L drip

4.5.5.3 Number of berries

The number of berries per spike increased with quantity of drip irrigation and the maximum number of berries were observed in plants irrigated with 8 L drip which was on par with 4, 12 and 16 L drip (Table 54). A significant decrease in the number of berries were observed in plants irrigated with 2, 12 L drips. During second year also maximum number of berries were observed with 8 L drip. However other irrigation levels were on par except 2 L drip which was inferior. The pooled mean also showed almost similar pattern. The number of berries were least in plants irrigated with 2 L drip during both the years (Table 55).

4.5.5.4 Compaction of spike

Compaction of spike did not differ significantly due to the quantity of drip irrigation (Table 54).

The compaction of spike was not significantly different during the first year. In the second year 16 L drip was superior to other irrigation treatments (Table 55). Minimum value of compaction was with 2 L drip which was on par with 4, 12, 16 L, drip and pot watering. The pooled mean was maximum with 16 L drip. All other irrigation levels were on par.

4.5.5.5 Hundred-berry weight

Maximum hundred berry weight was observed on plants irrigated with 8 L drip and this was on par with plants irrigated with 12 or 16 L drip or pot watering (Table 54). Drip irrigation at the rate of 2 and 4 L were inferior to higher quantities of drip irrigation and pot watering during first year.

The pooled mean showed the superiority of 8 L drip. However, it was on par with pot watering (10 L) (Table 56). Two and four litre drip were inferior to higher levels of drip irrigation.

4.5.5.6 Berry-volume

Drip irrigation at the rate of 8 L and 16 L (October–May) resulted in maximum berry-volume during first year and the least volume was observed in plants irrigated with 2 L drip (Table 54). Drip irrigation at the rate of 12, 16 L and pot watering were on par.

In the second year maximum berry volume was with 8 L drip, which was on par with pot watering (Table 56). Other irrigation levels were not significantly different. The pooled mean also showed similar trend.

4.5.5.7 Green berry yield

Maximum green berry yield was from plants irrigated with 8 L drip and the minimum was in plants irrigated with 2 L drip (Table 54). The second best yield was obtained from plants irrigated with 4 L drip and was on par with drip irrigation at the

Table 56:Effect of drip irrigation on spike characters, yield of bush pepper grown in coconut garden (pooled)

Quantity of drip L irrigation plant^{-1}	100 berry weight (g)			Volume			Green weight (g)			Dry weight (g)		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
2	3.0^{e}	9.4^{bcd}	6.2^{c}	4.0^{e}	8.0^{bcd}	6.0^{b}	12.0^{b}	82.3^{b}	47.1^{d}	3.0^{c}	40.2^{c}	21.6^{b}
4	4.0^{e}	10.7^{b}	7.3^{c}	4.7^{de}	9.7^{bc}	7.2^{bc}	24.3^{b}	129.0^{b}	76.7^{cd}	7.0^{c}	51.7^{c}	29.3^{b}
8	9.0^{bcd}	12.3^{a}	10.7^{a}	8.3^{bcd}	13.4^{a}	10.9^{a}	36.7^{b}	520.3^{a}	278.5^{a}	10.3^{c}	173.3^{a}	91.8^{a}
12	8.0^{d}	10.0^{bc}	9.0^{b}	6.7^{cde}	9.2^{bc}	8.0^{bc}	17.0^{b}	296.0^{ab}	156.5^{bc}	4.3^{c}	118.3^{b}	61.3^{a}
16	8.0^{d}	9.7^{bcd}	8.8^{b}	7.3^{bcde}	7.5^{bcde}	7.4^{bc}	21.3^{b}	299.0^{ab}	160.2^{bc}	5.3^{c}	119.7^{b}	62.5^{a}
16 (Oct.-March)	8.3^{cd}	9.8^{bcd}	9.1^{b}	8.3^{bcd}	8.3^{bcd}	8.3^{bc}	24.3^{b}	368.0^{ab}	196.2^{b}	6.1^{c}	122.7^{b}	64.4^{a}
Control Pot watering (10 L plant^{-1})	8.3^{cd}	10.7^{b}	9.5^{ab}	7.3^{bcde}	11.0^{ab}	9.2^{ab}	20.3^{b}	119.0^{b}	69.7^{d}	5.1^{c}	47.7^{c}	26.4^{b}

In a column means followed by a common letter are not significantly different at 5% levels by DMRT rate of 16 L (October–March), 16 L (October–May) and pot watering at the rate of 10 L per plant. Drip irrigation at the rate of 12 L per plant was on par with pot watering (10 L per plant) but inferior to all others except 2 L drip, which resulted in minimum yield.

During second year also maximum green berry yield was obtained with 8 L drip and was on par with all other high levels of drip irrigation (Table 56). Pot watering (10 L) and drip irrigation at the rate of 2 and 4 L were inferior as compared to other irrigation levels. The pooled mean also showed similar trends.

4.5.5.8 Dry berry yield

The dry berry yield (Table 54) was maximum in plants irrigated with 8 L drip and minimum in 2 L drip. This was followed by 16 L (October–March) and 4 L drip irrigation which were on par with 12, 16 L (October–May) and pot watering (10 L day^{-1}).

The second year results and the pooled mean showed same trend as that of green berry yield (Table 56). The highest yield was with 8 L drip followed by 12, 16 L (October-March) and 16 L (October-May) drip. Pot watering, 2 L and 4 L drips were inferior to other drip irrigations levels.

4.5.6 Quality of berries

4.5.6.1 Oleoresin

The oleoresin content (Table 54) of the berries showed significant variation depending on the quantity of drip irrigation. Maximum oleoresin content was in the berries from the plants irrigated with 8 L drip and minimum in 4 L drip. The berries

Table 57: Effect of drip irrigation on oleoresin and piperine content of berries of bush pepper grown in coconut garden (pooled)

Quantity of drip L irrigation $plant^{-1}$	Oleoresin (%)			Piperine (%)		
	1^{st} year	2^{nd} year	Mean	1^{st} year	2^{nd} year	Mean
2	10.7^{abc}	7.5^{e}	9.1^{bc}	0.8^{i}	3.0^{cd}	1.9^{g}
4	8.3^{de}	8.0^{e}	8.2^{c}	1.7^{h}	3.1^{c}	2.4^{f}
8	12.3^{a}	9.0^{cde}	10.7^{a}	3.0^{d}	3.7^{b}	3.3^{b}
12	8.4^{de}	9.0^{cde}	8.7^{bc}	2.5^{f}	3.6^{b}	3.0^{c}
16	11.8^{a}	7.7^{e}	9.7^{bc}	2.3^{g}	3.2^{c}	2.7^{e}
16 (Oct-March)	11.3^{ab}	7.9^{e}	9.6^{ab}	2.6^{a}	3.6^{b}	3.1^{a}
Control Pot watering (10 L $plant^{-1}$)	10.0^{bcd}	8.3^{de}	9.2^{bc}	2.7^{e}	3.1^{cd}	2.9^{d}

In a column means followed by a common letter are not significantly different at 5% levels by DMRT from the plants irrigated with 12 L drip showed low oleoresin content and was on par with the oleoresin content of the berries from 4 L drip irrigation. Pot watering resulted in low oleoresin as compared to 8 L and 16 L drip irrigation. The oleoresin content of the berries from plants irrigated with 2 L drip was low but on par with 8 L, 16 L drip and pot watering but superior to 4 L and 12 L drips.

During second year also maximum oleoresin content was observed with 8 L drip which was on par with 12 L drip (Table 57). The pooled mean confirmed the superiority of 8 L drip which was on par with 16 L drip.

4.5.6.2 Piperine

During both the years maximum piperine was observed in berries of the plants irrigated with 8 L drip (Table 54). The minimum piperine content was observed with 2 L drip irrigation followed by 4 L drip irrigation in the first year. The piperine content of the berries from plants irrigated with 12, 16 L (October–March) drip and 10 L pot watering were on par.

Pooled analysis of data during second year showed that maximum piperine was in 8 L drip followed by 16 L drip (October-March) and least in 2 L drip (Table 57).

4.5.7 Incidence of pests

The effect of drip irrigation on caterpiller attack was significant (Table 54) and it was high in 12 L drip. Drip irrigation at the rate of 16 L (October–March) and 2 L drip resulted in less caterpiller attack. The caterpiller attack was on par in 8 L drip and pot watering.

Effect of different levels of drip irrigation on incidence of thrips attack was significant. Maximum attack was observed in 2 L drip, followed by 4 and 8 L drip and the least in 16 L (October–March) drip.

4.5.8 Consumptive use, soil moisture distribution and field water use efficiency

The consumptive use (CU) increased with increasing the quantity of irrigation water (Table 58). The consumptive use was maximum with 16 L drip (October –May) and minimum in 2 L drip. In pot watering, CU was less than the irrigation water whereas in drip irrigation, irrespective of quantity of the drip, the CU was more than the irrigation water.

The total irrigation water requirement for the dry season varied from 276-2208 L depending on quantity of drip irrigation. In control, the total irrigation requirement was 1380 L. Seasonal consumptive use varied from 468 L with 2 L drip 2522 L drip with 16 L drip (October-May). The seasonal consumptive use in control was only 1465 L. The consumptive use was more than control when 12-16 L drip were used. As compared to the control, the CU decreased by 68, 52 and 15 per cent respectively when 2, 4 and 8 L drip were used. With 12 and 16 L drips, the CU increased considerably (33 to 72 per cent).

The soil moisture depletion by bush pepper was more or less equal from 0-20 cm and 20-40 cm depth. In Plants drip-irrigated from 2 -12 L per plant the maximum soil moisture depletion was from 20-40 cm layer. In the case of 8 L drip, soil moisture depletion was more from 20-40 cm layer than from 0-20 cm layer. In 16 L drip and pot watering (10 L plant^{-1} day^{-1}) soil moisture depletion was more from the surface layers.

Table 58: Consumptive use and field water use efficiency of drip irrigation in bush pepper (first year)

Drip irrigation (L $plant^{-1}$)	Total irrigation water (L)	CU* (L day^{-1} $plant^{-1}$)	% change of CU over control	Seasonal CU Oct-May (L)	% of moisture used from different soil depth		FWUE**	Yield kg ha^{-1}
					0-20 cm	20-40 cm		
2	276	3.1	-68	468	48	52	0.12	32.0
4	552	4.7	-52	710	49	51	0.12	66.0
8	1104	8.2	-15	1238	32	68	0.09	100.0
12	1656	12.9	+33	1948	47	53	0.03	46.0
16 (Oct.-May)	2208	16.7	+72	2522	60	40	0.03	57.6
16 (Oct.-March)	1440	16.3	+68	2461	56	44	0.05	65.7
Control (pot watering 10 L day^{-1})	1380	9.7	0	1465	53	47	0.04	54.9

* CU - Consumptive use
** FWUE - Field water use efficiency

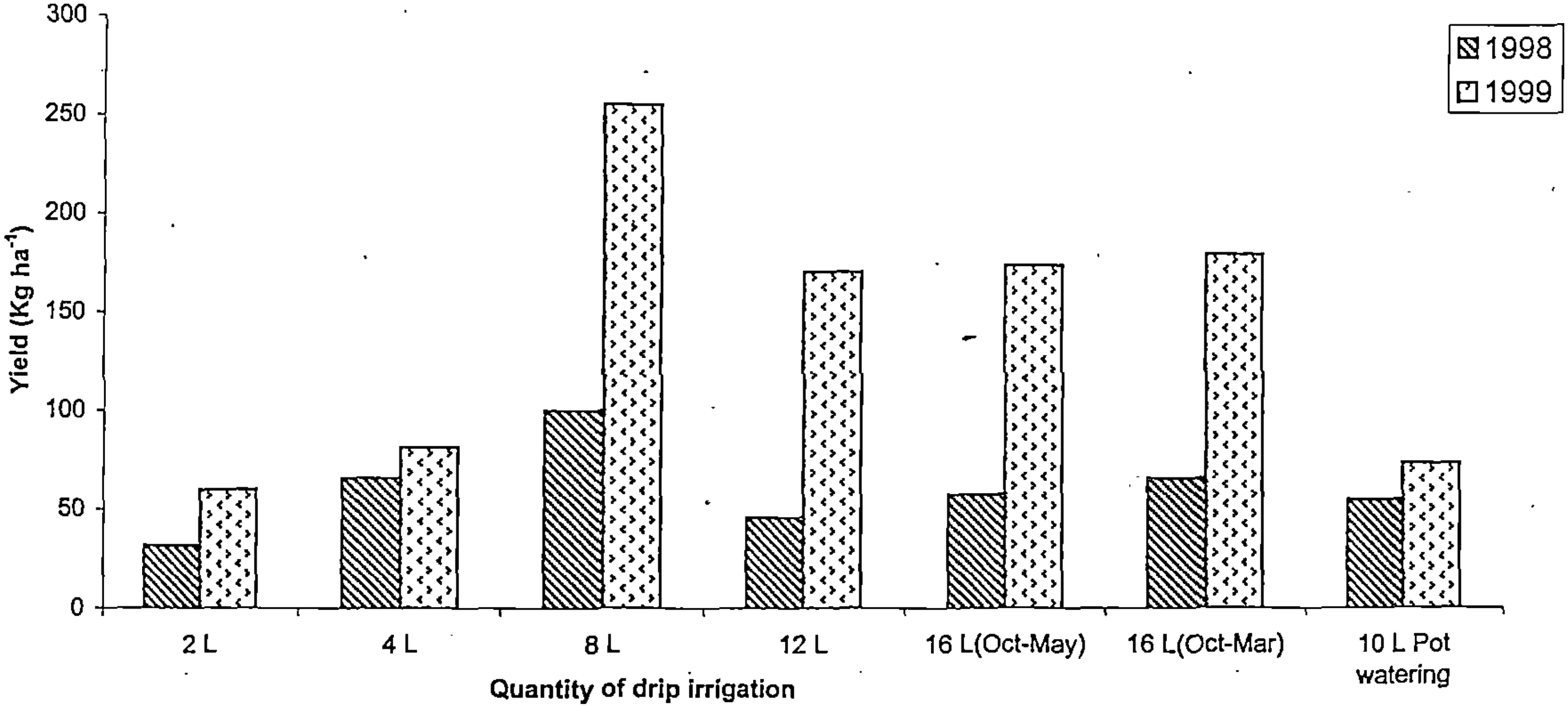


Fig.40. Effect of drip irrigation on yield of bush pepper planted in coconut garden

The field water use efficiency (FWUE) was high in 2, 4 and 8 L drip and it was considerably less in 12, 16 L drip and in pot watering.

4.5.9 Yield

The yield of black pepper was highest with 8 L drip irrigation, followed by 4 L and 16 L (October-March) drip irrigation. The lowest yield was recorded with 2 L drip. Drip irrigation at the rate of 12 L per plant showed lower yield than 8 and 4 L drip irrigation.

The pooled mean also showed maximum yield with 8 L drip followed by 16 L drip (October-March) and 12 L drip. The minimum yield was with 2 L drip. Four litres drip and pot watering also resulted in relatively low yield.

Discussion

DISCUSSION

The results of the experiments on the influence of soil moisture regimes on morphological, physiological and biochemical characters of black pepper varieties, variations of bush and vine pepper in their water stress tolerance, root distribution pattern ;. soil moisture depletion and drip irrigation of bush pepper are discussed in this chapter.

Experiment 1

Screening and characterisation of black pepper varieties for water stress tolerance

Preliminary screening of 44 black pepper varieties/cultivars showed that 38 of them were sensitive to water stress. Some of them showed permanent wilting within two days of water stress. The remaining 15 varieties did not survive water stress for three days. Only six varieties survived water stress for four days. The relative water content and membrane stability of the varieties under different periods of water stress provided corroboratory evidence on the level of water stress tolerance of the varieties.

5.1. Relative water content and membrane stability

Among the varieties which showed RWC above 90 per cent under no stress, none were tolerant to water stress. Stress tolerant varieties were having RWC ranging from 80–90 per cent, when they were not water stressed.

Some of the varieties which showed high RWC under no water stress wilted (permanent) within 2-4 days of water stress. This suggests that the RWC of the plant under no stress may not indicate the water stress tolerance of the variety.

The RWC decreased exponentially in some varieties while in others the decrease was gradual. Only six varieties *viz.*, Kalluvally-4, Kumbakodi, Padarpan, Panniyur–5, Poonjarmunda and Uthirankotta-2 survived four days of water stress. The survived varieties showed RWC ranging from 60 to 73 per cent even after four days of water stress. The RWC in the varieties Kalluvally-4, Kumbakodi, Padarpan, Panniyur–5, Poonjarmunda and Uthirankotta-2 were more stable under increasing water stress levels. So a stable RWC under the stress may be considered as one of the indices for screening water stress tolerant varieties. There exist many reports, which show very good correlation between RWC and water stress tolerance. (Cacao, Balasimha and Daniel, 1988; black pepper, Vasantha *et al.*, 1989; coconut, Voleti *et al.*, 1990; tea, Rajasekar *et al.*, 1988).

The six varieties, which survived four days of water stress showed membrane leakage ranging from 30.8 to 47.3 per cent. Varieties like Perumkodi, Kottanadan-1, TMBI, Kalluvally-1, which showed relatively low membrane leakage under no water stress died within two or four days of water stress. This indicates that membrane leakage under no stress is also not a reliable index to assess water stress tolerance of the varieties. However, varieties which survived four days of water stress showed relatively less membrane leakage when water stressed. Clarke and Mc Craig (1982) used membrane stability to evaluate water stress tolerance in wheat. Drought tolerant Maize (Premachandra *et al.*, 1991) Sorghum (Premachandra *et al*:, 1992) and coconut (Rajagopal and Balasimha, 1994) were reported to show reduced membrane leakage as compared to susceptible varieties.

The six varieties which showed water stress tolerance in the preliminary screening, showed considerable variation in their morphological, physiological, biochemical and anatomical characteristics as compared to the susceptible variety Panniyur-1.

5.2 Biometric characters

In all the varieties except Uthirankotta–2, increasing the water stress levels decreased height of the plants. The height of Panniyur–5 was relatively less influenced by water stress. In the variety Padarpan also, mild water stress did not influence the height. These responses indicate the superior water stress tolerance of Panniyur–5 and Padarpan.

Moderate and severe water stress decreased the number of leaves and leaf area per plant in all the varieties. The reduction in the number and area of leaves is an immediate response to water stress in many plants as these are two main factors deciding the transpiration rate and water relations in plants. Reduction in number of leaves and/or leaf area in response to water stress are reported in plants like tea (Chenkuorenn *et al.*, 1992) and cashew (Latha, 1998). At 60 days after the beginning of the water stress cycle mild water stress increased the girth of the varieties, Kalluvally-4 and Padarpan, whereas severe water stress decreased the girth in all the varieties. The water stress tolerance of Padarpan is evident here also. This result also indicates the preference of mild stress in some varieties.

The root dry weight decreased sharply due to mild water stress in Uthirankotta-2, Padarpan and Kalluvally-4 and marginally increased in Panniyur-5. Vartanian (1981) reported the production of short suberized roots in plants to with stand drought at stress period. Increased root production may be one of the adaptations of Panniyur–5 to survive under water stress.

Total dry matter production in Panniyur-5 and Kalluvally-4 increased under mild water stress. The root/shoot ratio decreased due to mild water stress, in all the varieties except in Poonjarmunda. The decrease in root/shoot ratio with water stress was sharp in Kalluvally-4 and Panniyur-5. Increased root/shoot ratio is considered as a drought tolerance trait in many crop varieties. In drying soil profile cotton roots grew faster and achieved a substantially greater total depth than in well watered soil, (Clarke and Hiler, 1973). Apart from change in root/shoot ratio, there may also be absolute increase in root growth under water stress (Schultze, 1974). Drought tolerant tobacco plants had higher root/shoot ratio than control (Riga and Vartanian, 1999). In this experiment biometric characters like height of plants, number of leaves, leaf area, internodal length, girth, total dry matter and root/shoot ratio of the plants showed varying responses due to water stress. However, based on the response in the above characters, varieties like Panniyur–5, Padarpan, Kalluvally–4 were judged as more tolerant to drought as compared to other varieties.

5.3 Stomatal conductance and transpiration

Due to moderate water stress, the stomatal conductance of Kalluvally-4 dropped considerably whereas that of Panniyur-1 and Kumbakodi continued to be higher (Fig. 6). The faster stomatal regulation in response to water stress in Kalluvally-4 as compared to the poor stomatal regulation of Kumbakodi and Panniyur-1 may be the reason for this response. When water stressed, the most steady value of stomatal conductance, was observed in Panniyur-5, corroborating the water stress tolerence of this variety. Stomatal regulation is considered to be an important physiological function deciding the water stress tolerance of crop plants. Naidu and Bhagyalakshmi (1967) have reported that drought resistant sugarcane variety close their stomata earlier than the susceptible types under moisture stress and control loss of water effectively. Rapid stomatal response may be a drought resistance mechanism to conserve soil water for later use (Jones *et al.*, 1981). Although small dehydrations are not likely to affect the rates of metabolic process directly, indirect effects on both photosynthesis and respiration may be expected since both depend on the conductance of O_2 and CO_2 through the stomata. Stomatal opening and closing is controlled by the turgor of both guard cells of stomata and other epidermal cells which in turn depends on the water stress tolerance of the species (Smart and Binghma, 1974). The dehydration induced inhibition of photosynthesis is also reported to be mostly due to stomatal resistance (Levitt, 1980).

The most conspicuous increase in stomatal conductance due to water stress was observed in Panniyur-1 (Fig. 7). In severely stressed plants, lowest stomatal conductance was observed in Poonjarmunda and highest in Panniyur-1. Under moderate water stress the stomatal conductance in Panniyur-5 and Kumbakodi did not vary significantly due to water stress. The transpiration rate also showed similar pattern. In Panniyur-1 mild water stress increased the transpiration rate. In all other varieties, transpiration decreased due to water stress. Under mild water stress, maximum transpiration rate was observed in Panniyur-1 followed by Padarpan and Kumbakodi. Panniyur-1 is a drought sensitive variety having poor stomatal regulation. Padarpan on the other hand is having poor stomatal control but at the same time is having other morphological and biochemical characters of a tolerant variety.

5.4 Leaf water potential

Among the varieties Panniyur-5 maintained a high ψ during the day (Fig. 36). The ψ dropped sharply with the progress of the day, in varieties Panniyur-1,

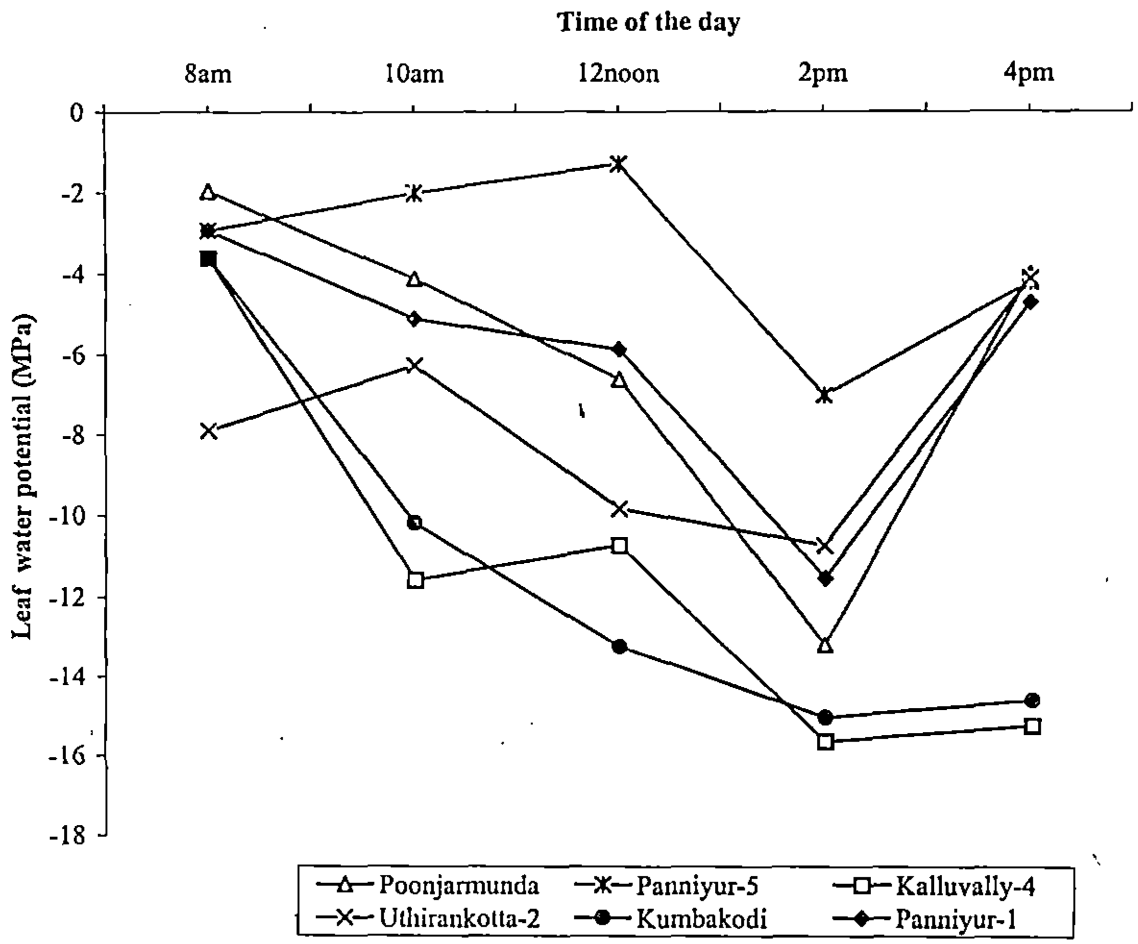


Fig. 36. Variations in leaf water potentials of black pepper varieties during the day

Kumbakodi, Kalluvally-4 and Poonjarmunda. This observation also indicate the adaptation of the variety Panniyur-5 to maintain high ψ with the increase in water stress naturally experienced by the plant when the day progresses. This is another indication for the water stress tolerance of the variety.

5.5 Biochemical characters

5.5.1 Chlorophyll

The chlorophyll of leaves, which showed a small increase under mild water stress decreased due to higher water stress levels, in varieties Poonjarmunda, Uthirankotta-2 and Kalluvally–4 whereas it increased in the variety Padarpan. As the sensitive variety Panniyur-1 did not survive till the time of recording this observation, the specific damage to chlorophyll in this varieties under water stress, could not be understood. The results indicate that the chlorophyll content in Padarpan is more stable under water stress than in Poonjarmunda, Uthirankotta-2 and Kalluvally-4. Chlorophyll stability under stress is one of the factors, which contribute drought tolerance in plants. In cashew chlorophyll stability index of drought tolerant accessions were higher than sensitive varieties (Latha, 1998).

5.5.2 Epicuticular wax

The epicuticular wax increased due to water stress. The wax content was relatively high in water stress tolerant varieties like Panniyur–5 and Padarpan followed by Kalluvally-4, Kumbakodi and Poonjarmunda. The varieties Uthirankotta-2 and Panniyur–1 showed very low epicuticular wax. The percentage increase in epicuticular wax was maximum in Kalluvally-4. So another reason, which contributed to the susceptibility of Panniyur-1 to water stress was low epicuticular wax.

5.5.3 Proline

When the varieties were daily irrigated maximum proline content was observed in Panniyur-1 which did not vary much due to increasing levels of water stress. In all the other varieties proline content increased by 30 to 105 per cent due to severe water stress. The water stress sensitive variety, Panniyur-1, showed less accumulation of proline due to water stress whereas apparently tolerant varieties *viz.* Poonjarmunda, Uthirankotta-2, Panniyur-5, Kalluvally-4 and Padarpan showed more accumulation of proline (Fig. 9). Plants accumulate osmotically active organic solute in free or combined form when exposed to environmental stress. Accumulation of proline in response to water stress has been reported in coffee (Venkataramanan *et al.*, 1989; Maestri *et al.*, 1995) black pepper (Vasantha *et al.*, 1991) tea (Rajasekar *et al.*, 1988), cacao (Rajagopal and Balasimha, 1994) and cashew (Latha, 1998).

Proline accumulation may also be due to the accumulation of carbohydrate. Elevated levels of carbohydrates are also reported to prevent proline catabolism (Handa *et al.*, 1983) inhibiting mitochondrial oxidation of proline (Oaks *et al.*, 1970). In addition proline function as hydrophyllic colloid (Schobert, 1977), stabilize enzymes (Paleg *et al.*, 1981) serve as a respiratory substrate (Blum and Ebercon, 1981) and increases the bound water capacity of plants (Palfi *et al.*, 1974).

Many other investigators have also reported accumulation of proline as a result of water stress (Stewart *et al.*, 1966). Proline accumulated in water stressed barley (Saveatskaya, 1967) and wheat (Tyankova, 1967), Vlasuek *et al.*, 1968). The content of free proline in plants with an optimum supply of water is usually very low

(0.2 to 0.69 mg/g dry matter). It rapidly rises to 40 to 50 mg/g^{-1} dry matter due to slow dehydration of tissues (Palfi *et al.*, 1973). In water stressed sunflower several amino acids increased initially and proline accumulated only at severe stress (Lowlor and Fock, 1977). Proline accumulation is enhanced by K in cucumber cotyledons (Udaykumar *et al.*, 1976) and in Maize leaves (Mukherjee, 1974). Proline accumulation may also be due to a decrease in proline utilization by decrease in protein synthesis during wilting (Stewart, 1973).

According to Protsenko *et al.* (1968) increases in proline and asparagine content of the leaves are signs of adaptations of winter wheat to drought. Proline is readily oxidized to glutamate in turgid barley leaves but in water stressed leaf proline oxidation was negligible (Stewart and Boggess, 1978). A lot of evidences have been put forward to show that proline is not accumulated simply by hydrolysis of protein in water stressed plants.

Since some amino acids are toxic, plant survival is possible only if these toxic amino acids are converted to nontoxic ones e.g. asparagines, glutamine and proline. This accounts for the commonly found accumulation of such amino acids especially proline.

5.5.4 Total sugars

In Poonjarmunda, Kumbakodi, Kalluvally-4 and Padarpan, sugar content increased due to increasing levels of water stress whereas there was a decrease in sugar in Uthirankotta-2, Panniyur-1 and Panniyur-5. The sugar content decreased in Panniyur–1 even in response to mild water stress. Here also clear difference were observed between water stress tolerant and sensitive varieties.

Accumulation of solute is a possible way for the plants to overcome the adverse effect of water stress by osmotic adjustment (Venkataramanan and Ramaiah, 1987). More over the solutes like proline, glycine, betaine and sugars such as sucrose tend to stabilize protein structures in stressed plant (Wyn Jones, 1979) and these solutes are also known to protect the membrane (Schwab and Heber, 1984).

5.5.5 Mineral elements

Severe water stress increased Nitrogen (N) Phosphorus (P) Potassium (K) content in leaves of black pepper varieties. Maximum increase in P content was observed in variety Panniyur-5 when subjected to moderate water stress. The Calcium (Ca) content of the leaves of Uthirankotta-2 and Panniyur–5 increased due to severe water stress. The Magnesium (Mg) content decreased with mild water stress except in Kalluvally-4 and Padarpan, where it increased due to mild water stress. Severe water stress increased Mg content in all the varieties. The zinc content of the leaves though decreased due to water stress in some varieties there was no definite trend. In most of the varieties water stress increased the copper (Cu) content of the leaves. In general water stress decreased the Iron (Fe) & Manganese (Mn) content in all the varieties except Kalluvally-4.

Even though the mineral nutrient concentration in the leaves showed high variation in response to water stress, all the varieties showed N and P accumulation during severe water stress. The role of some of the mineral nutrients in osmotic adjustment and stomatal regulation are emphasised by many authors. Hanson and Hitz (1981) have observed nitrogen accumulation to some extent in water stressed plants. Nitrogen acts as regulatory element along with potassium by influencing stomatal opening of coffee leaves (Kumar, 1979). Phosphrous is reported to be capable of increasing drought resisting properties of the plant (Stockev, 1960).

The role of K in stomatal regulation is well documented and the increased leaf K observed in water stressed plants of black pepper may also have implications in its stomatal regulation. Venkataramanan and Ramaiah, (1987) observed accumulation of mineral nutrients like N, P, K, Ca, in response to water stress in some drought tolerant coffee cultivars. Ca has the ability to maintain the integrity of the membrane under severe stress (Stadelmann and Stadelmann Lee, 1974).

5.5.6 Amino acids

The amino acid decreased due to water stress in varieties Uthirankotta-2 and Kumbakodi. In other varieties amino acid content did not vary due to water stress. However, the amino acid showed an increasing trend due to severe water stress in varieties Poonjarmunda, Panniyur-1, Panniyur-5 and Padarpan.

The decrease in amino acid content of the water stressed plants may be the result of the impaired N metabolism. The adverse effect of water stress on N metabolism and amino acid synthesis in water stressed plants are reported in response to water stress in many plants.

5.6 Enzyme activities

The peroxidase and catalase activities and lipid peroxidation in the black pepper varieties varied considerably due to water stress (Fig. 9). The maximum percentage increase in peroxidase activity was in Uthirankotta-2 and Padarpan and the minimum increase was in Panniyur-1 (Fig. 9).

Mild water stress decreased the catalase activity, except in Padarpan and Panniyur-5. Moderate and severe water stress increased the catalase activities in all the varieties and the percentage increase over control was maximum in Padarpan followed by Panniyur-5. The variety Panniyur-1 showed a decrease in the enzyme activities due to severe water stress. An increase in activity of this enzyme in response to water stress are reported in coconut (Chempakam *et al.*,1993).

The SOD activity increased in all the varieties except in Panniyur-1 with increasing water stress levels. Maximum increase in SOD activity due to water stress was observed in Panniyur-5 followed by Kumbakodi, Kalluvally-4 and Padarpan. Lipid peroxidation also increased due to mild water stress in all the varieties but further increase in water stress resulted in a decrease (Fig. 9). All the varieties except Panniyur-1 and Kumbakodi showed a sharp decrease in lipid peroxidation due to water stress. The lipid peroxidation progressively increased in Panniyur–1 with increase in water stress levels.

The peroxidation of lipids in the cell membrane is one of the most damaging reactions observed in response to water stress. The lower lipid peroxidation observed in the apparently water stress tolerant varieties like Poonjarmunda, Uthirankotta-2, Kumbakodi, Kalluvally-4, Panniyur-5 and the higher lipid peroxidation observed in sensitive variety Panniyur-1 may be due to less membrane damage in the tolerant varieties as compared to the sensitive variety, Panniyur-1.

SOD is an enzyme which catalyse the reaction of superoxide radicals (O_2), and it is the cells primary defence systems against damage from oxygen. It limits the damage due to lipid peroxidation in various annual crops during periods of stress (Kellong and Fridovich, 1975). They are reported to be essential for the survival of aerobic cells (Dhindsa *et al.*, 1982). In this investigation SOD activities was more in all the varieties except Panniyur-1. The highest increase was in Kumbakodi and Panniyur-5. SOD being one of the protective enzyme during water stress (Chempakam *et al.*, 1993), an increase in its activity under stress situations is expected, especially in water stress tolerant varieties. This enzyme dismutates and makes nonreactive the superoxide radicals formed in the cells during the periods of water stress. The declining activity of SOD and catalase in the sensitive variety Panniyur-1 favours the production and accumulation of H_2O_2, cell injury and rapid wilting. There are several reports on increased H_2O_2 coupled with decreasing activity of SOD and catalase in plants subjected to water stress (Brennen and Frenkel, 1977; Mondal and Choudhuri, 1981).

The results indicates higher activities of SOD, catalase, peroxidase and lower lipid peroxidation levels in water stressed tolerant black pepper varieties. Similar observations were made in drought tolerant wheat (Li and Liang, 1981), coconut genotypes (Chempakam *et al.*, 1993; Shivashankar and Nagaraja, 1996) tea (Tong *et at.*, 1992). The activities of the enzymes peroxidase and catalase were more in Panniyur-5 and Padarpan and it was minimum in Panniyur-1 (Fig. 8). The increase in activities of these enzymes which are having protective role, in Panniyur-5 and Padarpan indicates the biochemical adaptabilities of these two varieties to tolerate water stress. The lower levels of lipid peroxidation observed in Panniyur-5 and Padarpan and high level of lipid peroxidation in Panniyur-1 also corroborates the water stress tolerance of the former two and the susceptibility of the latter mentioned varieties. It may be noted that the susceptable variety, Panniyur-1 had low activities of the enzymes, catalase, peroxidase and SOD and very high level of lipid peroxidation.

5.7 Electrophoretic pattern of protein

Even though, the protein content of the leaves did not show perceptible variation due to water stress, the electrophoretic patterns of the proteins of the susceptible variety Panniyur-1 and tolerant varieties Panniyur-5, Kumbakodi, Poonjarmunda, Padarpan and Uthirankotta-2 varied (Fig. 24, 25). Some of the proteins disappeared from Panniyur-1, when water stressed and no new proteins were produced in this variety in response to water stress. The few number of bands observed in water stressed plants of Panniyur-1 and poor resolution indicate impaired protein synthesis and the susceptible nature of the variety. In the drought tolerant varieties additional protein bands were observed in response to water stress. The extra protein bands observed in the tolerant varieties and disappearance of a few protein from the susceptible varieties are indications of production of stress proteins or fragmentation and/or aggregation of proteins in response to water stress (Newton *et al.*, 1991).

Water stress may also lead to degradation of many tissue proteins and a new set of proteins known as stress shock proteins may be produced in some of the plants (Shinozaki and Yamaguchi Shinozaki, 1997).

5.8 Anatomical characters

The varieties of black pepper varied in their anatomical characters. The leaf and stem cuticle thickness was highest for Kumbakodi and lowest in Panniyur–1 (Fig. 37). The low leaf and stem cuticle thickness may be one of the reasons for the sensitivity of Panniyur–1. The leaf thickness in Panniyur–1 and Panniyur–5 decreased while that of Padarpan increased due to water stress. The thinner leaves of Panniyur–1 may be another reason for its poor tolerance when subjected to water stress.

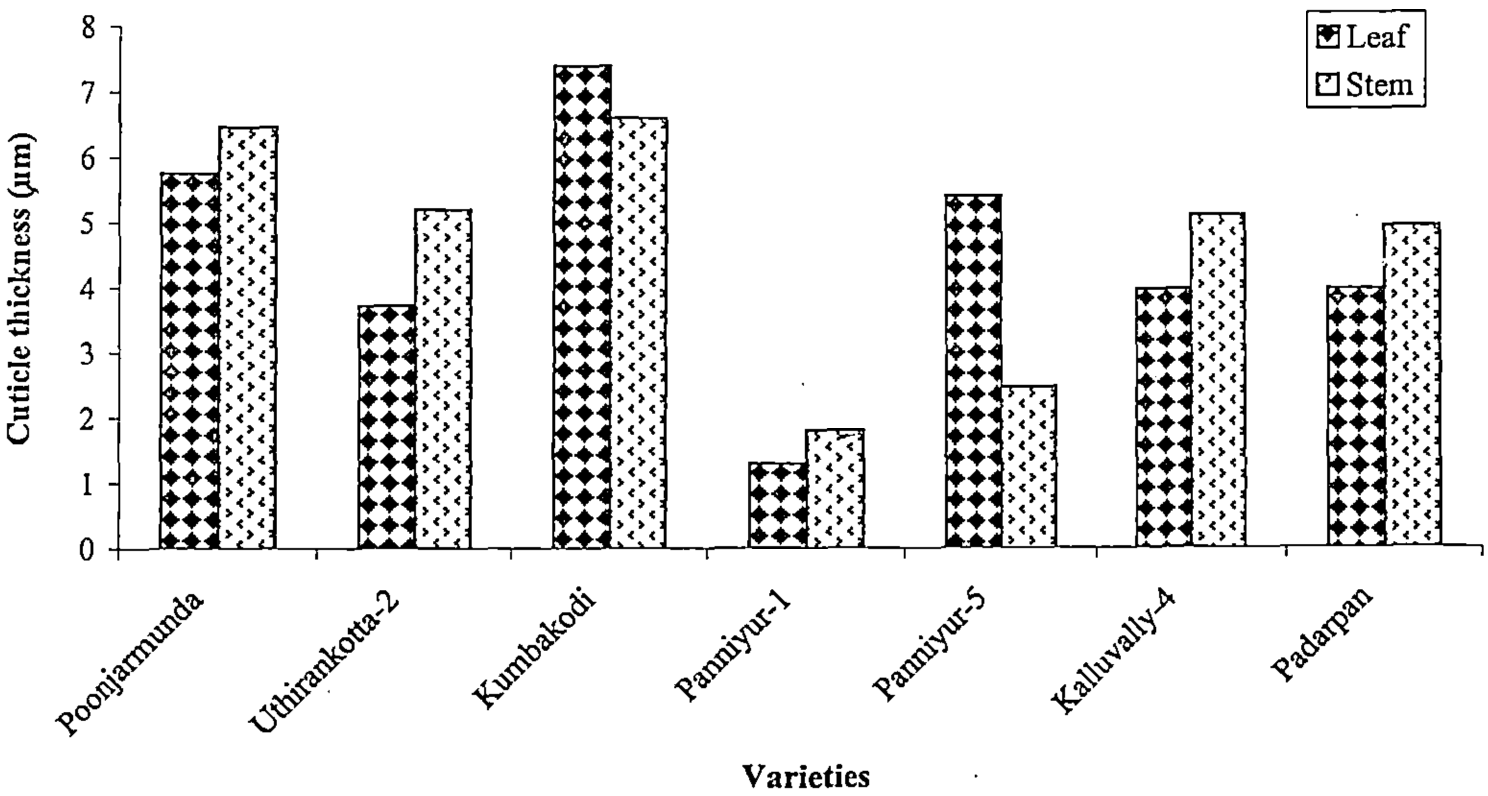


Fig. 37. Stem and leaf cuticle thickness of black pepper varieties

Panniyur-5 also had thin leaves like Panniyur-1. However, Panniyur-5 was having many other characters to overcome water stress tolerance. A positive relation between leaf thickness and palisade layer thickness was obtained in drought tolerant cacao accessions (Balasimha, 1999). Increased leaf thickness and cuticle thickness was reported in drought tolerant cashew varieties (Latha, 1998).

Another conspicuous anatomical character which was observed in all the tolerant varieties was the more number and thickness of sclerenchyma tissue on hypodermis tissues and around the vascular bundles. The sclerenchyma tissues were a few or poorly developed in the susceptible variety Panniyur-1. The susceptiability of Panniyur-1 was also due to the low thickness of the epicuticular wax on the upper epidermis and thickness of cuticle. Panniyur-5 was rated high in all these characters, which might have contributed to the high water stress tolerance of this variety. Similar result was reported in drought tolerant sorghum cultivars (Salih *et al.* 1999).

Experiment II

6.1 Response of bush pepper to soil moisture stress

The bush and vine type of black pepper showed variation in morphological and physiological characteristics in response to water stress. The variety Panniyur–1 was very sensitive that both bush and vine type of this variety wilted and died within 20 days of starting the water stress cycle. In Panniyur–5, both bush and vine type tolerated and survived severe water stress. It is evident from the previous experiment that Panniyur-1 is a very sensitive variety due to the absence of physiological, biochemical and morphological adaptations. The susceptibility of Panniyur-1, irrespective of whether bush or vine type is further confirmed from these results.

There were no significant variation between bush and vine pepper in their biometric characteristics. Bush type had more root length and root dry weight compared to vine type. Root length increased with higher levels of water stress. These characters might have contributed to the ability of the bush type pepper to withstand water stress as compared to vine type.

6.2 Physiological characters

The stomatal conductance, transpiration rate, leaf temperature, leaf water potential and chlorophyll content varied in bush and vine type pepper under water stress. The bush type showed higher stomatal conductance than vine type at 8 A.M. So in the same variety the stomatal conductance and transpiration rate may vary in plants propagated from laterals (bush type) and runner vines (vine type). The stomatal conductance of bush type decreased considerably due to higher levels of water stress indicating the efficient stomatal regulation in response to water stress at 2 P.M.

The leaf water potential was less in vine type as compared to bush type. This may be the result of poor stomatal regulation in bush type as indicated by the more or less steady transpiration rate observed when exposed to higher levels of stress.

The higher leaf water potential observed in bush type of pepper indicates its ability to with stand drought than vine type pepper. The higher leaf water potential observed under water stress is considered as an indication of water stress tolerance in many species (Hanson *et al.*, 1977; Novero *et al.*, 1985 and Cortes and Sinclair, 1987).

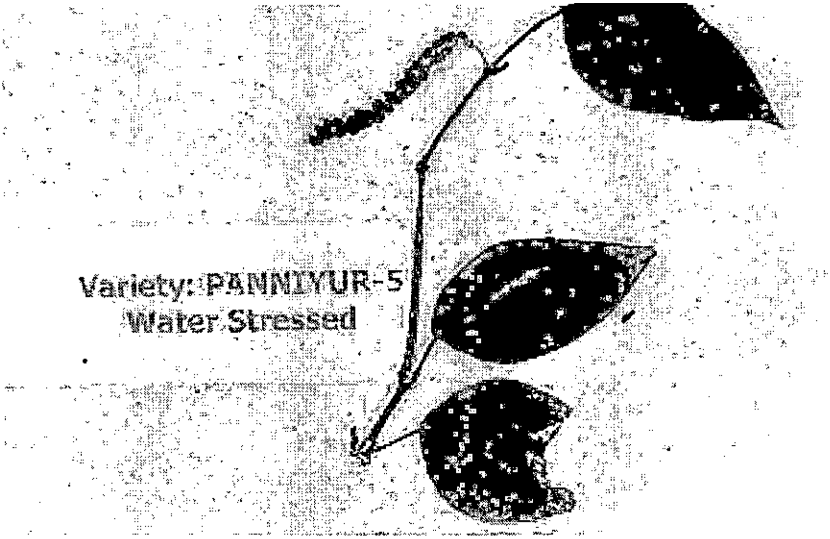
The chlorophyll a and b and the total chlorophyll content were more in vine type than in bush pepper. Mild water stress decreased the chlorophyll content in vine type considerably whereas, in bush type the decrease was negligible. This indicates the higher stability of chlorophyll in bush pepper under water stress. However, at higher levels of water stress in both bush and vine type, chlorophyll a and b were considerably decreased, indicating the water stress susceptibility of both.

Even though physiological responses indicate superior water stress tolerance by bush pepper this need to be confirmed by long term field studies. The biometric observations present refers to a brief spell of growth of the two types of pepper, it may be premature to make any commends based on these.

6.3 Carbon translocation in bush pepper

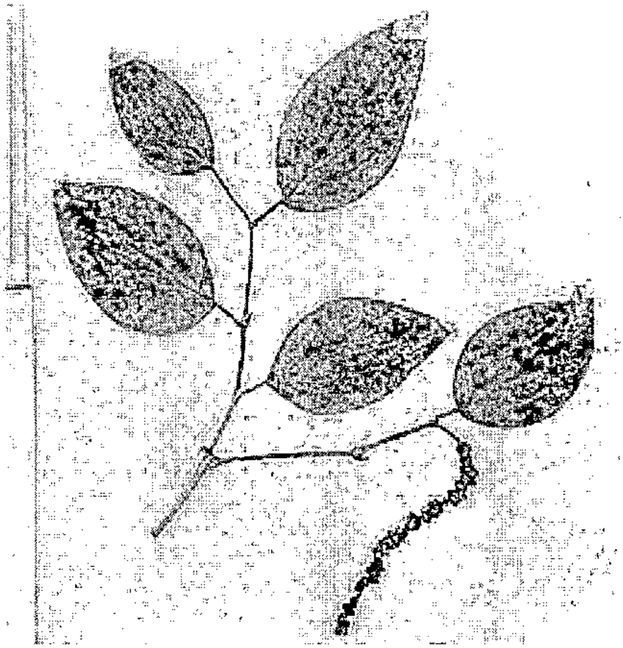
Water stress showed considerable influence on carbon translocation and partitioning in bush pepper of the varieties Panniyur–1 and Panniyur–5. In Panniyur–5 carbon from the leaves were translocated to the spikes on the node and small quantities to other spikes (Table 45). In Panniyur–5 without berries, $^{14}CO_2$ was translocated to stem and other leaves, when water stressed. In Panniyur–1 without berries, when water stressed, carbon translocation to leaves were inhibited (Fig. 34). The efficient translocation of carbon even when water stressed may be one of the basis for the stress tolerance of Panniyur–5.

In Panniyur–5 with berries, when water stressed, there was translocation of carbon to the spike on the node of the treated leaves as well as to other spikes where as in Panniyur–1 the translocation was to spike on the node only. In daily irrigated plants the spikes on the node of the treated leaf in Panniyur–1 acted as a stronger sink compared to the same spike in Panniyur–5. There were weak translocation to leaves in both the varieties (Fig. 28). These results indicate that in the bush pepper varieties Panniyur-1 and Panniyur-5 differed in their pattern of translocation of photosynthates



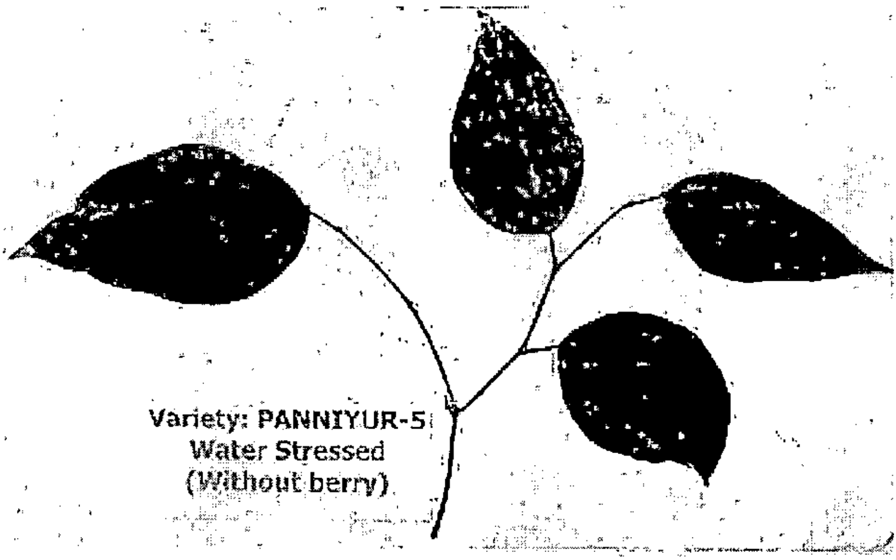
Photograph of the branch of
bush pepper used for autoradiograph

Fig. 29. Autoradiograph Showing the photosynthate translocation in water stressed black pepper variety Panniyur - 5 (with berries)



Photograph of the branch of
bush pepper used for autoradiograph

Fig. 30. Autoradiograph Showing the photosynthate translocation in unstressed black pepper variety Panniyur - 5 (with berries)



Photograph of the branch of
bush pepper used for autoradiograph

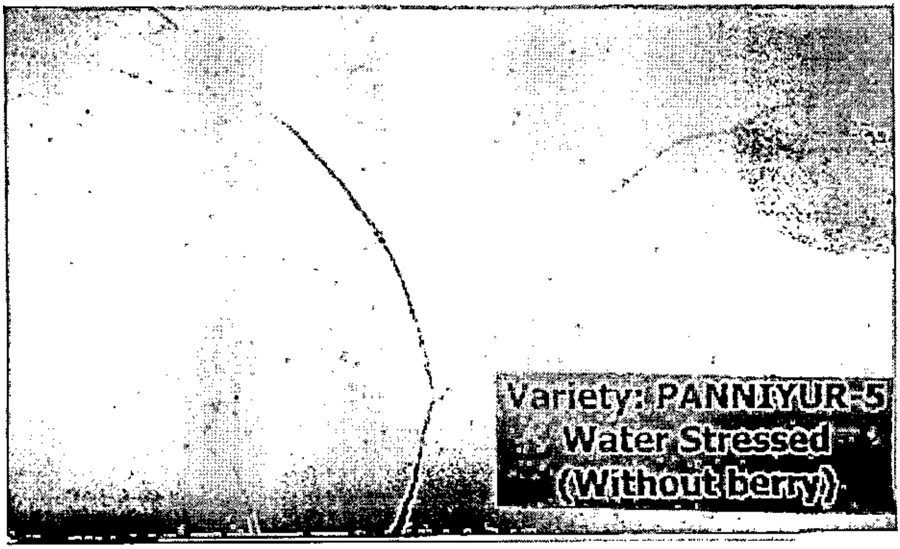
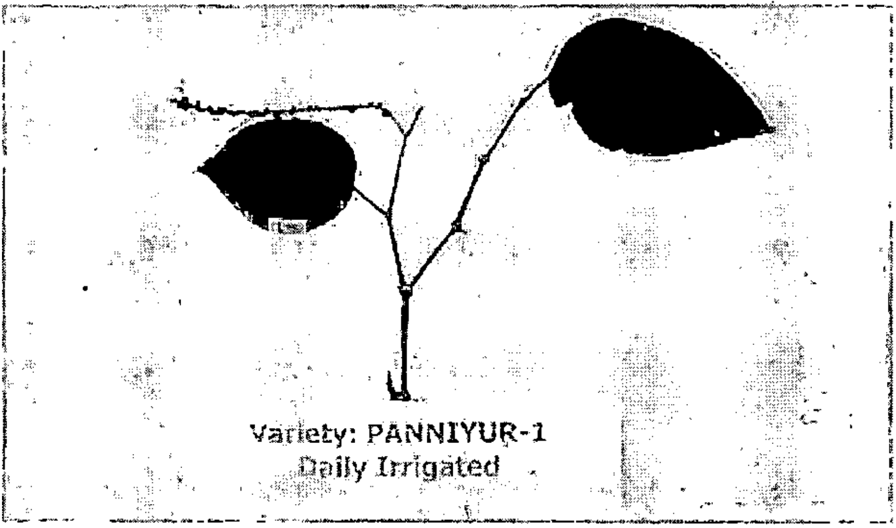


Fig. 31. Autoradiograph Showing the photosynthate translocation in water stressed black pepper variety Panniyur - 5 (without berries)

Photograph of the branch of
bush pepper used for autoradiograph

Fig. 32. Autoradiograph Showing the photosynthate translocation in water stressed black pepper variety Panniyur -1 (with berries)



Photograph of the branch of
bush pepper used for autoradiograph

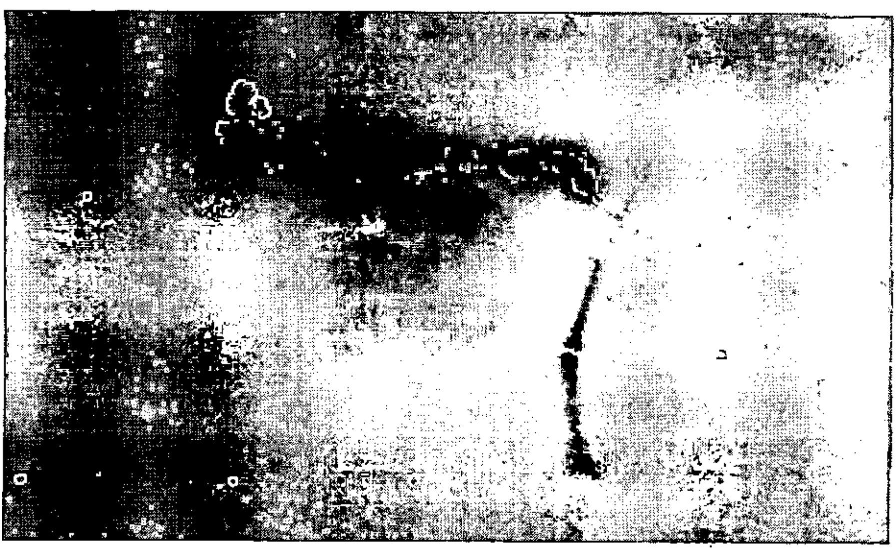
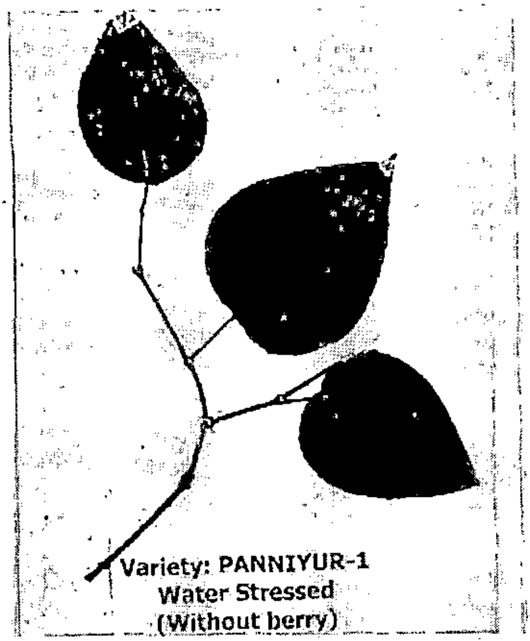


Fig. 33. Autoradiograph Showing the photosynthate translocation in unstressed black pepper variety Panniyur - 1 (with berries)



Photograph of the branch of
bush pepper used for autoradiograph

Fig. 34. Autoradiograph Showing the photosynthate translocation in water stressed black pepper variety Panniyur - 1 (without berries)

when water stressed. In Panniyur-1 the translocation of photosynthates was only to the spike of the corresponding node both in stressed and unstressed plants, whereas in Panniyur-5 there were translocation to the spike to the corresponding node of the leaf as well as to other spikes. On the other hand the translocation pattern in unstressed plants of Panniyur-5 was similar to Panniyur-1. So in water stressed situations Panniyur-5 may show much more efficient translocation than Panniyur-1. This was also evident from the carbon translocation pattern in plants without spikes. In water stressed Panniyur-1 photosynthates from the leaf accumulated in the stem, whereas in Panniyur-5 it was translocated to stem and other leaves. The source sink relationship in many species showed that reproductive structures are a stronger sink than vegetative parts.

In some plant species dehydration affects translocation rather than photosynthesis Zholkevich *et al.* (1958) observed an accumulation of photosynthetic product in leaves of water stressed sugar beet inspite of slightly reduced photosynthesis. When the roots of cotton plants were subjected to water stress soluble sugars accumulated in the leaves and proportionately decreased in the roots. (Vigira-da-Silva, 1968). In the case of *Lolium temulentum* transfer of labeled assimilation product from the photosynthetic tissue to the conducting tissue was delayed in water stressed leaves (Wardlow, 1969).

Experiment III

7.1 Optimum percentage of depletion of available soil moisture for bush pepper

The rate of depletion of available soil moisture influenced total number of branches, number of leaves, leaf area, number of spikes, and yield characters like length of spikes, number of berries, weight of berries, dry weight of the plant etc.

Maximum number of branches were observed in plants irrigated when 50 per cent of available soil moisture were depleted (Fig. 35). Depletion of 75 per cent available soil moisture resulted in drastic reduction in number of branches per plant. The number of branches in daily irrigated plants were less as compared to irrigation at 25 or 50 per cent depletion of available soil moisture. Maximum number of leaves were also observed in plants irrigated at 50 per cent depletion. Highest value of leaf area was in daily irrigated plant followed by irrigation at 50 per cent depletion. The number of spikes harvested were also maximum in plants irrigated at 50 per cent soil moisture depletion. Maximum length of spike was observed in plants irrigated daily followed by irrigation at 50 per cent depletion. The number of berries and volume of berries also followed the same trend. The green and dry berry weight were also maximum in plants irrigated at 50 per cent depletion of available soil moisture.

The oleoresin content of the berries were maximum in plants irrigated at 50 per cent depletion of the soil moisture followed by daily irrigation. The piperine content was maximum in plants irrigated at 25 per cent depletion followed by irrigation at 50 per cent depletion. From the results it is evident that the yield characteristics, yield and quality characters of berries were favourably influenced by irrigation at 50 per cent depletion of available soil moisture. Daily irrigation or irrigation at 25 per cent depletion were on par or inferior to irrigation at 50 per cent depletion. Considering these results irrigation at 50 per cent depletion of available soil moisture is recommended for black pepper. Kerala Agricultural University recommends irrigation of black pepper vines at an IW/CPE ratio of 0.25 indicating the low frequency of irrigation (KAU, 1996). In many field crops like pearl millet, finger millet, barley (Reddy and Reddy, 1998) and plantation crops like coffee (Awatramani *et al.*, 1973) irrigation at 50 per cent depletion of available moisture is recommended for maximum yield. This is the first experimental report on the allowable soil moisture depletion of black pepper.

Experiment IV

8.1 Root distribution pattern of field planted bush pepper

The root distribution pattern were deduced from the ^{32}P counts observed in the soil around the plants labeled with ^{32}P. The ^{32}P counts in the soil increased with lateral distance from the plants upto 30 cm and decreased beyond. The ^{32}P counts at various depth varied with lateral distance and maximum counts were at 40 cm depth. The maximum counts were at a lateral distance of 10 cm when pooled over the depths upto 60 cm. The maximum count was at a depth of 20 cm when the total counts from all the lateral distance were considered. From the ^{32}P counts it is evident that most of the roots in field planted bush pepper are concentrated in the surface layer of the soil up to 20 cm depth and upto a lateral distance of 30 cm. The roots are also concentrated in the deeper layers of 40 and 60 cm within a lateral distance of 10 cm. About 40–60 per cent of the roots were distributed in 20 cm depth and about 30 per cent roots were distributed in 20 to 40 cm depth. Overall 70–87 per cent of roots were distributed within 40 cm depth, only 13–27 per cent roots were observed at 60 cm depth. When the lateral distances were considered, 79 to 93 per cent roots were distributed within 30 cm lateral distance. About 89 per cent of the total counts observed were within a lateral distance of 30 cm and a depth of 60 cm. This root zone, i.e. upto 30 cm lateral distance and 60 cm depth may be considered as the active root zone of the bush pepper grown in the field. The area outside this zone where only 10 per cent of the counts were observed may be considered as the passive root zone with relatively few numbers of roots.

Application of fertilizers and manures may be done within the soil zone of 30 cm lateral distance and upto 40 cm where about 64 per cent of the roots are distributed. This proposal is made by taking into consideration the possibility of leaching down of some nutrients into deeper layers which may be utilized by a few roots at 60 cm depth. For the purpose of irrigation the root zone may be considered as 40 cm lateral distance and 60 cm depth. There are no earlier reports on the root zone or root distribution or root activities of bush pepper. There were a few reports on the root activities of vine pepper. Sankar *et al.* (1988) observed 90 per cent of the root activity within 30 cm radius around the vine in black pepper trailed on erithrina or teak. Geetha (1990) also reported similar finding in black pepper trailed on teak pole. The results of the present study shows that the lateral spread of the roots of the bush pepper are same as that of the vine pepper.

More detailed studies on root distribution and root activity patterns of bush pepper at different stages of growth and seasons may be necessary before arriving at a definite conclusion.

Experiment V

9.1 Scheduling of irrigation in bush pepper

The vegetative growth and the yield of bush pepper planted as an inter crop in coconut garden were influenced by the rate of drip irrigation. The number of branches, leaves and leaf area were maximum in plants irrigated with 16 L of drip. Minimum number of leaves, leaf area and number of branches were observed with 2 or 4 L of drip irrigation. Four, eight and twelve litres drips were on par with pot watering at the rate of 10 L per plant. These results indicate that drip irrigation at the rate of 16 L per plant promote good vegetative growth in bush pepper. However, the

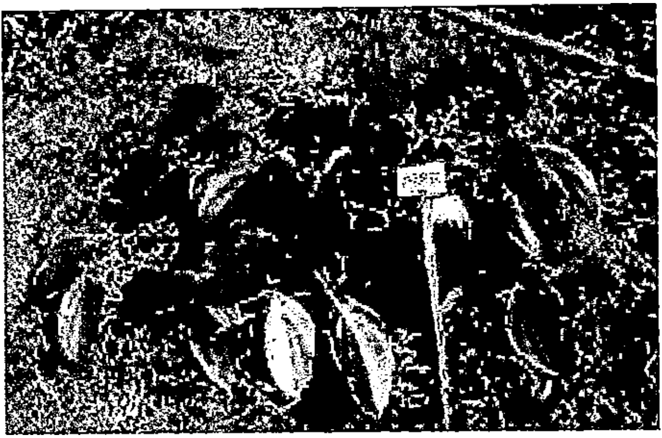


Fig. 38. Drip-2 L

Fig. 39. Drip-8 L

yield characters like number of spikes, length of spikes, number of berries per spike, 100 berry weight and berry volume were superior with lower levels of drip irrigation. Maximum number of spikes were harvested from plants irrigated at 8 L of drip followed by drip irrigation at the rate of 4 L per day. The length of spike and number of berries per spike, 100 berry weight, berry volume were also maximum with 8 L drip irrigation.

The pooled mean of yield was maximum with 8 L drip followed by 16 L and 12 L drips (Fig. 40). Drip irrigation from October-March at the rate of 16 L per plant was superior to 16 L drip irrigation from October-May with respect to dry berry yield. This indicates the requirement of a water stress period for induction of flowering and yield in bush pepper. In vine pepper a dry spell of March-May was reported to induce flowering and yield (Pillai *et al.*, 1988).

The oleoresin and piperine content of the berries were best with 8 L drip. Considering the yield and quality of berries, drip irrigation with 8 L drip is the best for bush pepper planted in coconut garden. In places where irrigation water is limiting, drip at the rate of 4 L per plant may give reasonable yield as compared to pot watering (10 L). Sixteen litres drip irrigation, though encouraged vegetative growth was not good for yield of berries. May be under high rate of irrigation vegetative growth is encouraged at the expense of reproductive growth. When higher quantities of water is used for irrigation a break in irrigation from April–May is beneficial for reproductive growth as indicated by the relatively higher yield observed in 16 L drip (October–March) as compared to 16 L drip (October–May). Basin irrigation at an IW/CPE ratio of 0.25, from October–March was found to be best for field planted vine pepper of the variety Panniyur–1 (Satheesan *et al.*, 1998). However, they have not investigated the influence of irrigation from April-May. Preliminary irrigation experiments conducted on vine pepper showed that irrigation at the rate of 7 L per day through drip during October-May was better than 7 L drip during October-March (IISR, 1998).

In the present experiment on bush pepper, the influence of a break in irrigation from April-May was investigated only with 16 L drip and not with lower rates of 2 to 12 L drips. However, from the reports of IISR (1998), Satheesan *et al.* (1998) and the results of the present study it may be deduced that with lower rates of drip irrigation, a break in irrigation in peak summer months of April–May, may not be advisable.

Sivanappan (1998) observed that the best yield in black pepper vines are obtained when drip irrigation at the rate of 3.5 L per plant were given. In many crops considerable saving in quantity of irrigation water were reported by adopting drip irrigation. In coconut 100 L required under conventional irrigation was reduced to 30, 40 L required in arecanut was reduced to 15, 20 L required in rubber was reduced to 10 L per plant (Satheesan, *et al.,* 1994). In black pepper the recommended quantity of irrigation under conventional method is 100 L per vine at an interval of 8–10 days from October-March (Satheesan *et al.*, 1998). That means, irrigation of 10–12 L per plant per day is required. However, there are no recommendation on the quantity of water required for bush pepper under conventional irrigation practices. Compared to the 10–12 L of water required for vine pepper, under conventional irrigation, only 8 L is required by adopting drip irrigation. This accounts to a saving of 25 per cent irrigation water. However, as the bush pepper plantation in the present study is only three year old, observation have to be continued for a few more years before conclusions are arrived at and recommendations are made.

Inspite of the improved vegetative growth in 16 L drip, yield obtained was less probably because of the partitioning of more photosynthates to vegetative parts. Leaf area and dry matter are the two plant characters that determine the total biological production, but partitioning of total biological yield is the most important factor that determine the economic yield (Donald and Hamblin, 1976). Pelevitch *et al.* (1980) reported that higher amount of irrigation did not result in higher fruit yield of papriku (*Capsicum annum*).

The yield was least from the plants irrigated with 2 L drip (Fig. 40). This was mainly due to less vegetative growth, less number of spikes and other yield contributing characters. Lower availability of soil moisture might have reduced the uptake of mineral nutrients. Thrips attack was also more in this treatment. The reason attributed for thrips attack is raised temperature. If the rise in temperature of water stressed plant is close to the optimal thermal requirement of the insect the insect can grow faster and larger with low mortality (Haack *et al.*, 1984).

9.2 Consumptive use and soil moisture depletion

The consumptive use increased with increasing quantity of irrigation water. The consumptive use was maximum with 16 L drip irrigation (October–May) and minimum in 2 L drip irrigation. In pot watering, CU was less than the irrigation water whereas in drip irrigation, irrespective of the quantity of drip, the CU was more than the irrigation water. In the drip method, as the water is continuously delivered to the surface soil, the loss by evaporation may be higher. On the other hand in pot watering, as the whole quantity of irrigation water is delivered at a time, the water will percolate down and get stored in deeper layers of root zone. Hence the loss of water by evaporation from the surface soil may be less in pot watering. This could be the reason for higher CU observed in drip irrigation. Sunilkumar (1998) observed changes in CU with increasing the quantity of drip irrigation in Okra and the CU was always slightly above the quantity of irrigation water.

The soil moisture depletion by bush pepper was more or less equal from 0–20 cm and 20–40 cm depth. However, in plants irrigated with drip at the rate of 2-12 L per plant, the maximum depletion was from 20–40 cm soil depth. In 8 L drip, depletion from surface soil (0-20 cm) was only 32 per cent and from deeper zones it was 68 per cent. The higher depletion of soil moisture from deeper layer in this treatment may be due to better growth of the plant and more vigorous root system in the deeper layers of soil. The soil moisture depletion in 10 L pot watering, was more from surface layer than the deeper layers. When more water was applied, the surface soil remain wetted and most of the roots may be distributed over the surface layer. This could be the reason for higher soil moisture depletion observed from surface soil when higher quantity of water is applied by drip or pot watering. Even though the field water use efficiency was maximum for 2 and 4 L drip, considering the yield and yield contributing characters 8 L drip is advantageous.

Summary

SUMMARY

Five experiments, three pot culture and two field trials were conducted to study the influence of soil moisture regimes on black pepper, both vine type and bush type. In the first pot culture experiment 44 black pepper (vine type) varieties were screened and selected varieties were characterized for water stress tolerance. In the second pot culture experiment, bush pepper and vine pepper were compared for their response to water stress. The third pot culture experiment was to fix the optimum percentage of depletion of available soil moisture in bush pepper for scheduling irrigation. All these pot culture experiments were conducted at Kerala Agricultural University - Main Campus, Vellanikkara, Thrissur from December 1997-May 1999. The root distribution pattern of bush pepper and its response to different levels of drip irrigation were studied in two separate field experiments at Peruvannamuzhi farm of IISR, Kozhikode, from December 1998 to January 2000. The results of these experiments are summarized below.

Experiment I

Screening and characterization of black pepper varieties for water stress tolerance

Among the 44 black pepper varieties/cultivars grown in polythene bags, 15 wilted by second day of water stress and only six varieties *viz.* Kalluvally-4, Kumbakodi, Padarpan, Panniyur-5, Poonjarmunda and Uthirankotta-2 survived four days of water stress. These varieties also showed high relative water content (RWC) and membrane stability (MS) under water stress. The RWC and the MS decreased in plants exposed to water stress. However, the survival of the plants

under water stress were not related to the high RWC and MS observed in unstressed plants in some of the varieties.

The height and the number of leaves varied among the varieties due to water stress. The conspicuous response to water stress was a reduction in leaf area and girth of vine in all the varieties. The number of leaves, leaf area, the dry weight of root and shoot and total dry weight were more in Panniyur-5 under severe water stress, as compared to other varieties.

The varieties Poonjarmunda, Panniyur-5 and Kalluvally-4 showed low stomatal conductance while Panniyur-1, Kumbakodi and Padarpan recorded relatively high stomatal conductance. When severely water stressed, the varieties Kumbakodi and Padarpan showed higher transpiration rate.

The enzymes peroxidase, catalase and superoxide dismutase (SOD) increased due to water stress in general. The maximum percentage increase in peroxidase and catalase activity, in response to water stress were in Padarpan and the least in Panniyur-1. The SOD activity in response to water stress was the highest in Panniyur-5 and the least in Panniyur-1. When water stressed, the lipid peroxidation level was the highest in Panniyur-1 and the least in Kalluvally-4.

The epicuticular wax increased due to water stress. The highest value was in Panniyur-5 and the least in Panniyur-1. Chlorophyll content decreased in all the varieties due to severe stress. The proline and sugar content of the varieties increased due to water stress. Percentage increase in proline content of the leaves over control was maximum in Poonjarmunda and the least in Padarpan. Among the water stressed plants, maximum sugar content was observed in variety Kalluvally-4, followed by Poonjarmunda and Padarpan. The amino acid content showed an increasing trend due to severe stress in variety Poonjarmunda, Panniyur-1, Panniyur-5 and Padarpan.

The protein content of the leaves did not show much variation due to water stress. However, the composition of protein as evidenced by the electrophoretic pattern varied in response to water stress. Electrophoretic pattern of protein showed an intermediary/additional band in water stress tolerant varieties, Panniyur-5, Poonjarmunda and Padarpan. In the susceptible variety Panniyur-1, no new bands were observed when water stressed.

The nitrogen content increased with moderate and severe water stress and maximum N content was observed in Panniyur-5 and minimum in Kumbakodi. Phosphorous and Potassium content of the leaves also increased due to severe stress. Maximum P accumulation was observed in Poonjarmunda followed by Padarpan and Panniyur-5. Potassium content was higher in Poonjarmunda, Kumbakodi and Panniyur-5. The calcium, zinc and copper content of the leaves increased due to water stress in Panniyur–5, while an increase in Mg content was observed in varieties Uthirankotta-2, Kumbakodi and Panniyur-5. Water stress decreased the Fe and Mn content in most of the varieties.

Leaf thickness increased due to severe stress in all the varieties except Panniyur-1 and Panniyur-5 due to severe stress. Kalluvally-4 showed maximum leaf and stem cuticle thickness and the minimum was in Panniyur-1. The variety Panniyur-1 had low epicuticular wax, less thickness of cuticle and sclerenchyma tissue of leaves, low wax content, less cuticle thickness of stem, low starch deposition and less number of sclerenchyma tissue on hypodermis of stem.

Experiment II

Response of bush pepper to soil moisture stress

Bush and vine type of Panniyur-1 did not survive the water stress cycle for more than twenty days. The bush pepper and the vine pepper of Panniyur-5 varied in their response to water stress. The number of leaves and girth of the stem did not vary significantly in bush pepper and in vine pepper due to water stress. Bush type had higher root length than the vine in response to water stress.

The shoot and root dry weight as well as total dry weight of bush pepper were higher than vine type under water stress. Stomatal conductance of bush pepper increased at 8 A.M. decreased at 2 P.M. considerably with higher levels of water stress, whereas in vine type there were no significant differences. Transpiration rate decreased in bush pepper due to severe stress and in vine pepper there was no much difference. The leaf temperature did not vary much in bush and vine pepper. The bush pepper showed higher leaf water potential than the vine type. Chlorophyll content was more in vine type than the bush pepper.

In bush type of Panniyur-5, $^{14}CO_2$ fixed in the leaf were translocated to the spike on the corresponding node as well as to other spikes of the plant under mild and moderate water stress. In daily irrigated plants of the variety Panniyur-5, translocation from the leaf to spikes other than the one on the corresponding nodes were negligible. In Panniyur-1, all the $^{14}CO_2$ from the leaf was translocated to the spike on the corresponding node and there was no translocation to other spikes in water stressed as well as in daily irrigated plants.

Water stress interfered with the translocation of carbon in the variety Panniyur-1 without berries also. $^{14}CO_2$ accumulated in the stem and there was no translocation to other leaves, whereas, in Panniyur-5 translocation was observed towards the stem and other leaves, both in irrigated and water stressed plants.

Experiment III

Allowable depletion of soil moisture in bush pepper

The number of leaves, total number of branches, root, shoot and total dry weight were more in plants irrigated at 50 per cent depletion of available soil moisture as compared to irrigation at <10, 25 and 75 per cent depletion. Number of berries, number of spikes, compaction of spikes, green berry weight, dry berry weight and oleoresin content of the berries were higher in plants irrigated at 50 per cent depletion of soil moisture.

Experiment IV

Root distribution pattern of bush pepper

Seventy to eighty seven per cent roots were distributed within 40 cm depth and 20-30 cm lateral distance. The intensive root zone of bush pepper was around 20-30 cm lateral distance and 40 cm depth and the extensive root zone was around 30-40 cm lateral distance and 60 cm depth. The effective foraging zone of bush pepper was between 20-30 cm lateral distance and 40 cm depth.

Experiment V

Scheduling of irrigation in bush pepper

The vegetative growth characters like number of leaves, leaf area and number of branches were maximum in 16 L drip irrigation during October-March.

Number of spikes, length of spikes, number of berries, 100 berry weight, berry volume, green berry yield, dry berry yield, oleoresin and piperine content were maximum in plants irrigated with 8 L drip.

Conclusions

CONCLUSIONS

The black pepper yield in the state which is affected due to the periodic dry spell from October-May can be managed by two approaches. One is by cultivating drought tolerant varieties. Second is by judiciously scheduling irrigation depending on the availability of water resources. Among the varieties evaluated Panniyur-5 possesses the best morphological, physiological, biochemical and anatomical adaptations to tolerate water stress and Panniyur-1 has poor adaptations. In drought prone areas Panniyur-5 may be preferred over Panniyur-1, both for bush as well as vine pepper.

Irrigation may be scheduled for field grown bush pepper considering the root zone as 30 cm around and 60 cm deep from the plant and the optimum depletion of available soil moisture as 50 per cent. Drip irrigation at the rate of 8 L per plant per day during October-May is better in bush pepper than pot watering 10 L per plant per day.

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Appendices

Appendix –1

Abstract of weather parameters during the experimental period at Vellanikkara

Standard weeks 1997	Month & date	Maximum temperature (°C)	Minimum temperature (°C)	Relative Humidity (%)		Wind Speed Km h^{-1}	Sun shine hours (h)	Rainfall (mm)	Evaporation (mm)
				M	E				
1	Jan 01 - Jan 07	31.2	21.7	75	46	7.3	9.6	0	5.4
2	Jan 08 - Jan 14	32.0	23.2	77	50	8.8	9.1	0	6.0
3	Jan 15 - Jan 21	32.4	22.2	79	42	6.0	9.6	0	5.3
4	Jan 22 - Jan 28	32.7	21.4	79	44	5.7	9.7	0	5.3
5	Jan 29 - Feb 04	32.5	21.0	80	43	5.7	10.1	0	6.0
6	Feb 05 - Feb 11	33.5	21.7	90	45	2.7	9.2	0	5.0
7	Feb 12 - Feb 18	33.9	21.7	76	33	4.7	9.2	0	5.8
8	Feb 19 - Feb 25	34.4	22.7	85	42	3.1	8.5	0	5.4
9	Feb 26 - Mar 04	35.8	22.5	76	21	5.9	10.2	0	7.7
10	Mar 05 - Mar 11	36.1	22.9	80	22	4.2	10.1	0	7.1
11	Mar 12 - Mar 18	34.7	24.3	91	46	3.3	9.1	0	5.7
12	Mar 19 - Mar 25	35.2	24.9	84	51	3.3	8.7	0	5.9
13	Mar 26 - Apr 01	36.4	24.8	76	39	4.7	9.2	0	7.0
14	Apr 02 - Apr 08	35.3	24.1	86	52	3.2	9.8	8.2	6.4
15	Apr 09 - Apr 15	34.7	24.3	84	48	3.7	10.3	0	6.1
16	Apr 16 - Apr 22	35.5	24.2	81	49	3.2	9.3	0	6.3
17	Apr 23 - Apr 29	35.4	25.3	83	53	3.2	8.9	0	6.0
18	Apr 30 - May 06	35.4	24.3	85	56	3.3	7.3	15.4	5.3
19	May 07 - May 13	34.6	24.8	90	61	2.8	6.1	19.6	4.8
20	May 14 - May 20	33.7	24.7	86	59	3.4	3.6	0	4.7
21	May 21 - May 27	34.7	23.8	87	52	3.7	8.1	28.0	5.4
22	May 28 - Jane 03	34.0	24.9	89	57	3.0	8.9	24.0	5.2

Contd.....

Standard weeks 1998	Month & date	Maximum temperature (^0C)	Minimum temperature (^0C)	Relative Humidity (%) M	Relative Humidity (%) E	Wind Speed Km h^{-1}	Sun shine hours (h)	Rainfall (mm)	Evaporation (mm)
1	Jan 01 - Jan 07	31.6	24.2	70	49	9.9	8.6	0	6.2
2	Jan 08 - Jan 14	32.0	23.3	74	48	8.1	10.0	0	6.4
3	Jan 15 - Jan 21	33.7	22.1	87	52	2.3	8.3	0	3.8
4	Jan 22 - Jan 28	34.2	24.3	83	47	5.1	9.7	0	4.5
5	Jan 29 - Feb 04	34.6	24.3	76	45	8.8	10.5	0	7.1
6	Feb 05 - Feb 11	34.8	23.3	82	51	6.4	9.9	0	6.9
7	Feb 12 - Feb 18	34.4	23.4	80	48	5.5	9.9	0	6.3
8	Feb 19 - Feb 25	33.4	23.6	88	59	2.9	8.7	0	4.7
9	Feb 26 - Mar 04	35.3	24.3	89	50	2.8	9.6	0	5.3
10	Mar 05 - Mar 11	35.9	23.6	89	47	3.5	10.3	0	6.2
11	Mar 12 - Mar 18	35.5	23.8	83	46	4.1	10.3	0	6.6
12	Mar 19 - Mar 25	37.5	23.7	84	44	3.6	10.5	0	6.5
13	Mar 26 - Apr 01	36.2	22.9	88	50	2.8	9.0	11	5.9
14	Apr 02 - Apr 08	37.5	25.1	83	40	3.6	9.6	0	6.5
15	Apr 09 - Apr 15	36.4	26.1	86	52	2.8	9.1	0	5.5
16	Apr 16 - Apr 22	36.6	26.8	85	53	3.1	8.5	4.2	5.4
17	Apr 23 - Apr 29	35.9	24.6	89	54	3.0	8.7	57.2	6.0
18	Apr 30 - May 06	35.2	25.5	89	61	2.7	8.5	4.8	4.7
19	May 07 - May 13	35.5	25.3	88	59	2.3	6.5	79	4.2
20	May 14 - May 20	32.4	24.1	93	72	2.1	6.6	107.8	3.4
21	May 21 - May 27	33.6	25.7	91	62	2.9	8.3	11.0	4.1
22	May 28 - Jane 03	34.4	25.2	86	63	3.2	8.8	24.4	4.3

Contd....

Standard weeks 1999	Month & date	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Relative Humidity (%)		Wind Speed Km h^{-1}	Sun shine hours (h)	Rainfall (mm)	Evaporation (mm)
				M	E				
1	Jan 01 - Jan 07	31.9	21.8	75	45	7.4	9.4	0	5.6
2	Jan 08 - Jan 14	33.5	21.9	79	43	5.1	9.5	0	5.0
3	Jan 15 - Jan 21	32.2	22.8	70	40	9.8	10.0	0	6.9
4	Jan 22 - Jan 28	32.5	19.5	74	32	5.5	7.9	0	5.9
5	Jan 29 - Feb 04	33.9	22.1	83	39	3.6	10.1	0	4.5
6	Feb 05 - Feb 11	34.0	23.4	80	44	4.3	9.2	22.8	5.1
7	Feb 12 - Feb 18	34.7	23.2	79	39	5.3	10.0	0	6.3
8	Feb 19 - Feb 25	34.2	24.5	70	33	7.9	6.9	0	7.6
9	Feb 26 - Mar 04	36.4	22.2	74	33	5.0	10.4	0	7.6
10	Mar 05 - Mar 11	36.5	23.8	92	34	3.1	9.6	0	5.8
11	Mar 12 - Mar 18	35.2	25.0	89	54	2.8	8.4	0	4.9
12	Mar 19 - Mar 25	34.8	25.0	91	55	2.4	8.4	0	4.5
13	Mar 26 - Apr 01	34.9	25.1	89	54	2.4	7.5	0	4.9
14	Apr 02 - Apr 08	34.9	24.5	90	55	3.0	7.8	26.2	5.7
15	Apr 09 - Apr 15	33.2	25.8	86	59	3.3	7.4	0	4.6
16	Apr 16 - Apr 22	33.1	26.2	89	62	3.2	4.6	7.6	3.9
17	Apr 23 - Apr 29	32.0	25.9	90	59	3.4	4.2	5.2	3.6
18	Apr 30 - May 06	33.6	25.8	89	59	3.1	6.3	35.0	4.4
19	May 07 - May 13	31.0	25.2	90	66	3.5	6.4	37.0	3.1
20	May 14 - May 20	30.4	25.1	88	74	3.1	5.5	51.6	3.2
21	May 21 - May 27	29.4	21.8	95	85	2.6	2.6	221.2	2.9
22	May 28 - Jane 03	29.8	23.5	96	75	2.3	5.0	143.2	3.1

Appendix-2

Abstract of weather parameters during the experimental period at IISR farm, Peruvannamuzhi

Standard Week No.	Month and Date	Maximum Temperature (°C)	Minimum Temperature (°C)	Sunshine hours	Relative Humidity		Evaporation (mm)	Rainfall (mm)
					M	E		
28	Oct 01-Oct 07	26.6	25.1	1.4	93.7	83.4	1.7	8.5
29	Oct.08-Oct 14	25.9	25.0	0.8	93.7	90.9	1.8	31.9
30	Oct 15-Oct 21	27.1	25.5	3.2	90.9	84.2	2.8	16.9
31	Oct 22-Oct 28	28.2	25.7	5.0	90.9	76.9	3.9	4.1
32	Oct 29-Nov 4	27.5	25.4	5.2	89.1	81.9	3.2	2.9
33	Nov 5-Nov 11	28.1	25.7	3.1	89.7	74.7	2.1	10.7
34	Nov 12-Nov 18	28.9	27.9	5.6	85.6	67.2	4.4	4.7
35	Nov 19-Nov 25	28.4	25.6	4.0	85.1	74.1	3.4	4.3
36	Nov 26-Dec 2	28.2	25.0	7.0	85.1	69.1	4.1	2.0
37	Dec 3-Dec 9	28.2	25.5	7.1	92.0	70.0	3.1	2.0
38	Dec 10-Dec 16	27.5	25.5	2.6	93.1	78.4	1.6	4.4
39	Dec 17- Dec 23	28.4	25.2	8.6	77.4	64.4	5.1	0.7
40	Dec 24-Dec 31	29.4	23.4	8.4	70.4	56.4	3.8	0
41	Jan 01-Jan 07	28.7	24.5	8.6	83.7	61.6	4.6	0
42	jan 08-Jan 14	28.3	23.5	8.0	83.4	53.3	4.4	0
43	Jan 15-Jan 21	28.9	23.8	8.7	80.4	49.3	4.8	0
44	Jan 22-Jan 28	27.5	22.1	7.0	78.1	46.3	3.9	0
45	Jan 29-Feb 4	28.3	23.6	8.2	84.9	52.1	3.9	0
46	Feb 5-Feb 11	28.9	23.9	7.2	87.0	51.6	4.5	0
47	Feb 12-Feb 18	28.3	23.6	9.0	84.9	51.6	4.7	0
48	Feb 19-Feb 25	29.0	23.7	7.3	83.0	48.4	4.1	0
49	Feb 26-Mar 4	29.1	23.6	8.2	83.4	46.6	4.6	2.7
50	Mar 5-Mar 11	30.0	24.0	7.5	82.9	45.4	4.2	2.3
51	Mar 12-Mar 18	30.3	24.6	6.6	85.1	48.9	4.5	0
52	Mar 19-Mar 25	30.2	24.9	7.5	78.1	48.1	3.8	0
53	Mar 26-April 01	32.1	26.6	7.0	76.1	52.4	4.2	0
54	April 02-April 08	31.9	26.0	6.2	75.7	48.7	4.7	0
55	April 09-April 15	31.9	26.4	5.3	76.0	54.6	4.2	0.4
56	April 16-April 22	31.8	26.7	3.6	82.4	60.6	2.8	0
57	April 23-april 29	30.0	26.1	4.4	81.6	65.7	3.1	0
58	April 30-May 6	30.8	25.7	2.5	86.0	65.1	2.3	1.7
59	May 07-May 13	27.6	25.3	1.8	86.6	79.1	1.0	0.7
60	May 14-May 20	28.5	25.9	2.2	94.1	75.6	1.1	5.1
61	May 21-May 27	25.8	24.7	0.5	93.7	85.6	0.2	3.1
62	May 28-June 03	27.8	25.7	2.0	93.7	71.9	1.0	33.2

Appendix-3. Abstract of ANOVA (Exp. I)
Relative water content and membrane stability of varieties

Source	Degrees of freedom	Mean square					
		RWC			Membrane stability		
		Control	2 DAT	4 DAT	Control	2 DAT	4 DAT
Between	43	244.80**	1427.55**	1154.27*	200.14**	1754.83*	393.058*
Within	44	0.056	0.017	0.003	0.046	0.026	0.026

* Significant at 5 per cent levels
** Significant at 1 per cent level

Appendix-4. Abstract of ANOVA (Exp. 1)
Effect of water stress on growth characters of black pepper varieties

Source	Degrees of freedom	Mean square							
		Height 30 DAT	Height 60 DAT	No. of leaves 30 DAT	No. of leaves 60 DAT	Leaf area 30 DAT	Leaf area 60 DAT	Internode length 30 DAT	Internode length 60 DAT
Variety	5	706.54**	1855.14**	6.24	31.62**	13103.41*	39342.94**	20.87	8.24**
Water stress	3	405.79**	310.88*	2.29	37.53**	196.46	31655.66**	0.45	1.97*
Variety × water stress	15	545.97**	242.03**	7.16*	3.61	3476.60	3347.89*	1.40*	0.75
Error	72	86.33	91.91	3.21	2.09	2660.12	2341.67	0.77	0.67

Contd...

Appendix-4. Abstract of ANOVA (contd...)
Effect of water stress on growth characters of black pepper varieties

Source	Degrees of freedom	Mean square							
		Girth 30 DAT	Girth 60 DAT	Leaf thickness 30 DAT	Root length 60 DAT	Root dry weight 60 DAT	Shoot dry weight 60 DAT	Total dry matter	Root:Shoot ratio
Variety	5	0.014	0.005	28.54**	339.9*	252.60**	0.12**	0.136**	0.567**
Water stress	3	0.034*	0.038**	15.42**	23.1	11.70*	0.03	0.081*	0.119**
Variety × water stress	15	0.012	0.008	8.94**	49.67	81.14*	0.04**	0.075**	0.098**
Error	72	0.009	0.007	0.78	19.44	42.42	0.01	0.022	0.036

Appendix-5. Abstract of ANOVA (Exp. 1)
Effect of water stress on physiological characters of black pepper varieties

Source	Degrees of freedom	Mean square								
		0800 hrs			1400 hrs					
		Stomatal conductance	Transpiration rate	Leaf temperature	Stomatal conductance	Transpiration rate	Leaf temperature	Chlorophyll a	Chlorophyll b	Total Chlorophyl
Variety	6	88.09**	6.90**	7.29**	29.59**	1.40**	1.5	0.12**	0.162**	0.438*
Water stress	3	31.47**	0.36**	8.27**	13.80**	2.69**	54.3**	0.24**	0.058**	0.243
Variety × water stress	18	7.91**	1.30**	2.65**	5.35**	0.914**	0.580	0.21**	0.032**	0.129
Error	28	0.07	0.05	0.12	0.03	0.054	0.859	0.01	0.006	0.095

Appendix-6. Abstract of ANOVA (Exp. 1)
Effect of water stress on biochemical characters of black pepper varieties

Source	Degrees of freedom	Mean square						
		Epicuticular wax	Proline	Total sugar	Total amino acids	Peroxidase	Catalase	Lipid peroxidation
Variety	6	3.97**	28.54**	167.54**	0.153**	148.14**	975.35**	0.039
Water stress	3	7.59**	15.42**	220.61**	1.05**	140.51**	849.27**	0.054*
Variety × water stress	18	2.25**	8.49**	252.98**	0.302**	11.31**	278.86**	0.058
Error	28	0.18	0.78	29.85	0.033	0.446	26.48	0.006

Appendix-6. Abstract of ANOVA (contd...)
Biochemical characters

Source	Degrees of freedom	Mean square	
		Superoxide dismutase	Protein
Variety	2	1.45**	15.81
Water stress	4	15.30**	520.20
Variety × water stress	6	2.56**	48.20*
Error	7	0.18	25.70

Appendix-7. Abstract of ANOVA (Exp. 1)
Effect of water stress on nutrient content in leaves of black pepper varieties

Source	Degrees of freedom	Mean square								
		Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Iron	Manganese	Zinc	Copper
Variety	5	1.04	0.15**	0.56**	0.70**	0.029	166538**	19329.12**	10120**	774.93**
Water stress	3	0.38*	0.008**	1.41**	0.08	0.026	5701**	5431.41**	3920.6**	1454.89**
Variety × water stress	15	0.01	0.005	0.15**	0.34**	0.006	22808**	3513.84**	3348**	1787.42**
Error	24	0.007	0.00029	0.02	0.10	0.005	4.30	123.93	8	2.00

Appendix-8. Abstract of ANOVA (Exp. II)
Effect of water stress on growth characters of bush and vine type of variety Panniyur-5

Source	Degrees of freedom	Mean square							
		Height 30DAT	Height 60DAT	No. leaves 30 DAT	No. leaves 60 DAT	Leaf area 30 DAT	Leaf area 60 DAT	Inter nodel length 30 DAT	Inter nodel length 60 DAT
Type	1	6.39	1.53	9.03	0.500	8515.12	0.056	0.17	1.93
Water stress	3	4.75	5.78	1.03	2.250*	5652.5	6728.27*	1.99	0.91
Type × water stress	3	24.90	28.37	0.45	1.75*	4469.61	650.73*	0.49	0.10
Error	24	32.7	45.28	1.43	0.625	3725.05	1696.44	0.758	0.69

Appendix-8. Abstract of ANOVA (Exp. II) (Contd...)
Effect of water stress on growth characters of bush and vine type of variety Panniyur-5

Source	Degrees of freedom	Mean square						
		Girth 30 DAT	Girth 60 DAT	Root Length	Dry weight of shoot	Dry weight of root	Total dry matter	Root shoot ratio
Type	1	0.07	0.036*	355.78**	129.2**	4.12**	117.9*	0.53
Water stress	3	0.02	0.012	203.82*	0.54*	0.56**	3.05*	0.38
Type × water stress	3	0.02	0.015	239.56*	0.69	0.55	1.24*	0.09
Error	24	0.01	0.008	74.56	0.35	0.06	0.453	0.01

Appendix-9. Abstract of ANOVA (Exp. II)
Effect of water stress on physiological characters of bush and vine type of variety Panniyur-5

Source	Degrees of freedom	Mean square									
		Stomatal conductance (0800 hrs)	Transpiration rate (0800 hrs)	Stomatal conductance (1400 hrs)	Transpiration rate (1400 hrs)	Leaf temperature (0800 hrs)	Leaf temperature (1400 hrs)	Leaf water potential	Chlorophyll a	Chlorophyll b	Total chlorophyll
Type	1	380.25**	24.48	1.1	16.0*	96.53*	83.27**	0.39**	0.49**	0.25**	0.331**
Water stress	3	376.74**	33.33**	2.5	8.0*	39.23*	21.67**	0.02*	0.15**	0.06*	0.692**
Type × water stress	3	350.70**	32.70**	8.6*	7.37*	37.60*	18.86**	0.006	0.02	0.04*	0.04*
Error	8	3.98	0.583	1.6	1.96	0.47	0.101	0.004	0.01	0.009	0.02

Appendix-10. Abstract of ANOCOVA (Exp. III)
Effect of soil moisture depletion on growth characters of bush pepper

Source	Degrees of freedom	Mean square								
		No. of leaves			No. of branches			Leaf area		
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Replication	5	8.4	22.1	8.96	35.52	18.15	8.96	37135.5	48642.84	66156.01
Water stress	3	148.0	89.2	69.97	153.67	79.26	69.97	22131.4	42037.09	33571.50
Covariate	1	584.7	167.1	195.59	11.33	97.20	195.59	22.4	474456.91	306578.48
Error	14	52.9	35.9	13.59	35.02	12.20	13.59	44570.1	17817.87	29201.47

Appendix-10. Abstract of ANOCOVA (Exp. III) contd...
Effect of soil moisture depletion on growth characters of bush pepper

Source	Degrees of freedom	Mean square								
		Length of primary branches			Length of secondary branches			Length of tertiary branches		
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Replication	5	36.23	47.80	40.08	13.39	27.64	18.82	4.62	4.4	3.6
Water stress	3	20.71	30.58	113.78	33.34	9.15	10.7	52.70	13.2	3.7
Covariate	1	113.55	59.52	6.16	87.60	8.73	25.1	11.25	23.6	0.79
Error	14	23.33	40.70	46.81	35.77	14.18	20.1	17.06	9.2	7.57

Appendix-10. Abstract of ANOCOVA (Exp. III) contd...
Effect of soil moisture depletion on growth characters of bush pepper

Source	Degrees of freedom	Mean square								
		No. of spikes on primary branches			No. of spikes on secondary branches			No. of spikes on tertiary branches	Green berry weight	Dry berry weight
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	90 DAT	90 DAT
Replication	5	6.11	7.22	0.86	5.3	1.9	9.58	35.7	89.06	5.27
Water stress	3	2.34	15.87	1.33	41.4	4.4	2.19	20.5	649.92	58.79
Covariate	1	85.24	4.82	2.98	36.0	20.8	11.21	65.4	507.46	44.28
Error	14	13.24	10.11	1.27	11.2	0.81	7.61	4.0	65.67	4.21

Appendix-10. Abstract of ANOVA (Exp. III) contd...
Effect of soil moisture depletion on growth and spike characters of bush pepper

Source	Degrees of freedom	Mean square												
		Root dry weight	Shoot dry weight	Total dry matter	Root shoot ratio	Total no. of spikes harvested	Length of spikes	Compaction of spikes	No. of berries on spike	Volume	Hundred berry weight	Degrees of freedom	Oleoresin	Piperine
Between	3	70.34*	133.7	710.9*	0.324	161.67*	12.75*	9.03*	407.33**	74.26*	1.11	3.0	15.44**	0.94*
Within	20	22.99	69.7	244.4	0.152	22.22	2.02	0.873	1.13	18.61	1.13	12.0	0.385	0.027

Appendix-11. Abstract of ANOVA (Exp. IV)
^{32}P counts in soil around the bush pepper plant

Source	Degrees of freedom	Mean square	
		Leaf feeding	Root feeding
Depth	32	7286.1*	405640.14*
Distance	3	22864.4*	415617.02*
Depth × Distance	6	16369.0	113234.98
Error	36	188.7	1.104

Appendix-12. Abstract of ANOCOVA (Exp. V)
Effect of drip irrigation on growth characters

Source	Degrees of freedom	Mean square								
		No. of leaves	Leaf area	Number of branches	Length of branches			Number of spikes	Green berry yield	Dry berry yield
					Primary	Secondary	Tertiary			
Replication	2	1838.33	3363396.8	672.32	22.67	19.54	4.99	5.72	9.39	1.62
Water stress	6	1445.96*	4221275.13*	217.64*	59.63	23.65*	4.94*	77.81*	131.7*	62.8*
Covariate	1	156.75	218038.2	6.20	42.70	134.82	218.4	4.67	1.07	2.7
Error	11	201.37	1050730.4	28.08	23.70	10.651	0.806	14.43	4.23	

Appendix-13. Abstract of ANOVA
Effect of drip irrigation on incidence of pests

Source	Degrees of freedom	Mean square	
		Catterpillar attack	Thrips attack
Between	6	57.8*	0.742*
Within	14	19.5	0.184

Appendix-14. Abstract of ANOVA (Exp. V)
Effect of drip irrigation on spike characters (pooled)

Source	Degrees of freedom	Mean square								
		No. of spikes	Length of spikes	Number of berries	Compaction	100 berry weight	Volume	Green berry yield	Oleoresin	Piperine
Drip irrigation	6	480.69*	7.00**	263.65*	6.29*	12.87**	14.72*	40594.70**	3.87**	2.82*
Irrigation × year	6	416.84	5.69**	47.87	5.28*	7.35**	6.77	35021.99**	4.61**	1.43*
Error	24	185.17	1.09	76.14	1.68	0.961	3.74	4485.26	0.920	0.006

INFLUENCE OF SOIL MOISTURE REGIMES ON GROWTH AND YIELD IN BUSH PEPPER

(*Piper nigrum* L)

By

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ABSTRACT OF A THESIS

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ABSTRACT

Black pepper (*Piper nigrum* L.) is the most valued spice crop of India. "Bush pepper" and "vine pepper" are two morpho-types of the crop, regenerated by planting laterals (Plagiotropic) and runner vines (orthotropic) respectively. Most of the area under black pepper in India is occupied by vine pepper trailed on live standards. Bush pepper, because of its bushy growth, shade tolerance, early and year round bearing offer great scope for growing in terrace gardens, kitchen gardens, homesteads and as an under-storey crop in coconut plantations and agroforestry systems. The productivity of the crop is very low in India. Seasonal water stress due to uneven distribution of rainfall is considered as the major constraint in increasing the productivity of black pepper. This problem can be solved to a great extent by growing drought tolerant varieties and/or providing supplementary irrigation. Knowledge about the optimum percentage of depletion of available water and the root zone of the crop is necessary to schedule irrigation. Hence experiments were conducted to screen and characterize water stress tolerant black pepper varieties and to compare the response of bush pepper and vine pepper to soil moisture stress. The optimum percentage of depletion of available soil moisture and the root zone of bush pepper for scheduling irrigation were estimated. The best drip irrigation schedule for field planted bush pepper was also found out. For this three pot culture experiments were conducted at Kerala Agricultural University Campus at Vellanikkara, Thrissur, from December 1997-May 1999 and two field experiments at Peruvannamuzhi farm of IISR, Kozhikode, during December 1998 to January 2000.

Forty four varieties were screened for water stress tolerance. From these, six water stress tolerant varieties and one sensitive variety were selected based on relative water content, membrane stability and number of days taken for wilting, when progressively water stressed. These varieties were subjected to mild, moderate and severe water stress and compared with an unstressed plant, in a pot culture experiment, laid out in completely randomized design and replicated four times. In another pot culture experiment the response of bush pepper to mild, moderate and severe water stresses were compared with vine pepper. Root distribution of bush pepper was studied using ^{32}P-plant injection technique in a completely randomized design experiment, replicated five times. Seven drip irrigation levels (2, 4, 6, 8, 12, 16 L October-May and 16 L October-March) were compared with daily pot watering (10 L) in another field experiment, in mature coconut garden, laid out in randomized block design and replicated thrice.

Out of 44 varieties, 15 wilted by second day of water stress and only six varieties survived water stress for four days. The six survived varieties maintained high relative water content and membrane stability, when water stressed. The height, number of leaves and leaf area decreased in all the varieties due to water stress.

The increases in the activities of peroxidase, catalase and superoxide dismutase, in response to water stress were more in Panniyur-5 and Padarpan. The maximum percentage increase in peroxidase and catalase activities, in response to water stress were in Padarpan and the least in Panniyur-1. High level of lipid peroxidation was observed in Panniyur-1. Chlorophyll content decreased in all the varieties due to severe water stress. The epicuticular wax content was the highest in Panniyur-5 and the least in Panniyur-1.

Accumulation of proline, sugar and amino acid were observed in response to water stress in some of the varieties. Percentage increase in proline content of the leaves over control was maximum in Poonjarmunda and the least in Padarpan. Among the water stressed plants maximum sugar content was observed in the variety Kalluvally-4 followed by Poonjarmunda and Padarpan. The amino acid content increased due to water stress, in varieties Poonjarmunda, Panniyur-1, Panniyur-5 and Padarpan. Electrophoretic pattern of protein revealed additional bands in water stressed plants of Panniyur-5, Kumbakodi. In Poonjarmunda, Padarpan and Panniyur-1 the number of protein bands were less in water stressed plants as compared to the unstressed plants. The N, P, K, Ca, Mg, Cu, Zn content of leaves increased in general due to water stress whereas Fe and Mn decreased.

The variety Panniyur-1 had low epicuticular wax, less thickness of cuticle and sclerenchyma tissue on leaves and stem.

The bush and vine type of Panniyur-1 did not survive one to three days of water stress cycle for more than twenty days and it is deduced that both bush and vine types of Panniyur-1 are very sensitive to water stress. In Panniyur-5, which survived the water stress, there was no significant variation between bush and vine pepper in most of their biometric characters. Stomatal conductance, transpiration rate and leaf water potential of Panniyur-5 showed variations between bush and vine type, when water stressed.

In bush type of Panniyur-5, $^{14}CO_2$ fixed by the leaf was translocated to the spike on the corresponding node as well as to other spikes, when exposed to mild and moderate water stress, whereas, in unstressed plants the translocation was mainly from the leaves to the corresponding spike on the node. In Panniyur-1, there was no translocation of $^{14}CO_2$

from the leaf to other spikes, in water stressed as well as in daily irrigated plants; $^{14}CO_2$ was translocated to the spike on the corresponding node only. In water stressed plants of Panniyur-5, without berries, $^{14}CO_2$ translocation was observed towards the stem and other leaves, whereas in Panniyur-1, $^{14}CO_2$ accumulated in the stem and there was no translocation to other leaves.

For scheduling irrigation the optimum percentage of allowable depletion of soil moisture for bush pepper was fifty per cent. Biometric characters such as number of leaves, total number of branches, shoot dry weight, root dry weight and total dry weight were more in plants irrigated at fifty per cent depletion of available soil moisture and the lowest in plants irrigated at seventy five per cent depletion. Similarly, dry berry weight and oleoresin content of the berries were higher in plants irrigated at fifty per cent depletion of soil moisture.

The root zone of field planted bush pepper was at a lateral distance of 30 cm and depth of 60 cm. The effective foraging zone for the crop was between 20-30 cm lateral distance and 40 cm depth.

The vegetative growth of bush pepper was superior with 16 L (October-May) and pot watering 10 L per day. But the yield contributing characters like the number of spikes, length of spikes, number of berries, hundred berry weight, berry volume, green and dry berry yield and oleoresin content of berries were maximum in plants irrigated with 8 L drip and the least in 2 L drip. It was deduced that 8 L drip irrigation is better than daily irrigation (10 L pot per day) for three years old bush pepper variety Karimunda grown in coconut garden.